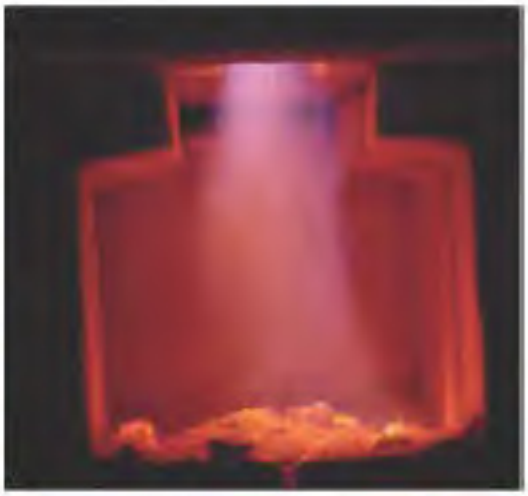
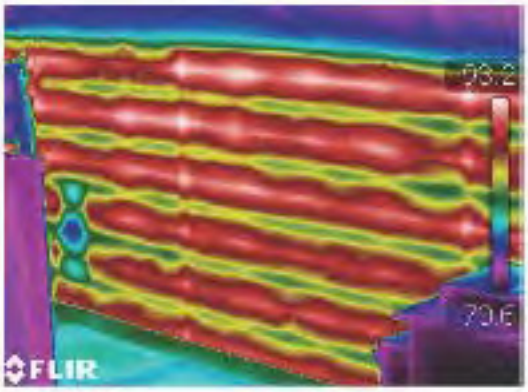
Design Assistance Manual for High-Efficiency, Low-Emissions Biomass Boiler Systems

In Residential and Commercial Buildings









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Design Assistance Manual for High-Efficiency, Low-Emissions Biomass Boiler Systems

In Residential and Commercial Buildings

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Table of Contents

Notice **2**
Liability Disclaimer **2**
1 Introduction **6**
2 Cordwood Gasification Boilers **8**
2.1 Importance of Thermal Storage 11
2.2 Protection Against Overheating 13
2.3 Sizing a Cordwood Gasification Boiler 18
3 Pellet-Fired Boilers **21**
3.1 Boiler Control 24
3.2 Single Sensor Control 25
3.3 Two-Temperature Sensor Control 27
3.4 Pellet Storage 28
3.5 Pellet Conveyance Systems 32
3.6 Content Measurement of Pellet Silo 39
3.7 Pellet Boiler Sizing 41
4 Boiler Air Supply and Venting Systems **46**
4.1 Applicable Standards 46
4.2 Air Supply Requirements 46
4.3 Motorized Dampers 48
4.4 Chimney Options 50
4.5 Masonry Chimneys 51
4.6 Sidewall Venting and Power Venting 53
4.7 Chimney Bracing 54
4.8 Vent Connector Piping 55
4.9 Draft Regulation 59
4.10 Draft Regulator Location 62
5 Thermal Storage **65**
5.1 Unpressurized Thermal Storage Tanks 66
5.2 Heat Exchanger Options for Unpressurized Thermal Storage Tanks 68
5.3 Temperature Limitations of Unpressurized Thermal Storage Tanks 70
5.4 Pressurized Thermal Storage Tanks 70
5.5 Thermal Storage Tank Insulation 74
5.6 Thermal Storage Tank Piping Configurations 77
5.7 Temperature Stratification Within Thermal Storage Tanks 77
5.8 Flow Diffusers 79
5.9 Full Participation of the Tank's Water Volume 82

5.10 Tank Piping Configurations 84
5.11 Four-Pipe Tank Configuration 84
5.12 Hydraulic Separation 85
5.13 Anti-condensation Details 85
5.14 Characteristics of Four-Pipe Tank Configurations 86
5.15 Two-Pipe Tank Configurations 86
5.16 Three-Pipe Tank Configuration 91
5.17 Multiple Thermal Storage Tank Configurations 93
5.18 Piping Options for Multiple Thermal Storage Tanks 95
5.19 Close-Coupled Multiple Tank Systems 97
5.20 Boiler-to-Storage Flow Rate 100

6 Heat Emitters and Heating Distribution Systems 101

6.1 The Importance of Low-Temperature Systems 101
6.2 Low-Temperature Heat Emitter Options 103
6.3 Low-Temperature Fin-Tube Baseboard 104
6.4 Panel radiators 105
6.5 Radiant Panels 106
6.6 Heated Floor Slabs 107
6.7 Reducing Supply Water Temperature for Existing Systems 111
6.8 Adding Heat Emitters to Lower Supply Water Temperature 113
6.9 Adding More Finned-Tube Baseboard 113
6.10 Other Heat Emitter Options 118
6.11 Piping for Supplemental Heat Emitters 119
6.12 Converting Series Loops to Parallel Branches 119
6.13 Creating New Zones 122
6.14 Design Guidelines 124
6.15 Outdoor Reset Control for Pellet Boiler Start Control 126

7 System Design Details 131

7.1 Preventing Negative Heat Flow from Storage to Boiler 131
7.2 Boiler Circulator Control 132
7.3 Thermosiphoning 134
7.4 Boiler Anti-condensation Protection 136
7.5 Anti-condensation Options 137
7.6 Boiler Over-Temperature Protection 143
7.7 Implementing Outdoor Reset Control for Pellet Boiler Control 147
7.8 Reducing Water Temperature to the Distribution System 150
7.9 Mixing with Three-Way Motorized Valves 150
7.10 Variable Speed Injection Mixing 153
7.11 Integrating Biomass Boilers with Existing/Auxiliary Boilers 155
7.12 Never Connect Boilers in Series 155

7.13 Biomass Boiler + Storage as Heat Source 156
7.14 Managing Heat Flow from Multiple Heat Sources 159
7.15 Buffering the Existing/Auxiliary Boiler 165
7.16 Providing Domestic Water Heating with Space Heating 167
7.17 Biomass Boiler Combined with Forced Air Distribution System 173
7.18 Multiple Pellet Boiler System Configuration 177
7.19 Temperature Sensor Details 178
7.20 Sensor Mounting 180
7.21 Boiler-to-Storage Flow Rate 184
7.22 Storage to Load Flow Rate 185

8 System Design Templates 186

8.1 System 1 186
8.1.1 Description of Operation for System 1 190
8.1.2 Suggested Settings for System 1 192
8.2 System 2 193
8.2.1 Description of Operation for System 2 197
8.2.2 Suggested Controller Settings for System 2 199
8.3 System 3 201
8.3.1 Description of Operation 204
8.4 System 4 207
8.4.1 Description of Operation 210
8.4.2 Suggested controller settings 213
8.5 System 5 214
8.5.1 Description of Operation 216
8.6 System 6 219
8.6.1 Description of Operation 223
8.7 System 7 226
8.7.1 Description of Operation 230
8.7.2 Suggested Initial Controller Settings 232
8.8 System 8 232
8.8.1 Description of Operation 236

Appendix A: Piping symbol legend A-1
Appendix B: Electrical symbol legend B-1
Appendix C: References C-1

1 Introduction

This manual presents design assistance information for a range of hydronic heating systems using cordwood gasification boilers and wood pellet-fired boilers. The concepts for heating systems presented are appropriate for single-family houses as well as light commercial and municipal buildings. Drawn from many sources, the information presented includes “lessons learned” based on New York State Energy Research and Development Authority (NYSERDA)-sponsored research projects as well as information gathered from systems installed under NYSERDA’s Renewable Heat NY incentive program.

The systems under discussion in the manual have yielded important insight into how biomass boilers perform when integrated into hydronic heating systems typical of installations in New York State. The information is presented in an effort to shorten the learning curve for designers who are new to biomass boiler systems and to help those designers avoid situations that can lead to less-than-optimal performance.

Sections 2 and 3 discuss how cordwood gasification boilers and pellet-fired boilers are intended to operate. Emphasis is placed on achieving long on-cycles, which improve thermal efficiency and reduce both carbon monoxide and particulate emissions.

Section 4 presents information on best practices for supplying air to and venting exhaust gases from biomass boilers. Proper air supply and venting are crucial to safe, efficient, and clean boiler operation. Best practices for new chimneys as well as retrofitting options for existing chimneys are discussed.

Section 5 provides a broad discussion of thermal storage systems for both cordwood gasification and pellet-fired boilers. It describes unpressurized and pressured thermal storage tanks, piping details, temperature stratification, and control strategies that promote optimal utilization of thermal storage and prevent common problems.

Section 6 describes the influence of heating distribution systems on the performance of biomass boilers. Emphasis is placed on creating new distribution systems or modifying existing distribution systems to allow adequate heat delivery at the lowest possible water supply temperatures. Low temperature distribution systems greatly enhance the performance of biomass boilers.

Section 7 describes many design details, each of which can significantly influence overall system performance. Those details include prevention of negative energy flow, anti-condensation strategies, boiler over temperature protection, boiler on/off control strategies, mixing options, integration of auxiliary boilers, differential temperature control, domestic water heating options, sensor mounting details, interfacing to forced-air delivery systems, and multiple pellet boiler sub-systems.

Section 8 combines many of the details described in the previous sections with several complete system templates. Each system template includes a summery description of the system, a piping schematic, an electrical control schematic, a description of operation, and possible controller settings that are appropriate given the design and anticipated operating conditions for the system. The templates cover a range of systems from those typical of residential applications to those well suited for larger buildings.

These templates are presented as starting points for subsequent system design. Although well documented, the templates do not represent complete installation documentation for any specific system. Designers remain responsible for selecting specific hardware and controller settings that could facilitate the concepts represented by any of these templates. It is also the designer's responsibility to verify that systems developed from the templates fully conform to any applicable building, energy, or mechanical codes in the jurisdiction where the system will be installed. Key points are emphasized in text boxes throughout the manual.

2 Cordwood Gasification Boilers

Those who have heated buildings using wood stoves, fireplaces, or standard wood-fired boilers are used to the routine of starting a fire, then adding a few pieces of cordwood every two or three hours. On especially cold days the fire is maintained at a higher rate of combustion by adding more wood, or adding it more often, to ensure sufficient heat output.

Although this approach to stoking traditional wood-fired appliances has worked for centuries, it does not represent optimal conditions with respect to combustion efficiency or minimizing emissions—and it is not how a modern cordwood gasification boiler should be operated.

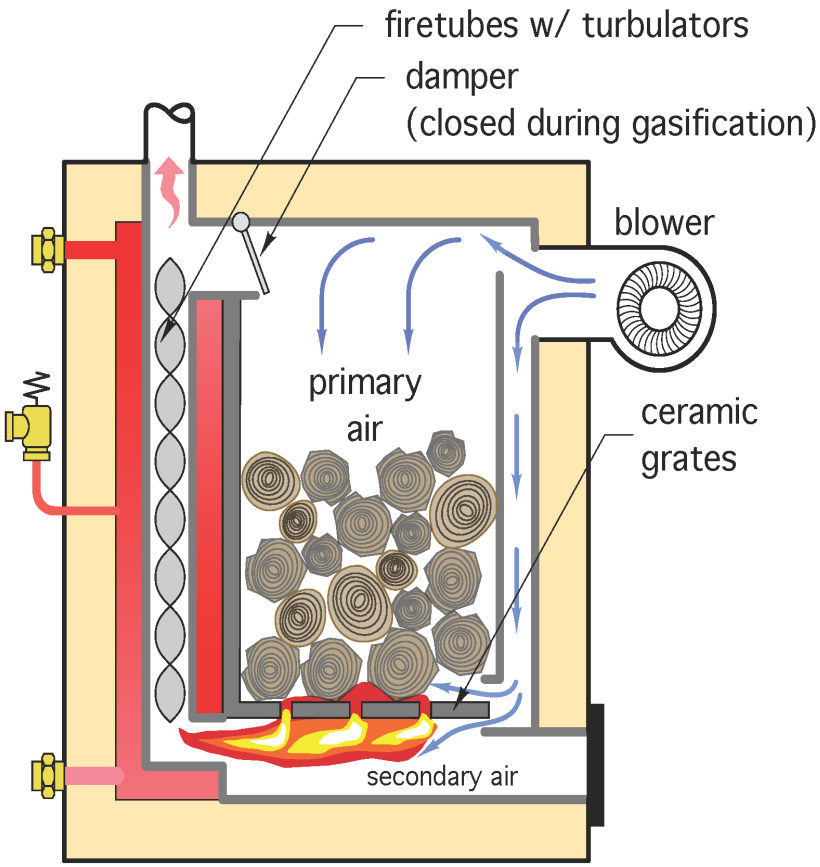
An example of a modern cordwood gasification boiler is shown in Figure 2-1. A cross section illustration of such a boiler is shown in Figure 2-2.

Figure 2-1. Modern cordwood gasification boiler

Courtesy of Econoburn



Figure 2-2. Cross section of a modern cordwood gasification boiler



The fire in cordwood gasification boilers is started by loading smaller pieces of kindling wood at the base of the boiler's upper combustion chamber. That material is ignited and allowed to burn for a few minutes to establish a bed of hot coals at the base of the upper chamber. Then, unlike a wood stove, the upper chamber is fully loaded with firewood.

Some cordwood gasification boilers are also loaded with kindling and a full charge of firewood before the fire is ignited using a butane torch. The tip of the torch is inserted through a special opening under the kindling stack.

During initial firing, a flue damper near the top of the upper combustion chamber is open, and the boiler operates in an updraft mode. This is similar to how combustion occurs in a wood stove or standard single-stage, wood-fired boiler.

Once the bed of hot coals has formed and the chamber is fully loaded with cordwood, the damper at the top of the chamber is closed and a blower turns on to direct the pyrolytic gases emitted by the heated cordwood downward through a slot in the ceramic base plate of the upper combustion chamber.

The blower forces air through holes in the side of this slot. The hot air mixes with the hot pyrolytic gases to create a secondary combustion reaction below the slot. Figure 2-3 shows an example of the secondary combustion.

Figure 2-3. Secondary combustion inside a cordwood gasification boiler

Courtesy of Econoburn



During secondary combustion the pyrolytic gases emitted by the heated wood are mixed with oxygen at a molecular level. The chemical efficiency of the secondary combustion reaction is far superior to that which occurs on or near the surface of cordwood burning in a standard wood-fired appliance, such as a fireplace or single-stage, wood-fired boiler. Temperatures in the secondary combustion reaction can exceed 2,000°F. The intense secondary combustion reaction is intended to continue until the full charge of cordwood is consumed. Thus, cordwood gasification boilers are intended to operate as "batch burners." When properly operated in this manner, they can achieve steady state combustion efficiencies over 80%. They cannot, however, produce this level of performance if operated like a conventional wood stove.

The boilers also cannot achieve high steady state combustion efficiencies if the system cannot accept heat at the rate it is being produced in the boiler.

Cordwood gasification boilers have temperature controls that reduce air flow to the combustion reaction chamber as the boiler approaches or reaches a set upper-temperature limit. If the water flow rate through the boiler cannot transport heat away from the boiler at the rate it is being produced, the boiler will reach its upper temperature limit prematurely. When this occurs, the combustion blower will either turn off or reduce its speed. This reduces oxygen input to the combustion reaction, which decreases heat output, but at the expense of lowered thermal efficiency and increased emissions; neither is desirable.

2.1 Importance of Thermal Storage

When properly operated, a cordwood gasification boiler produces heat at a rate often higher, and in many cases much higher, than the rate at which the building it serves requires heat. This is especially true when the heating distribution system is divided into multiple zones or operates under partial-load conditions.

When the rate of heat production from a wood stove or single-stage, wood-fired boiler significantly exceeds the building's heating load, air flow to the combustion chamber is reduced by partially closing a damper. On some stoves, this is done manually, while on others it is done automatically based on a predetermined, measured temperature. However, with cordwood gasification boilers it's imperative to maintain the high rate of combustion to ensure high-thermal efficiency and low emissions. Any method of reducing air flow to a cordwood gasification boiler when it is operating at a high rate of combustion reduces its combustion efficiency and increase emissions.

When properly operated, a cordwood gasification boiler produces heat at a rate often higher and in many cases much higher, than the rate at which the building it serves requires heat.

The solution to the difference between boiler heat output and heating load is water-based thermal storage. A relatively large and well-insulated thermal storage tank can absorb the difference between the rate of heat output from the boiler and the rate of heat dissipation by the load. The presence of this tank allows the cordwood gasification boiler to operate at optimal conditions, while capturing excess heat output for later use. A properly sized and piped thermal storage tank is essential in all systems using cordwood gasification boilers that do not have integral thermal storage.

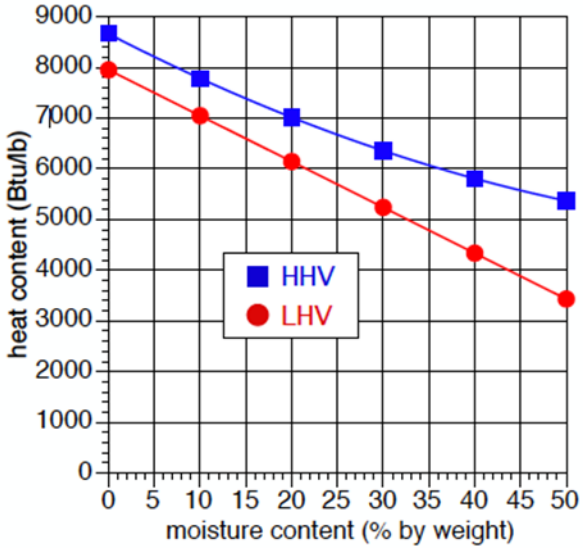
Cordwood gasification boilers qualified under NYSERDA's Renewable Heat NY program require a minimum size and well-insulated thermal storage tank. The size of that thermal storage tank is based on EPA certification testing and input from boiler manufacturers.

The minimum volume of that thermal storage tank depends on the specific qualified boiler and if the tank is pressurized or unpressurized. Pressured tanks allow for significantly higher water temperatures and can store more heat per gallon compared to unpressurized tanks.

Proper operation of a cordwood gasification boiler also requires dry wood. Figure 2-4 shows how the higher heating value (HHV) and lower heating value (LHV) of wood (hardwood or software) vary as a function of moisture content.

Proper operation of a cordwood gasification boiler also requires dry wood. The maximum moisture content of cordwood used in a cordwood gasification boiler is 20%.

Figure 2-4. Relationship between heat content and moisture content for wood based on higher heating value (HHV) and lower heating value (LHV)



The maximum moisture content of cordwood used in a cordwood gasification boiler is 20%, even drier cordwood is preferred. Reducing split cordwood to a moisture content of 20% or less generally requires storage with open air circulation and protection from precipitation for at least one year.

The moisture content of cordwood can be estimated using a simple and inexpensive moisture meter, such as shown in Figure 2-5.

Figure 2-5. An inexpensive moisture meter testing moisture content of internal fibers of cordwood that has just been split open



Proper assessment of the average moisture content of stacked cordwood should be based on measurements from several pieces taken from different areas of the stack. The end-grain moisture content along with the moisture content of internal fibers (wood samples are split open) should be measured. It's common for cordwood to have significantly higher internal compared to end-grain moisture content.

2.2 Protection Against Overheating

Cordwood gasification boilers can hold a large volume of wood in their combustion chamber. Under normal operation this is fine. However, if a power outage occurs during the batch burn the combustion process does not immediately stop as it does in boilers fueled by gas or oil. The residual cordwood in the primary combustion chamber continues to burn when a power outage occurs. However, if there is no backup power source for the blower, it will not function, and the rate of combustion will be reduced. Nevertheless, the heat produced as the residual fuel continues to burn must be safely dissipated from the boiler.

In most applications (e.g., all those without a backup power source) the heat dissipation process must occur in a controlled and safe manner without the use of fans or circulators. If adequate heat dissipation is not provided the boiler may reach a pressure where its pressure relief valve opens (typically at 30 psi), and steam will escape from the valve. The pressure relief valve should be the last resort method of protecting the boiler against excessive heat production during a power outage. Other means of heat dissipation should come into effect well before conditions cause the pressure relief valve to open.

The pressure relief valve should be the last resort method of protecting the boiler against excessive heat production during a power outage.

One method of overheat protection is through the use of a passive "heat dump," consisting of an array of finned-tube piping (e.g., the heating element used in common residential baseboard heat emitters) as the heat dissipater. Multiple finned-tubes are assembled in a parallel, reverse-return piping configuration as seen in Figures 2-6 and 2-7.

Figure 2-6. A passive heat dump system with finned-tubes assembled in a parallel, reverse-return piping configuration

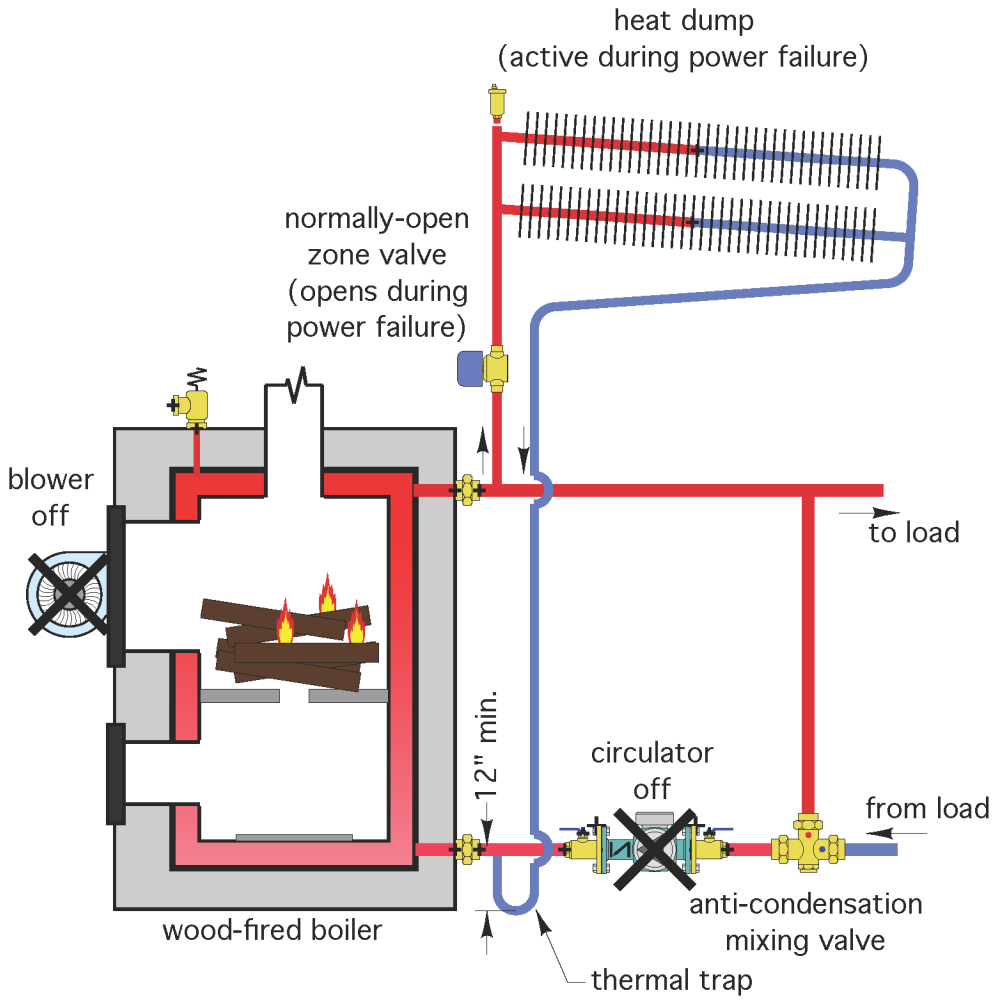


Figure 2-7. Installed passive heat dump system

Courtesy of Econoburn



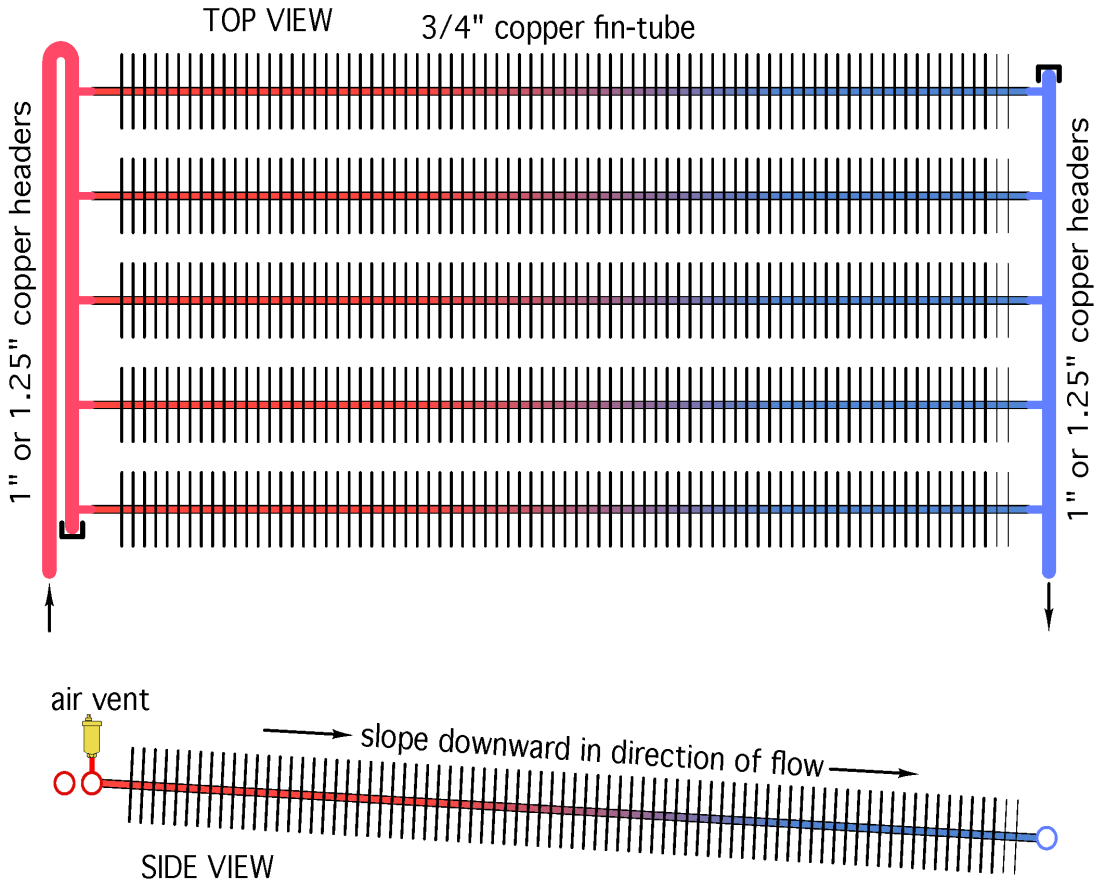
The finned-tube array is installed above the boiler and connected to the boiler's supply and return piping. It should have a slight downward slope in the direction of flow to encourage air bubbles to rise to a high-point vent or bleeder valve.

A normally-open zone valve (i.e., a valve that is open when not powered) is installed between the boiler supply pipe and the finned-tube array. When power is available this valve remains closed to prevent heat flow through the heat dump. When power is lost the valve opens allowing a thermosiphon flow to develop between the boiler and finned-tube array. The zone valve should use an internal spring that ensures it will fully open as soon as power is lost. The valve's operation should also be periodically tested by interrupting power and observing the valve's response. A manual test switch (spring loaded, normally closed contacts) can be installed to allow simple periodic testing of the valve.

The piping from a passive heat dump to the boiler inlet should also include an underslung thermal trap at least 12 inches deep, as shown in Figure 2-6. This trap minimizes heat transfer into the return side of the heat dump piping during normal boiler operation.

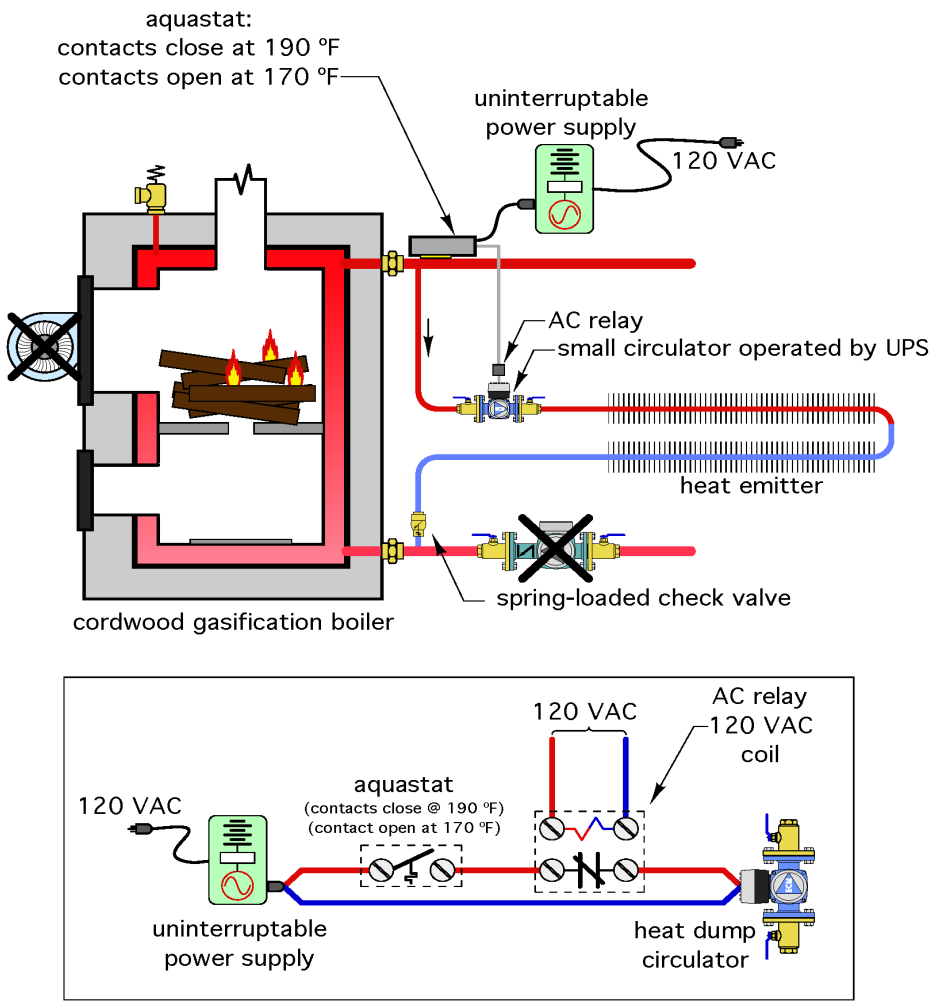
A suggested guideline for passive heat dumps is to provide a sufficient amount of finned-tube to dissipate 10% of the boiler's full-rated heat output, assuming a dissipation rate of 300 Btu/hr/ft of fin-tube. This is based on the use of a finned-tube typical of that used in residential baseboard. The finned-tube should be piped in parallel segments with reverse-return piping, as shown in Figure 2-8.

Figure 2-8. Passive heat dump system using a finned-tubing



It's also possible to create an active heat dump in which flow is created by a small circulator powered by an uninterruptible power supply (UPS). The concept is shown in Figure 2-9.

Figure 2-9. Piping and wiring for an active heat dump system



An electromechanical aquastat is installed on the piping near the boiler outlet. Its electrical contacts close whenever the boiler outlet temperature is at or above a setting where heat dissipation during a power outage should be in effect. The contacts open at a lower temperature where heat dissipation is not necessary. The aquastat limits heat dump operation to situations where the boiler is at an elevated temperature, and thus helps conserve battery energy within the uninterruptible power supply as the fire reduces in intensity.

Line voltage is passed from the closed contacts of the aquastat to the normal closed contacts of a relay with 120 volts of alternating current coil. The relay contacts remain open whenever electrical power is available and immediately close when it is not. This prevents the heat dump circulator from operating other than during a power outage.

Small circulators with electronically commutated motors that operate with input power requirements of 10–40 watts are well suited to this application.

The uninterruptible power supply should be capable of operating the heat dump circulator for at least 30 minutes. The battery in the uninterruptible power supply should also be periodically tested to ensure it maintains adequate charge for such operation.

When a circulator powered by a UPS is used to operate an active heat dump the heat emitters do not have to be above the boiler.

2.3 Sizing a Cordwood Gasification Boiler

Most boilers that are used as the sole heat source for a building are sized based on the building's estimated heating load on a design (e.g., coldest) day. In some cases, a reasonable safety factor, such as 10%, is added to the estimated design heating load when selecting the boiler. For example, if the design heating load of a building was calculated as 80,000 Btu/hr—based on industry standard methods such as the Air Conditioning Contractors of America (ACCA) Manual J with a 10% safety factor—the designer would try to select a boiler with a rated output of about 88,000 Btu/hr. A boiler selected in this manner should easily keep the building at the desired interior temperature under all expected conditions.

Although this approach has been used to size conventional boilers for decades, *it is not appropriate for sizing a cordwood gasification boiler.*

The reason is that cordwood gasification boilers are designed for batch burning, as previously discussed. The intended firing method is one that burns a full chamber of cordwood as fast and as hot as possible. This allows cordwood gasification boilers to achieve peak efficiency with minimal emissions. The substantial amount of heat produced during batch burning is deposited in thermal storage. It can then be conveyed to the building as needed to meet the load over several hours (sometimes even days), after the batch burn is completed.

This method of operation is very different from how conventional boilers are routinely turned on and off, in some cases several times an hour, to dispense heat directly to the load, and usually without thermal storage. The size of a cordwood gasification boiler is determined by how many batch burns the owner expects to provide during a cold design day. The fewer the number of batch burns, the larger the boiler needs to be, and vice versa.

The size of a cordwood gasification boiler is determined by how many batch burns the owner expects to provide during a cold design day. The fewer the number of batch burns, the larger the boiler needs to be.

Formula 2-1 can be used as a guideline for sizing a cordwood gasification boiler. This formula determines the required weight of firewood that must be consumed during each batch burn.

Formula 2-1:

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

Where:

- W = weight of firewood required for each batch burn (pounds)
- T_{in} = indoor air temperature for design load conditions (°F)
- T_d = outdoor design air temperature (°F)
- UA_b = heat loss coefficient of building (Btu/hr/°F)
- 24 = hours in day
- E_{daily} = daily heat required for domestic hot water (Btu)
- e = average combustion efficiency of wood gasification boiler while operating (decimal %)
- C = lower heating value of firewood being used, and based on moisture content (Btu/pound)
- N = number of batch burns per day under design load conditions
- 5 = the 24-hour average outdoor temperature is assumed to be 5°F above the outdoor design temperature

The following example illustrates how Formula 2-1 is used:

Estimate the weight of wood required for each batch burn using a cordwood 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°F, and the desired indoor temperature is 70°F. The building also requires 60 gallons per day of domestic hot water heated from 50°F to 120°F. The owner wishes to have no more than two batch burns during a design day. Assume that the wood used in the gasification boiler has an average moisture content of 20%, and that the average combustion efficiency of the boiler over the complete batch burn cycle is 70%.

Solution:

1. The value of UAb is found by dividing the building's design heat load by the design temperature difference:

$$UA_b = \frac{50{,}000\frac{Btu}{hr}}{[70 - (-5)]°F} = 667\frac{Btu}{hr \bullet °F}$$

2. The daily energy required for domestic water heating is estimated as follows:

$$E_{daily} = 8.33\left(\frac{Btu}{day}\right)(T_{hot} - T_{cold}) = 8.33\left(60\frac{Btu}{day}\right)(120 - 50) - 34{,}990\ Btu$$

- If the system only supplies space heating E_{daily} = 0.
- The lower heating value of wood at 20% moisture content can be found from figure 2-4. It is 6,143 Btu/lb.

3. Putting this data into Formula 2-1 yields:

$$W = \frac{[T_{inside} - (T_d + 5)](UA_b)24 + E_{daily}}{eCN} = \frac{[70 - (-5 + 5)](667)24 + 34{,}990}{(0.7)(6143)(2)} = 134ib$$

4. Estimate the volume of the boiler's primary combustion chamber in which the wood is to be placed. This requires an estimate of how densely the wood will be stacked within the upper combustion chamber, as shown in Figure 2-10.

5. A suggested stacking density is 15-20 pounds per cubic foot. The lower value (15 lb/ft^3) is appropriate if the wood is poorly dimensioned relative to the shape of the chamber, or haphazardly tossed into that chamber. The higher value (20 lb/ft^3) is appropriate if the wood is cut to minimize wasted space and neatly placed in the chamber.

6. The required volume of the primary chamber can be determined by dividing the required weigh of wood by the stacking density as follows:

$$V = \frac{134lb}{20\frac{lb}{ft^3}} = 6.7ft^3$$

Now that the volume of the primary combustion chamber has been estimated, the designer needs to search product specifications for boilers to find a make and model with a primary combustion chamber volume close to the calculated volume. It's likely that specific boilers will have chamber volumes slightly higher or lower than this calculated value.

The required combustion chamber volume is inversely proportional to the number of batch burns. Changing the number of batch burns in the previous example from 2 to 3 reduces the chamber volume requirement from 6.7 to 4.5 ft^3. This allows for a significantly smaller and less expensive boiler; the tradeoff should be carefully discussed with the future owner.

Figure 2-10. Wood stacked in the upper combustion chamber of a cordwood gasification boiler

Courtesy of Brookhaven National Laboratory



3 Pellet-Fired Boilers

Modern wood pellet boilers are fully automatic. As such they can provide heating similar to other boilers operating on conventional fuels such as natural gas, propane, and fuel oil. In some applications pellet-fueled boilers can operate for several weeks without any human intervention. They can automatically load pellets, ignite pellets, stabilize combustion processes, and turn off when there is no further demand for heat. Many modern pellet boilers can also periodically clean ash from their internal heat exchangers and send an alert when the ash pan needs to be emptied.

The processes involved in automatically burning wood pellets are different, and in some respects more complex than those used in boilers burning conventional fuels. This starts with fuel handling. In fully automatic systems, pellets are conveyed from a storage bin or silo to a “day hopper” located next to the boiler. In some systems the pellets are transferred by motorized augers, in others, they are transported using pneumatic conveyance systems. In either case, it’s important that the pellets arrived at the day hopper with minimal breakage and minimal dust.

The pellets must then be moved from the day hopper into the combustion chamber in a way that prevents flames from “back burning” along the pellet supply system. This involves motorized slide gates, motorized stoker augers, and sensors. On some boilers, there may also be a fire suppression system that can automatically detect and suppress any unsafe conditions in the pellet-feed system.

Once a small number of pellets are loaded into the combustion chamber of a non-firing pellet boiler, they must be ignited. This is typically handled by an electrically-powered ignitor. Once the pellets are ignited, combustion needs to be stabilized by adjusting air flow based on combustion gas sensing and temperature measurements. The air flow rate to the combustion chamber is regulated by a variable speed blower that responds to the oxygen concentration in the exhaust gases. Various sensors in the boiler monitor entering and leaving water temperature, the rate of temperature change, the presence of pellets in the stoker system, and other vital operating conditions.

Collectively these processes can require 10 to 20+ minutes between the time the “cold” boiler gets a signal to operate, and the time the boiler is ready to deliver heat to the load or a thermal storage system. This start up time is much longer than that required for conventional boilers and represents a unique characteristic that must be respected for optimal boiler operation.

The process of stopping the pellet boiler also requires time. Most modern boilers have a prescribed “burn out” sequence that ensures that pellets in the combustion chamber are fully consumed before the boiler goes into a full stop condition.

The thermal efficiency of a pellet boiler during its start-up and burn out phases of operation is not as high as during its steady state operating phase. The latter is the time when the boiler is operating at or near its full heat output rating with optimal combustion conditions. Emissions from the boiler are also higher during start up and burn out phases relative to those occurring during steady state operation.

To maximize thermal efficiency and minimize emissions, it's important to operate pellet-fired boilers over relatively long on-cycles, followed by relatively long off-cycles. One suggested guideline is to operate the boiler so that it has an *average* on-cycle duration of three hours per start.

To maximize thermal efficiency and minimize emissions, it's important to operate pellet-fired boilers over relatively long on-cycles, followed by relatively long off-cycles.

In many cases, the desired long on-cycle causes the boiler to produce more heat than the building requires over the same time. This is similar to the scenario associated with a properly operated cordwood gasification boiler. It is especially likely during partial-load conditions and with boilers that have heating capacities close to the building's design heating load.

When there is a significant difference between the rate of heat production and the rate of heat dissipation by the load, the solution is to add thermal storage to the system. All the pellet boiler systems described in this manual have water-based thermal storage tanks. These tanks are also referred to as buffer tanks.

At the time of publication, all pellet boiler systems eligible for funding through NYSERDA's Renewable Heat NY program must have a minimum of two gallons of water-based thermal storage per 1,000 Btu/hr of rated boiler-heat output. Thus, a pellet-fuel boiler rated at 75,000 Btu/hr would require a minimum of 150 gallons of water-based thermal storage.

One exception to the above requirement is that the Renewable Heat NY program allows 119-gallon thermal storage tanks (which are not subject to ASME pressure vessel standards) to be used with pellet boilers having rated outputs of 25 kW (85,300 Btu/hr) or less. The use of thermal storage can greatly extend the on-cycle duration of pellet boilers. Figure 3-1 shows a hypothetical comparison between the cycling time of a pellet boiler with and without thermal storage.

Figure 3-1. Hypothetical on-cycle and off-cycle durations for a pellet boiler with and without thermal storage

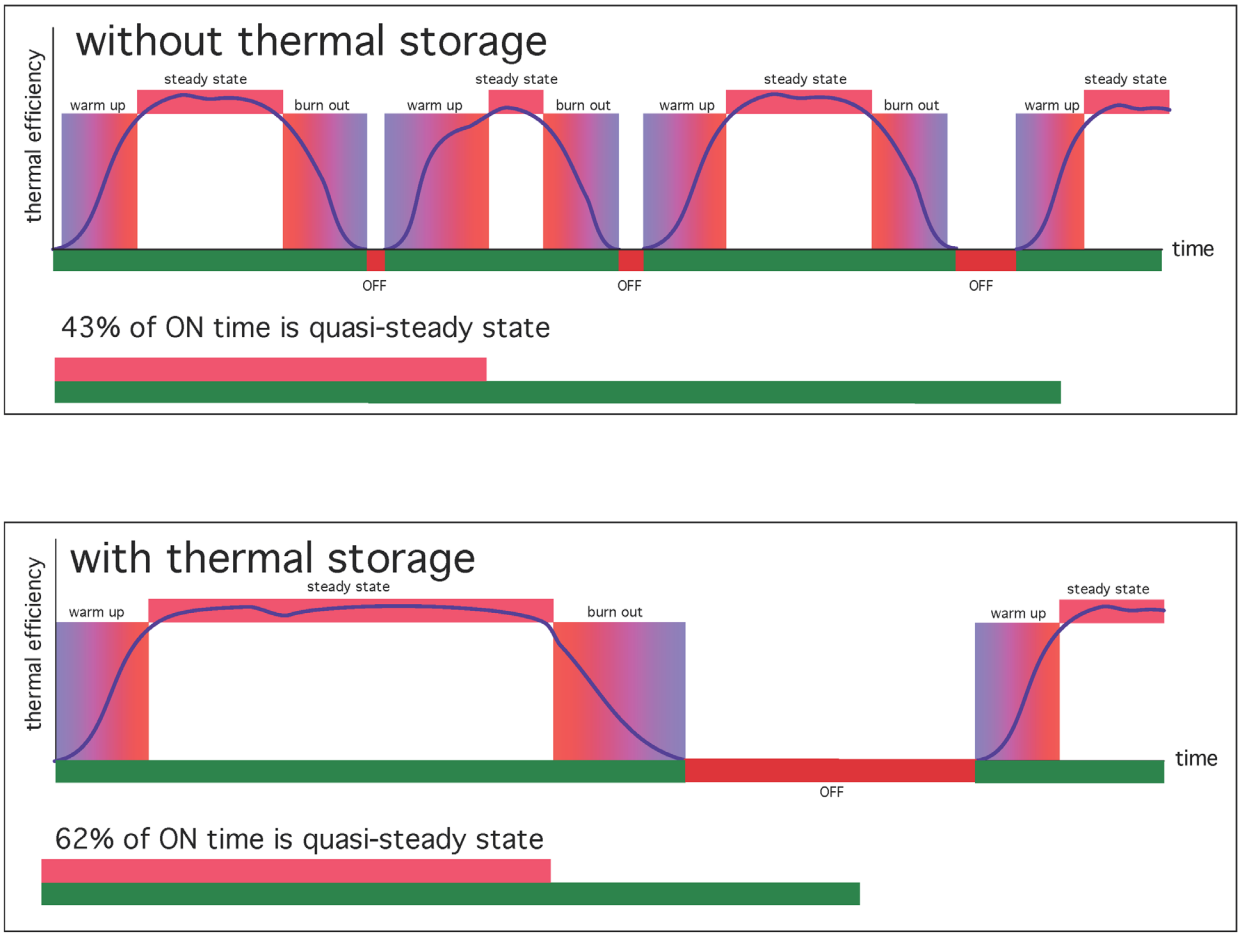
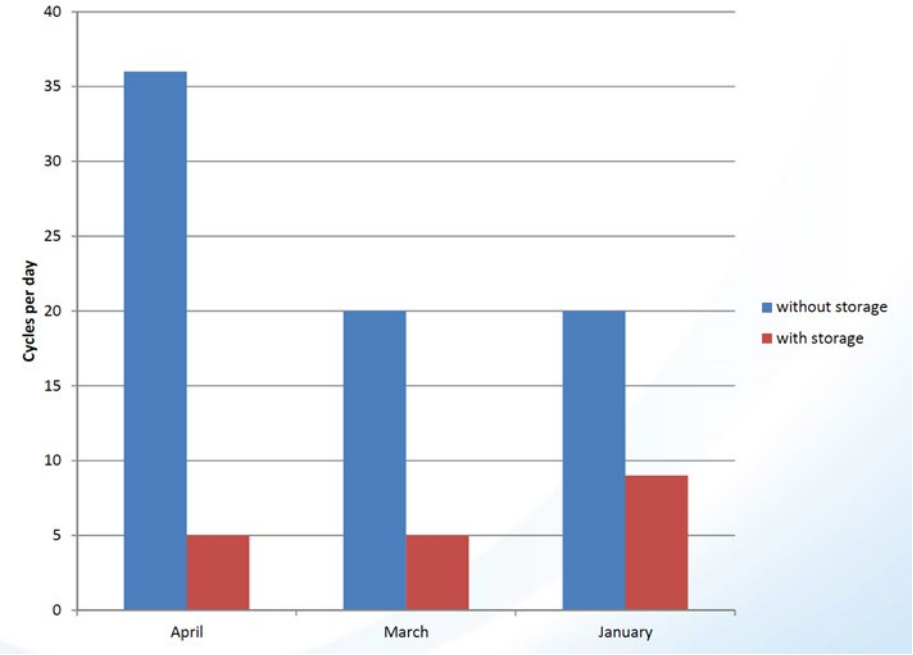


Figure 3-1 shows the percentage of elapsed time the boiler operates at or close to steady state combustions conditions. The scenario with longer and less frequent boiler cycling yields a higher percentage of quasi-steady state combustion. The higher this percentage, the higher the overall integrated efficiency of the boiler and the lower its emissions.

Figure 3-2 shows the results of pellet-boiler cycling tests conducted at Brookhaven National Laboratories. The 25 kW (85,300 Btu/hr) rated pellet boiler was operated to supply a heating-load profile typical of an Upstate New York house, with and without a 119-gallon thermal storage tank as part of the system.

Figure 3-2. Comparison showing cycles per day for a 25-kW rated pellet boiler with and without thermal storage

Courtesy of Brookhaven National Laboratory & Dr. Thomas Butcher



Notice the significant reduction in boiler cycles per day when storage is used, especially under the partial load conditions associated with April and March operation.

3.1 Boiler Control

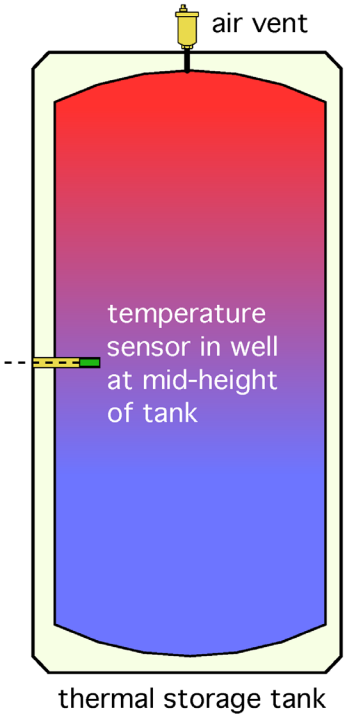
Most conventionally fueled boilers used in space heating systems are enabled to operate only when a call for heating comes from one or more building thermostats. This is not the case for most pellet-boiler systems that use thermal storage tanks. In these systems the pellet boiler operates independently from any call for heating by the load. Instead, the boiler turns on and off as necessary to maintain the temperature of water in the thermal storage tank between some lower and upper temperature limits. These temperatures are monitored by one or more controllers that connect to temperature sensors mounted within wells attached to the thermal storage tank. Some pellet boilers have internal control capability to monitor one or more tank temperature sensors, other boilers require external controllers.

There are several variations on how temperature controllers and sensors can be used to turn a pellet boiler on and off. They are described briefly in this section and in more detail in section 7.

3.2 Single Sensor Control

The simplest control method for a pellet boiler supplying a thermal storage tank is to monitor the temperature of a single sensor located at the mid-height of the tank, as shown in Figure 3-3.

Figure 3-3. A thermal storage tank showing placement of a temperature sensor located at mid-height of the tank



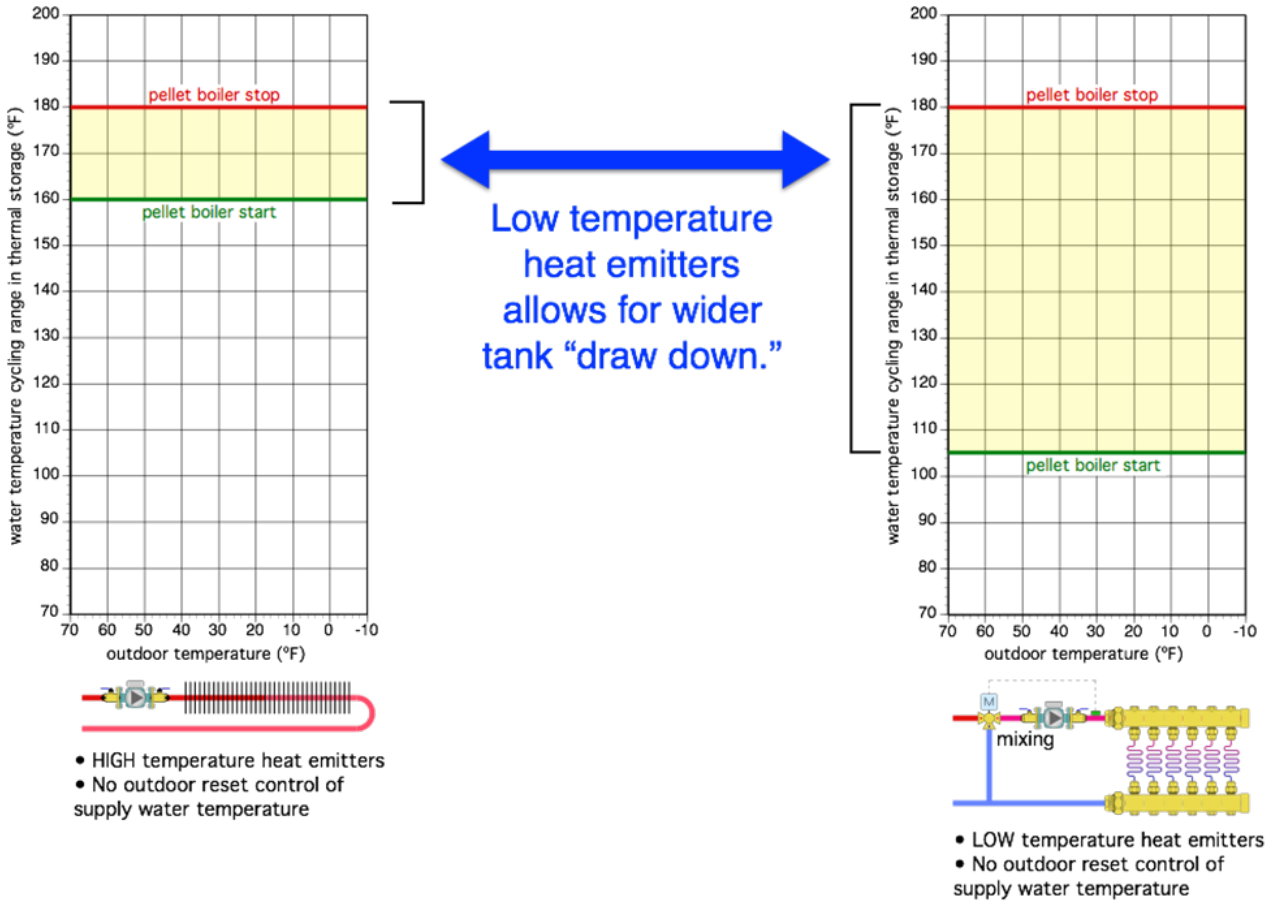
The controller monitoring this sensor closes a set of electrical contacts when the sensor's temperature drops to some value—determined by the setting on the controller. That setting is likely to depend on the heat emitters used in the system. If the distribution system uses high-temperature, fin-tube baseboard, the controller may be set to close its contacts when the sensor temperature is in the range of 170°F. This temperature is typical of and expected in the sizing for many existing fin-tube baseboard systems as a design load water temperature. If the distribution system supplies low-temperature radiant panel heating, the contacts in the controller may not close until the tank sensor temperature drops to a much lower temperature such as 100°F. In either case, the contact closure initiates the pellet boiler's start-up sequence, which is then managed by that boiler's internal controller.

Once started, the pellet boiler continues to operate until the temperature at the tank sensor reaches some upper limit, which again depends on the heat emitters used in the system. In a high-temperature baseboard system the upper limit temperature might be in the range of 180°F to 190°F. In a low-temperature, radiant panel system the upper limit could be lower. However, even in systems with low-temperature heat emitters, it's often beneficial from the standpoint of long boiler on-cycles to

keep the boiler running until the tank's temperature sensor reaches a relatively high temperature in the range of 170°F to 190°F. Doing so allows the temperature cycling range of the tank to be significantly wider (e.g., from a "boiler on" temperature of perhaps 100°F, to a "boiler off" temperature of perhaps 175°F). Wider temperature cycling ranges allow for longer boiler on-cycles and subsequently for longer boiler off-cycles. This yields higher overall efficiency and lower emissions. A mixing device would be used to reduce the temperature of the water supplied to the low-temperature heat emitters.

Figure 3-4 compares the temperature cycling range of a thermal storage tank using a single-temperature sensor control system in two systems. One with high-temperature heat emitters, and the other with low-temperature heat emitters.

Figure 3-4. Comparison of temperature cycling range for a thermal storage tank using high-temperature heat emitters versus low-temperature heat emitters



The graph on the left represents a system with fin-tube baseboard that has been sized to provide design-load heat output at a water temperature of 180°F. In this case, the pellet boiler is turned on when the tank sensor temperature drops to 160°F and remains on until the sensor temperatures climbs to 180°F. The shaded yellow area on the graph shows that this temperature cycling range is independent of outdoor temperature.

The graph on the right shows a system in which low-temperature radiant panels are supplied from the thermal storage tank. The pellet boiler is enabled to operate when the tank's temperature sensor drops to 105°F and remains on until the sensor temperature reaches 180°F. The yellow shaded area, as in the previous example, shows the temperature cycling range. Again, neither of these temperature settings change based on outdoor temperature.

In systems with low-temperature heat emitters, some type of hydronic mixing assembly must be used between the thermal storage tank and the distribution system.

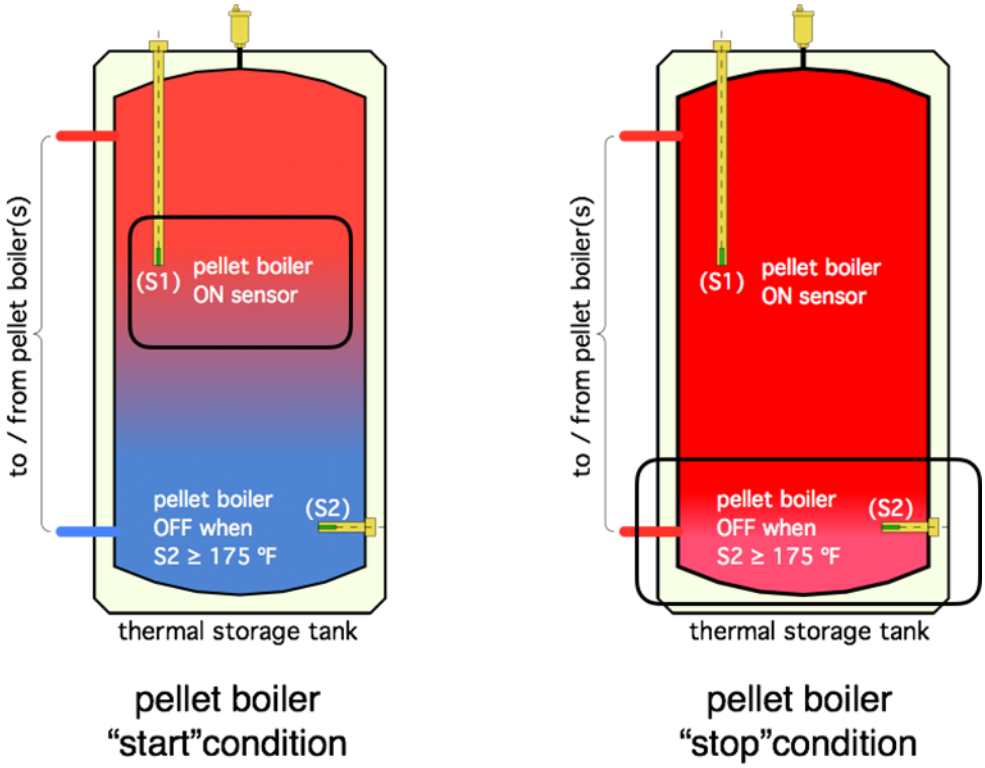
In systems with low-temperature heat emitters, some type of hydronic mixing assembly must be used between the thermal storage tank and the distribution system. The mixing assembly automatically reduces the water temperature supplied to the heat emitters to a level that allows for their proper and safe operation. It does this by blending a portion of the cooler water returning from the heat emitters with higher temperature water coming from the upper portion of the thermal storage tank. Several options for mixing assemblies are discussed in section 7.

A comparison of the yellow shaded areas in Figure 3-4 shows that the operating water temperature of the heat emitters used in the system has a major impact on the allowable temperature cycling range of the thermal storage tank. Systems using lower temperature heat emitters allow the thermal storage tank to operate with much wider temperature cycles. Those wider temperature cycles result in longer and less-frequent boiler cycling, and thus yield higher efficiencies and lower emissions. Using pellet boilers in combination with low-temperature heating distribution systems is always preferable.

3.3 Two-Temperature Sensor Control

Another method of controlling pellet-boiler firing based on thermal storage tank temperature uses two temperature sensors, one in the upper portion of the tank and the other in the lower portion, as shown in Figure 3-5.

Figure 3-5. Thermal storage tank with upper and lower temperature sensors for turning a pellet boiler on and off



The pellet boiler is turned on when the temperature at the *upper* sensor drops to some lower limit. The pellet boiler is turned off when the temperature at the *lower* sensor reaches some higher temperature limit. This combination of sensor locations and their associated "turn on" and "turn off" temperatures, allows the tank to undergo a greater temperature cycling range relative to the same tank with a single temperature sensor. This improves boiler efficiency and decreases emissions. This mode of temperature control will be described in more detail in section 7.

3.4 Pellet Storage

Pellet boiler systems can be configured with either interior or exterior pellet storage. Both approaches have strengths and limitations.

Interior pellet storage devices, such as reinforced fabric bins, can be constructed of materials that do not have to resist weathering. However, they also require a significant amount of space within the building, which might not be available, especially in retrofit situations. Some of the dust created when an interior bin is filled with pellets may also find its way into spaces surrounding the bin.

Exterior pellet storage devices must be resistant to weather and keep pellets dry. They offer some flexibility in placement outside the building, are fillable without the need of entering the building, and any dust created during filling remains outside the building.

Wood pellets emit small amounts of carbon monoxide (CO) due to complex chemical reactions that persist for a time after the pellets are produced, presenting a health and safety concern. Research on the exact processes that create carbon monoxide in wood pellets has been undertaken by Clarkson University with support from NYSERDA. The researchers at Clarkson University have determined the reaction mechanisms responsible for carbon monoxide production and have successfully found a way to prevent it in the laboratory and in a pilot project at a pellet mill. Efforts are now underway to apply this approach routinely to mitigate CO emissions from wood pellets.

All pellet boiler systems funded through NYSERDA's Renewable Heat NY program require bulk storage of wood pellets to be outside of spaces intended for human occupancy.

However, because these methods of reducing CO emissions from wood pellets have not yet been commercially implemented, all pellet boiler systems funded through NYSERDA's Renewable Heat NY program require bulk storage of wood pellets to be outside of spaces intended for human occupancy.

Exterior storage bins for residential systems typically hold three to five tons of pellets. Smaller bins require less space, but more frequent filling, which can increase the cost of bulk pellet delivery depending on the distance to the pellet supplier. Figure 3-6 shows an example of a modular exterior pellet storage bin that holds approximately three tons of pellets.

Figure 3-6. Modular exterior pellet storage bin that holds approximately three tons of pellets

Courtesy of Earhart Energy



It’s also possible to construct an exterior pellet storage bin from common building materials. An example is shown in Figure 3-7

Figure 3-7. Exterior pellet storage bin constructed from common building materials



The pellet storage building in Figure 3-7 has interior sloping plywood surfaces that form a hopper to channel pellets into a steel receiver at the base. The pellets are pulled from this receiver into the building through underground tubing routed through PVC protective sleeving.

Larger commercial, municipal, or industrial systems are typically equipped with larger pellet storage silos. There are several options ranging from galvanized steel silos as seen in Figure 3-8, to polyethylene silos, as seen in Figure 3-9.

Figure 3-8. Galvanized steel pellet storage silo

Courtesy of Carl Longnecker



Figure 3-9. Polyethylene pellet storage silo



It's also possible to have a pellet storage bin designed to coordinate with building architecture as seen in Figure 3-10.

Figure 3-10. Pellet storage bin incorporated into building architecture



In most projects, exterior pellet storage bins or silos are placed close to the building area containing the boiler. This minimizes the pellet transport piping required. Designers should select locations that are easily accessible by bulk delivery trucks. Avoid locations directly under eaves where roof water or sliding snow or ice will impinge on or come close to the storage bin or silo. Also, be sure that all seams in exterior pellet silos and associated conveyance systems are properly sealed to prevent water entry.

3.5 Pellet Conveyance Systems

Pellet transport from an exterior storage bin or silo to the boiler is typically provided by one of two options:

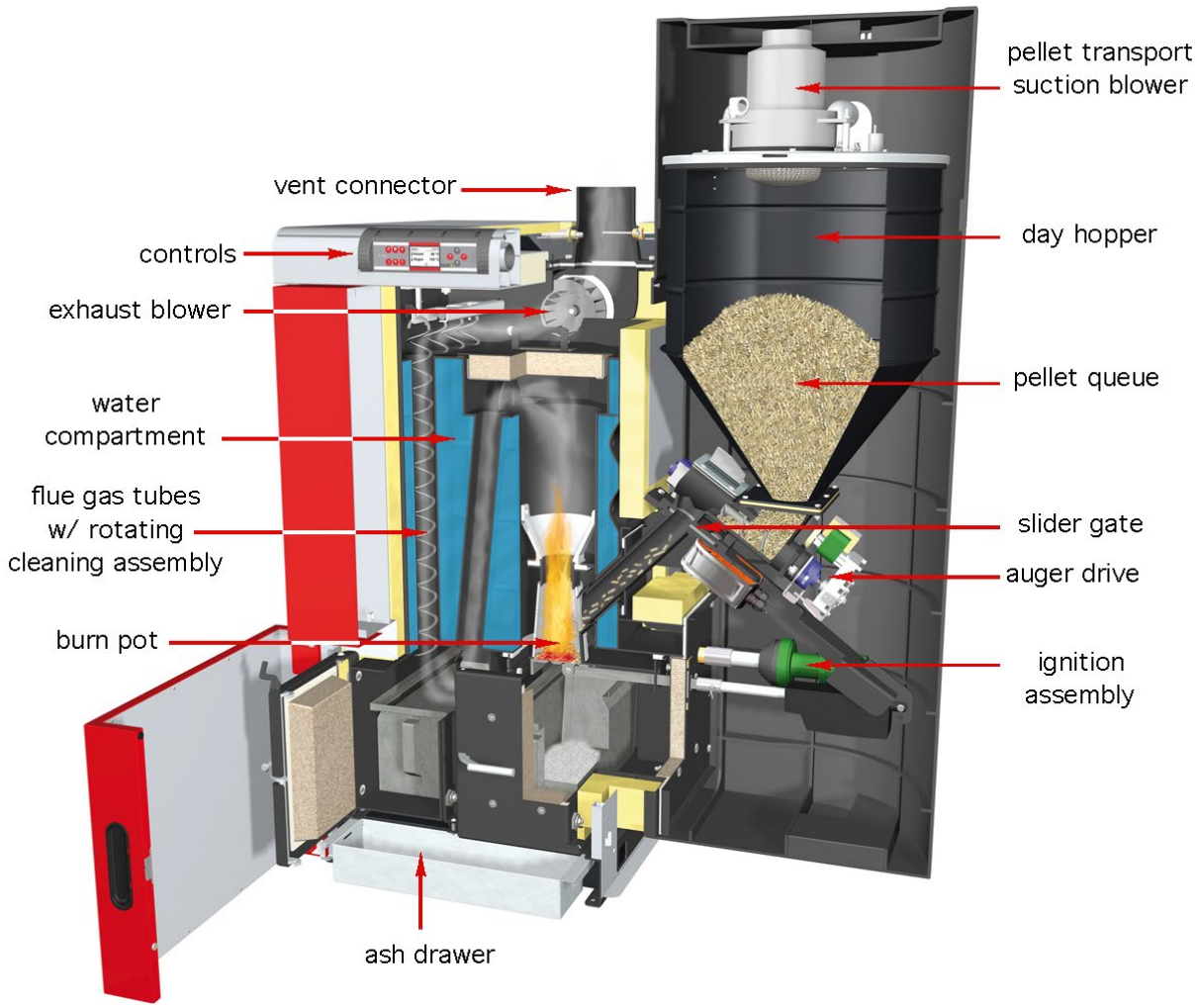
- A two-tube pneumatic conveyance system
- A single-pipe flexible auger system

Two-tube pneumatic conveyance systems use an electrically driven blower to create a combined vacuum and air-flow effect that moves pellets from bulk storage through flexible tubing and delivers them to a day hopper located adjacent to the boiler. This blower is automatically operated by the boiler's internal controller.

Figure 3-11 shows a cut away of a pellet boiler with the day hopper and stoker auger assembly seen on the right. The blower used for pneumatic pellet conveyance is seen on top of the day hopper.

Figure 3-11. Cutaway of a pellet boiler with its associated day hopper

Courtesy of Tarm Biomass



Pneumatic conveyance systems use two flexible tubes between the day hopper assembly and a pellet receiver mounted at the base of the exterior bin or silo. Figure 3-12 shows an example of the pellet receiver.

Figure 3-12. Pellet receiver to be installed at base of pellet silo

Courtesy of Carl Longnecker



The receiver reduces weight-induced packing of pellets, allowing them to be freely entrained by a fast-moving air stream and carried from the receiver to the day hopper. The pyramid shaped baffle in the receiver creates a space beneath the pellet column where the suction effect created by a fast-moving air stream can entrain pellets, carrying them into the supply tubing.

Figure 3-13 shows the two flexible tubes terminating at the blower assembly, which has been lifted off the day hopper.

Figure 3-13. Pneumatic pellet transport tubing between pellet receiver under silo and the day hopper

Courtesy of Carl Longnecker



In larger non-cylindrical bins, multiple “probes” or receivers are used to draw pellets from several locations at the base of the bin.

Figure 3-14 shows the base of a pellet silo that has been fitted with a partitioning assembly to create two independent pellet streams to two pellet receivers. The vacuum and air return tubes to each receiver are routed through the black corrugated polyethylene sleeving to protect them from ultraviolet degradation as well as to provide support and protection from the elements.

Figure 3-14. Pellet silo fitted with two pellet receivers to independently supply two boilers

Courtesy of Carl Longnecker



All tubing used for pneumatic pellet transfer should have a ground wire that's attached to the pellet boiler chassis, which itself is connected to an electrical ground. Electrical grounding drains away static electrical charge that could otherwise build up from dust moving along with the high-speed air through the pellet transfer tubing. See the pellet boiler's installation instructions for details on properly grounding the pellet transfer tubing.

Pellets can also be moved by a flexible helical auger that rotates within a single-flexible guide tube as seen in Figure 3-15.

Figure 3-15. Flexible helical auger installed within a single-flexible guide tube



A motor coupled to a gear box rotates the auger. The pellets slide along the guide tube as the auger rotates. The auger's operation is regulated by the boiler's internal controller. Most boilers can reverse the flexible auger, if necessary, to clear a potential jamb when detected based on auger motor current. The pellets arrive at a small queue at the base of the boiler and are transferred to another motorized auger that feeds them into the boiler's combustion chamber. Figure 3-16 shows the termination of the flexible auger, the gear motor assembly that rotates the auger, and the lower portion of the rigid stoker auger that carries the pellets into the boiler.

Figure 3-16. Transition from flexible auger assembly, and the stoker auger that carry pellets into the boiler



The length of flexible auger assemblies should be minimized to reduce potential abrasion of the pellets. It is also possible to install a "fines screen" on flexible auger systems as seen in Figure 3-17.

Figure 3-17. Fines screen installed on a flexible auger guide tube

Courtesy of Troy Boiler Works



As the pellets pass the screen, fine particles caused by fractured pellets fall through the openings. This reduces fines within the boiler's stoker queue and stoker auger. If a fines screen is used it should be supported above a collection pail. The pail should also be covered to prevent dust emitted from the screen from becoming airborne within the mechanical room. The collection pail should be periodically checked for accumulation and emptied.

Pellet boilers are not designed to efficiently convey or burn fines or wood dust. High-quality premium wood pellets (which is the only grade of pellets allowed in systems installed under the Renewable Heat NY program) should have a maximum fines content of 0.5% by weight. However, excessive handling of pellets during loading, transport, and unloading, or poor-quality control during manufacturing can increase fines. Situations that show evidence of excessive fines in the pellet delivery system should be investigated starting with the pellet manufacture, the supplier, and a careful review of the pellet transport system to identify any potential sources of excess pellet abrasion.

Some pellet silos are also equipped with rigid (linear) motorized augers as seen in Figure 3-18.

Figure 3-18. Pellet storage silo fitted with a rigid motorized auger assembly

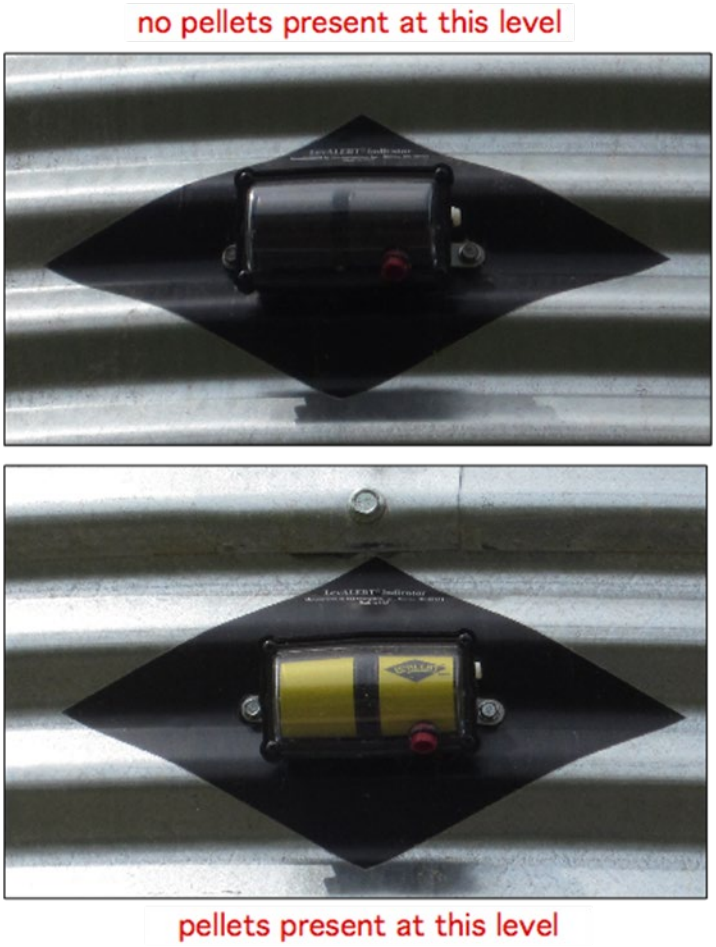


Regardless of the type of pellet transport system used, it is critically important that the pellet receiver assembly be designed, installed, and maintained so that precipitation cannot enter.

3.6 Content Measurement of Pellet Silo

Some pellet silos can be equipped with multiple, mechanical-level indicators at locations along the height of the silo that allow the volume of pellets to be estimated without looking into the top of the silo, see Figure 3-19.

Figure 3-19. Pellet silo fitted with multiple, mechanical-level indicators



Translucent polyethylene silos make it easy to see the pellet level, as shown in Figure 3-20.

Figure 3-20. Translucent polyethylene silos show the pellet level



It's also possible to measure the pellet contents of a storage silo by suspending the silo on load cells, which send electrically encoded signals based on the weight they support. Figure 3-21 shows an example of a custom-built pellet silo suspended on four load cells.

Figure 3-21. Pellet silo supported on load cells that measure weight of silo and the pellets it contains



It's important to electrically ground metal pellet bins and silos. A conductor attached to the metal bin or silo is routed to a driven grounding rod, typically adjacent to the pad supporting the bin or silo. Grounding prevents accumulation of static electrical charge that could potentially create a spark. It also helps protect the silo against lightning strikes.

Exterior pellet bins and silos are generally supported on concrete foundations. Silo manufacturers usually provide a specification for the foundation pad or piers based on the height of the silo and the weight it will support.

3.7 Pellet Boiler Sizing

Most boilers are sized based on the design heating load of the building they serve. Common practice is to estimate the design heating load using acceptable methods such as ACCA Manual J, and then select a boiler with a rated heat output that's equal to or slightly greater than the load.

When a pellet boiler is the *only* source of space heating for a building, it can also be sized using the same procedure.

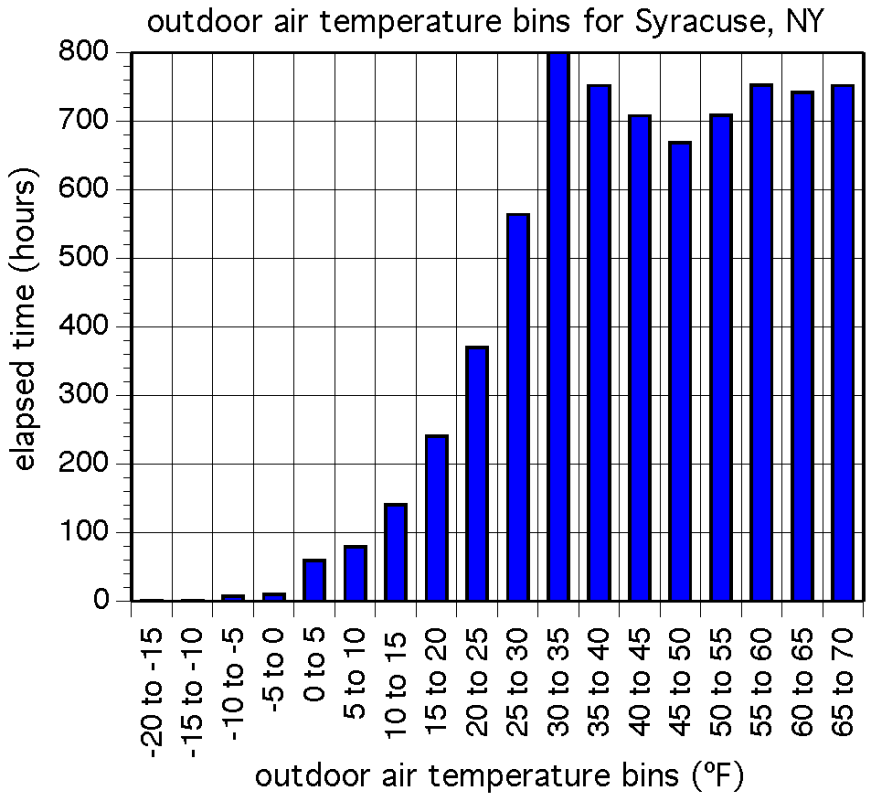
However, when a pellet boiler will be combined with another auxiliary heat source or retrofitted into a system with an existing boiler, other factors should be considered. One of these is the desire to keep the pellet boiler operating with long on-cycles followed by long off-cycles. Recall that a previously suggested operating goal for a pellet boiler is an average on-cycle time of three hours per start. It is much more likely that this condition can be achieved when the pellet boiler is not sized to the full-design heating load.

Pellet boilers that are sized in the range of 50–75% of the design heating load can still cover the majority of the seasonal heating needs of a building.

Pellet boilers that are sized in the range of 50–75% of the design heating load can still cover the majority of the seasonal heating needs of a building. This is possible because of the many hours of partial-load operation that occur in a typical heating season.

The graph in Figure 3-22 shows "bin temperature" data for Syracuse, NY. The hourly average outdoor temperatures for an entire year are grouped into "bins" that each represent a 5°F span of temperature.

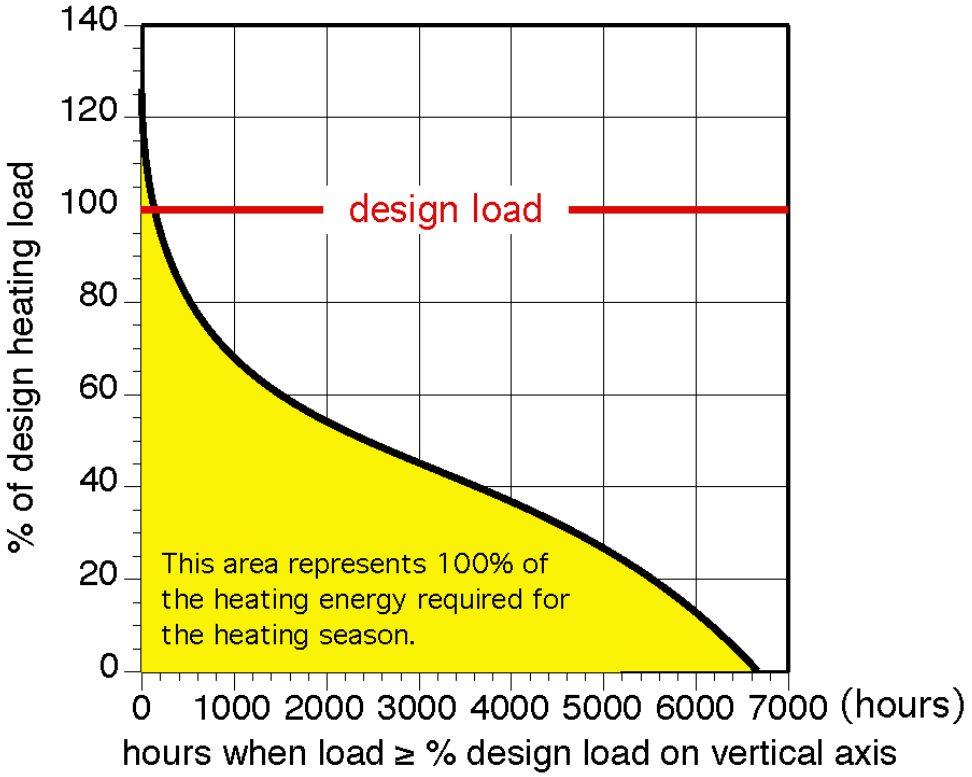
Figure 3-22. Hourly average outdoor temperatures in Syracuse in 5°F "bin" groupings



The 99 and 99.6% design dry-bulb temperatures for this location are 4.9°F and -0.7°F respectively. Notice that the vast majority of the hours in a typical year have corresponding outdoor temperatures well above these design temperatures. Under these conditions the heating load will be substantially lower than during the very infrequent design-load conditions.

The data for Figure 3-22 is represented in a different form in Figure 3-23.

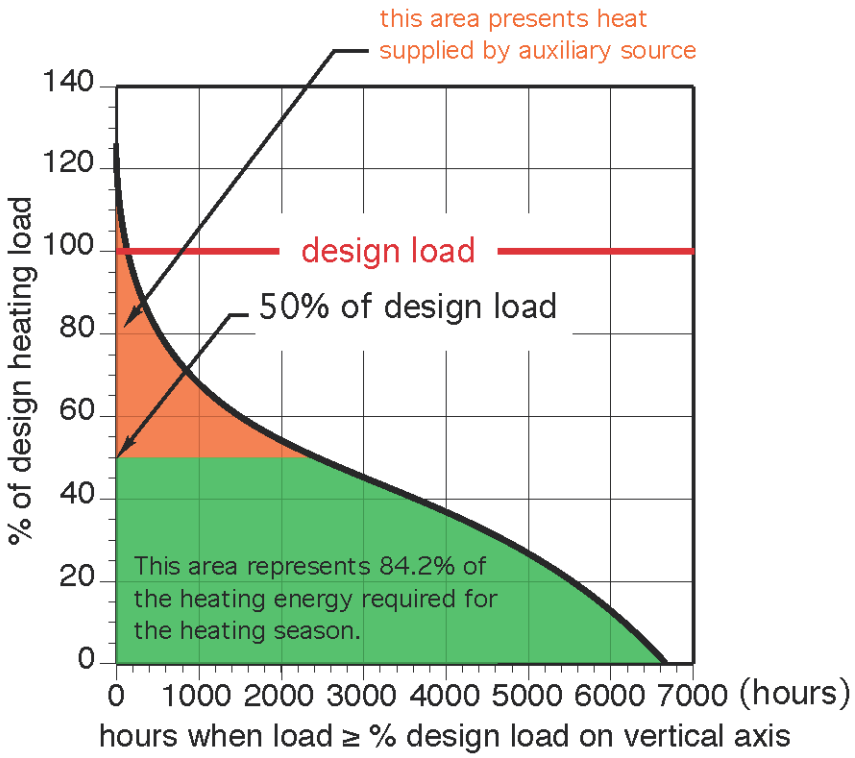
Figure 3-23. Graph showing percent of design load versus hours where load is greater than or equal to a given percentage of design load for Syracuse, NY



The vertical axis of this graph represents the percent of the design-heating load. The horizontal axis shows the hours during which the heating load is equal to or greater than the percent of design-heating load on the vertical axis. Although this graph is specific to the statistical weather data for Syracuse, NY, the characteristic curved shape of the shaded area is typical of other cool or cold climate locations.

The yellow area on the graph is proportional to the total seasonal space heating energy use of a building. Figure 3-24 shows the same curve as in Figure 3-23, but with a horizontal line across the graph at 50% of design load.

Figure 3-24. Graph, based on Syracuse, NY weather data, showing that 84.2% of total seasonal heating energy is used when the heating load of the building is less than 50% of the design heating load



The green shaded area shows that 84.2% of the total seasonal heating energy use occurs when the heating load is 50% or less of design load. The remaining 15.8% of seasonal energy use occurs when the heating load is greater than 50% of design load. This implies that a boiler sized to 50% of design load could supply about 84% of the total seasonal heating energy requirement.

If the horizontal line is moved to higher percentages of design load, the percent of total seasonal space-heating energy supplied by a boiler sized to that specific percentage of design load increases, as shown in Figure 3-25.

Figure 3-25. Percent of seasonal heating energy supplied by a pellet boiler versus the heating capacity of that boiler relative to design load

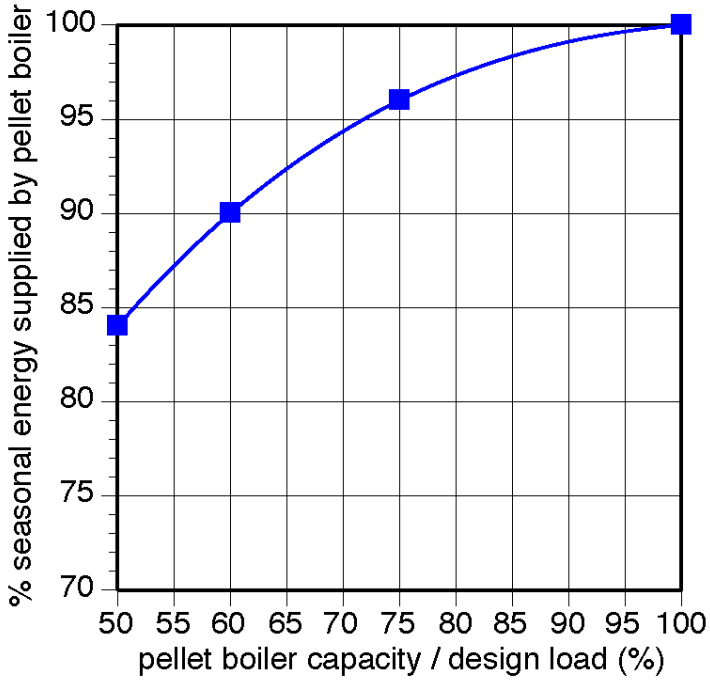


Figure 3-25 indicates that a pellet boiler sized to 75% of design load, in Syracuse, NY, could supply about 96% of the total seasonal space heating energy requirement. The remaining 4% would be provided by a supplemental heat source, such as another boiler, or other heating devices in the building.

In consideration of this relationship between pellet boiler size, percent of annual space heating energy use, and the goal of obtaining long boiler on-cycles, it is suggested that pellet boilers be sized to provide 60–75% of design heating load. Supplemental heating device(s) can be used to provide the balance of the heating energy requirement.

Pellet boilers can be sized to provide 60% to 75% of design heating load.

For systems seeking approval through NYSERDA's Renewable Heat NY program, and in a situation where a pellet boiler has a rated output of 300,000 Btu/hr or more, the boiler's rated output cannot exceed 60% of the design heating load.

4 Boiler Air Supply and Venting Systems

All biomass boilers rely on adequate air supply for proper combustion. They also rely on safe and long-lasting venting systems to carry the flue gases produced out of the building. This section discusses both air supply and venting based on applicable standards and field experience.

4.1 Applicable Standards

Every biomass boiler installation must conform to applicable codes and standards. Many state codes that relate to boiler installations refer to standards developed by the National Fire Protection Association (NFPA). Designers should also verify that their venting systems fully conform to any local codes that may be more stringent than state codes. It's also important to realize that codes and standards change with time. Designers should always verify that their designs conform to the latest applicable codes and standards.

The standard NFPA 54 ANSI Z223.1 National Fuel Gas Code (NFPA 54) is one of the most commonly referred to documents regarding air supply and venting of boiler systems. Much of the information presented in this section in based on the standard.

The standard NFPA 54 ANSI Z223.1 National Fuel Gas Code (NFPA 54) is one of the most commonly referred to documents regarding air supply and venting of boiler systems.

4.2 Air Supply Requirements

NFPA 54 (2018) requires that the spaces where boilers are located have adequate air supply. Air is needed for combustion, flue-gas dilution, and ventilation of the mechanical room.

Most pellet and cordwood gasification boilers are designed to draw the air required for combustion directly from the space surrounding the boiler. It's very important that the space around the boiler is not used to store chemicals such as chlorine, bromine, or other halogens, pool chemicals, detergents, or refrigerants. If present, vapors from these chemicals mix with interior air and are drawn into the boiler's combustion chamber, where they form very aggressive hydrochloric or hydrofluoric acids. Those acids can quickly and severely corrode the boiler's heat exchanger and venting system. Hanging laundry to dry in the space around the boiler should also be avoided due to residual detergent vapors or disinfectant vapors. It's also advisable to not locate a biomass boiler in the same mechanical space as chiller where potential refrigerant leakage could occur.

Some biomass boilers are equipped with ducting to bring outside air into the boiler jacket. However, this should not be confused with sealed combustion systems. When outside air is ducted to a biomass boiler it enters the boiler's jacket rather than its combustion chamber. This is beneficial in that the potential for contaminants in the boiler's air supply is reduced. The incoming air is also partially heated by passing across surfaces inside the boiler's jacket before entering the combustion chamber.

The NFPA 54 (2018) requirements relevant to solid-fuel boilers can be categorized as follows:

1. If the space containing the boiler has a volume of at least 50 cubic feet per 1000 Btu/hr of heat input rating of the boiler, AND the air change rate of that space is known to be at least 0.4 natural air changes per hour, there is no need to provide additional outside air to that space. Interior spaces that meet this condition are called "unconfined spaces."
2. If the natural air change rate of the space containing the boiler has been determined using blower door testing, and does not exceed 0.6 air changes per hour, the minimum volume requirement of the space is 21/(air change per hour) cubic feet per 1000 Btu/hr of heat input rating of the boiler. For example, if the measured air change rate was 0.5 air changes per hour, the minimum volume requirement of the space (to exempt it from additional outside air provision) would be 21/0.5 = 42 cubic feet per 1000 Btu/hr of boiler input rating. If the boiler has fan assisted combustion the requirement reduces to 15/(air changes per hour) per 1000 Btu/hr of boiler input rating. The boiler's fuel input rate can be estimated by dividing its rated heat output by its steady state thermal efficiency.
3. If the space surrounding the boiler doesn't meet the above requirements outside air needs to be provided. Designers should verify any local or state code requirements that may defer to the boiler manufacturer's prescribed outdoor air provisions. In the absence of those provisions, or in cases where local/state codes don't recognize those provisions, the requirements of NFPA 54 (2018) are as follows:

    - If two openings are provided between the mechanical room and outside, each opening needs to have a minimum free area of 1 square inch per 4,000 Btu/hr of fuel input rating of all combustion appliances in that space. One opening has to begin within 12 inches of the mechanical room floor, and the other has to begin within 12 inches of the mechanical room ceiling. The free area of the opening is the opening areas divided by 0.75 if metal louvers are used over the opening or opening area divided by 0.25 if wood louvers are used. The openings can be screened, but that screen must have openings no smaller than 0.25 inches.

If piping must be near the lower opening it should be routed above the opening where cold air flow is less likely; take extra precaution with piping leading to expansion tanks.

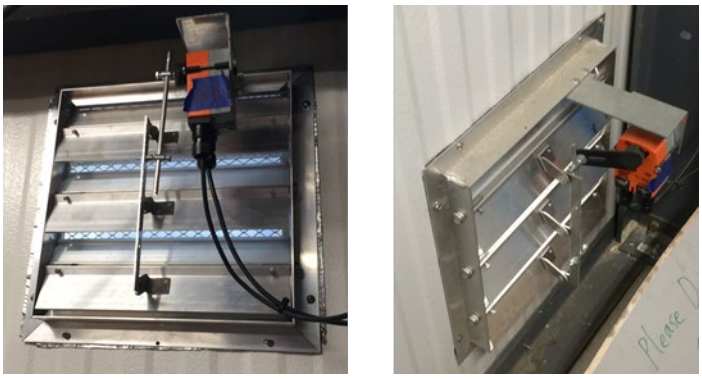
- If one opening is provided between the mechanical room and outside, the minimum free area of that opening is 1 square inch per 3,000 Btu/hr of fuel input rating of all combustion appliances in that space. The opening must begin within 12 inches of the mechanical room ceiling. The same ratios apply for determining free area based on opening area and use of louvers.

In many climates the air entering mechanical rooms through outside air opening can, at times, be below freezing. Care should be taken to keep piping carrying water away from these outside openings, especially the lower opening. If piping must be near the lower opening it should be routed *above* the opening where cold air flow is less likely. Be especially careful with piping leading to expansion tanks since there is limited water movement.

4.3 Motorized Dampers

One way to prevent excessive air flow into mechanical rooms with outside air openings is to install motorized dampers on those openings. Examples of two openings equipped with motorized dampers are shown in Figure 4-1.

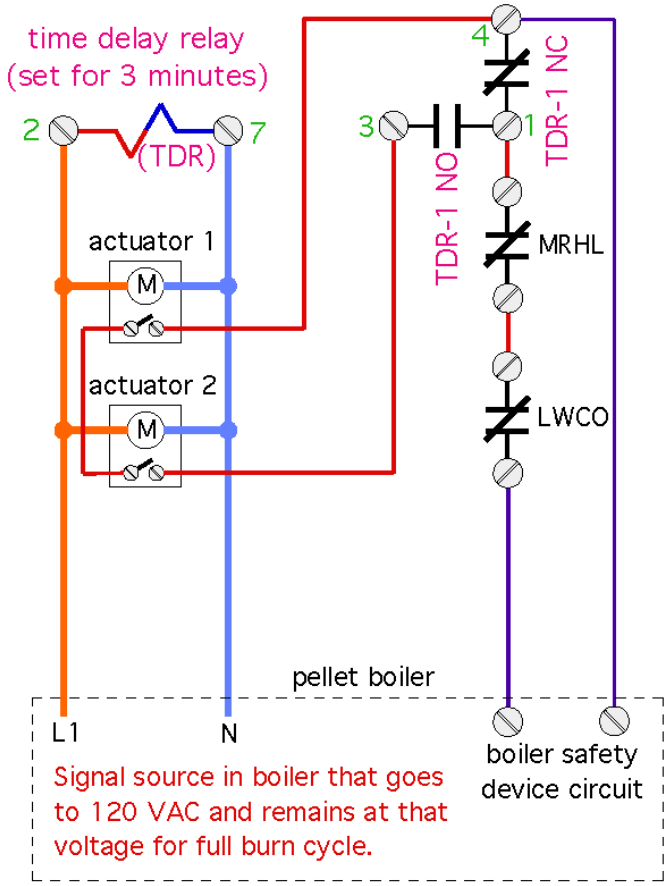
Figure 4-1. Motorized fresh air dampers installed in exterior wall of mechanical room



If motorized dampers are used, codes require that their actuators are equipped with “end switches” that close only when the damper is fully open. These end switches should be wired in series. The series-connected end switches must then be wired into the boiler’s control system so that the boiler cannot fire if the dampers fail to open or fail to remain open.

One nuance to using the above wiring occurs when the pellet boiler fires based on the temperature of one or more sensors in the thermal storage tank, AND the control logic associated with this operation is internal to the boiler. In such cases, there is no external contact closure that calls the pellet boiler to fire. One possible approach to this scenario is based on tapping into a voltage source within the pellet boiler that is live and stable during the entire combustion cycle. Figure 4-2 shows how an internal 120 VAC voltage source could be used to operate motorized air dampers in coordination with other safety controllers.

Figure 4-2. Circuit for operating motorized fresh air dampers based on a 120 VAC signal generated by pellet boiler whenever it is firing



The damper actuators and the time delay relay (TDR) are energized as soon as a 120 VAC signal within the boiler turns on at the beginning of the combustion cycle. That signal source must provide a stable 120 VAC throughout the combustion cycle. A normally closed contact (TDR-1 NC) is wired in series with the normally closed terminals of the manual reset high limit (MRHL) and low-water cutoff (LWCO) safety devices. These three normally closed contacts, in series, represent a temporary closed circuit to the boiler safety device terminals.

After a time delay period of two to three minutes the damper actuators should be fully open and the ends switches in both actuators should be closed. When the time delay relay times out, it opens its normally closed contact and closes its normally open contact. The latter puts both actuator-end switches in series with the normally closed contacts in the MRHL and LWCO. These four closed contacts represent normal operating conditions for the duration of the firing cycle. If any of these four contacts open, the boiler safety device circuit opens, and the boiler stops firing. This operating logic could also be created within systems using building automation controls.

The preferred chimney system for biomass boilers in residential and light commercial systems is an “all fuel” prefabricated chimney conforming to the standard UL103-HT.

4.4 Chimney Options

The common standards for chimney design and construction are NFPA 54 and NFPA 211. Visit http://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards to access both standards online.

The preferred chimney system for biomass boilers in residential and light commercial systems is an "all fuel" prefabricated chimney conforming to the standard UL103-HT. Chimneys meeting this standard are rated to operate continuously at temperatures of 1,000°F, and for up to 10 minutes at temperatures of 2,100°F. They are "double wall" chimneys with inner walls constructed of stainless steel (304 or 316) surrounded by a layer high-temperature fiber insulation and an outer wall of chrome-plated steel (with other outer-wall options sometimes available). UL103-HT chimney systems are available from several manufacturers in a variety of sizes. Figure 4-3 shows some of the components available for a UL103-HT chimney.

Exterior masonry chimneys, such as shown in Figure 4-4 can be problematic in combination with modern heating appliances.

Figure 4-3. UL103-HT chimney components

Courtesy of Simpson Duravent



All chimneys must meet installation requirements set by local or state codes. Many of those codes refer to NFPA 211 which, among others, includes the following exterior chimney requirements:

The top of any chimney that is within 10 feet of a roof ridge or parapet wall must be at least two feet higher than the ridge or parapet wall.
The top of a chimney that is more than 10 feet from a roof ridge must be at least two feet higher than anything within a 10-foot radius, and at least three feet above the upslope
location where it penetrates the roof.
A solid fuel appliance and other fuel burning appliances cannot share a common chimney flue.

4.5 Masonry Chimneys

Before prefabricated chimneys were widely available, most chimneys were of masonry construction. Those chimneys usually have a fire-clay liner surrounded by supporting concrete block construction. Some brick chimneys in very old buildings have no flue liner and should never be used (as is) to vent any modern heating appliance.

Exterior masonry chimneys, such as shown in Figure 4-4 can be problematic in combination with modern heating appliances.

Figure 4-4. Exterior masonry chimney



Exposed masonry chimneys, such as shown in Figure 4-4, present several concerns. First, modern heating appliances, including pellet and cordwood gasification boilers, seldom produce flue-gas temperatures over 350°F. These temperatures are relatively low compared to the temperatures produced by older heating appliances. Existing masonry chimneys that were designed for older appliances may not produce adequate drafts to properly vent a modern biomass boiler operating at significantly lower flue-gas temperatures.

In locations where the 99% design dry-bulb temperature is 4°F or lower masonry chimneys with one or more sides exposed below the roof's eave height are not recommended for any venting application.

The second issue is that exterior masonry chimneys have much higher thermal mass compared to UL103-HT chimneys. This thermal mass can get very cold during winter days when the biomass boiler may be off for several consecutive hours. This characteristic makes exposed masonry chimney slow to warm up when a biomass boiler begins operating. This can result in very limited draft (e.g., the inability to transport flue gases up the chimney as fast as they are produced by the boiler). This situation is exasperated by boilers with draft inducting blowers, which includes most pellet and cordwood gasification boilers. In combination, these factors can produce temporary conditions where the vent connector piping between the boiler to the chimney operates at a slight positive pressure relative to surrounding air, which can cause leakage of flue gases and small amounts of fly ash into interior spaces—a condition that is first and foremost unsafe, as well as messy.

The NFPA 54 standard also limits the use of masonry chimneys that have one or more sides exposed to the outside below the roof line. The limitation specifies the minimum heat output of appliances connected to the chimney based on its height, flue cross-sectional area, and the local 99% design dry-bulb temperature. In climates where the 99% design dry-bulb temperature is between 5–16°F, the minimum appliance rating would be 430,000 Btu/hr, which is well above what most residential and light commercial systems require. In locations where the 99% design dry-bulb temperature is 4°F or lower (which includes much of Upstate New York) masonry chimneys with one or more sides exposed below the roof's eave height are not allowed based on NFPA 54 for any venting application.

Masonry chimneys that are primarily routed through heated space (below the roof line) are better than exposed masonry chimneys, but still subject to constraints imposed by NFPA 54. If such chimneys are being consider for venting a pellet boiler or cordwood gasification boiler, it is recommended that they be retrofitted with a stainless-steel liner. Liner systems are available in both straight length and flexible stainless steel, as well as pre-insulated. Straight lengths of stainless-steel liner are typically inserted from the top of the masonry chimney, using the existing flue as a chase. Liner sections are joined using stainless-steel pop rivets. The bottom liner section is usually fitted with a stainless elbow that is placed after removing some of the surrounding masonry materials. Prior to committing to relining, chimneys

should be assessed using an inspection camera lowered through the existing flue. Verify that the flue is straight enough to receive the straight liner sections. Flexible stainless-steel liners, both bare and pre-insulated, are available for situations where a straight liner could not be used. Figure 4-5 shows a flexible stainless-steel liner being placed into an existing masonry chimney.

Figure 4-5. Flexible stainless-steel liner being inserted into a masonry chimney

Courtesy of Interphase Energy



4.6 Sidewall Venting and Power Venting

Unlike fossil fuel boilers that immediately stop operating when a power outage occurs, biomass boilers containing wood (e.g., cordwood or pellet) continue to burn. Under such conditions the carbon monoxide emissions from biomass boiler can also be hundreds of times higher than those from oil or gas-fired boiler. If the venting system relies solely on an electrically powered blower to exhaust flue gases through the sidewall of a building, and that blower is off, there's a strong possibility of flue-gas spillage into the building. This concern has largely eliminated the use of venting systems that rely solely on powered blowers for use with biomass boilers. The powered sidewall venting systems sometimes used with oil-fired boilers, and commonly used with gas-fired boilers, do not assure that combustion products will be fully expelled from the building during power outages. Because of this, sidewall venting should not be used for biomass boilers.

4.7 Chimney Bracing

UL103-HT chimney systems that rise more than five feet above the roof line or used on buildings with metal roofs subject to snow slides should be carefully braced. Snow sliding from metal roofs can break apart unsupported chimneys. Most manufactures of UL103-HT chimneys offer stainless-steel bracing systems. Figure 4-6 shows examples of braced chimneys.

Figure 4-6. Steel bracing of a UL103-HT chimney above a metal roof



All braces should be secured directly to building structural elements (rafters, trusses, etc.) using stainless-steel hardware and grommets or sealants to waterproof all roof penetrations. Another possibility is to install a snow splitter upslope from the chimney as seen in Figure 4-7.

Figure 4-7. Snow splitter installed upslope from a structurally braced chimney

source: Small-cabin.com

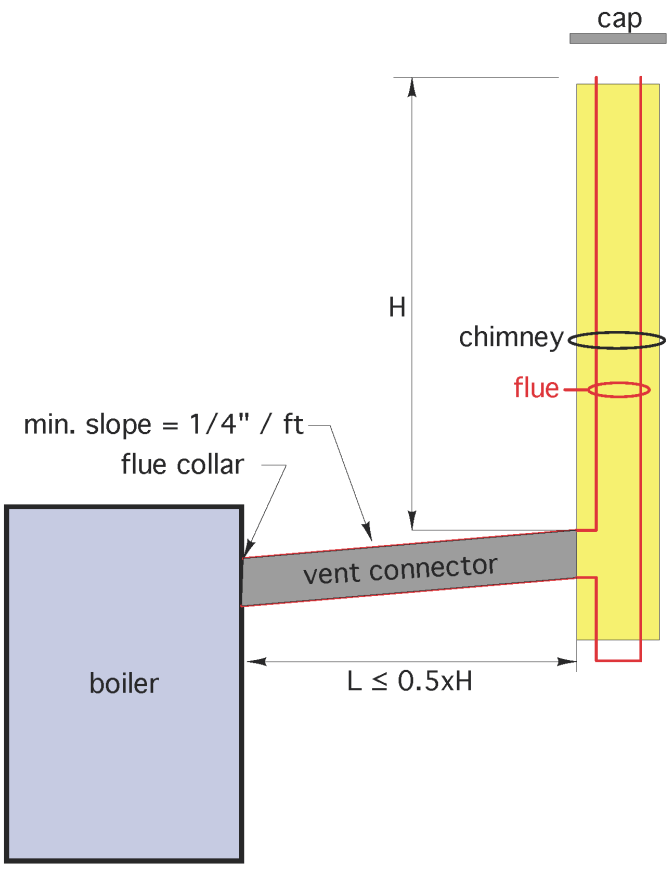


Snow splitters are designed to deflect sliding snow around the chimney and its flashing. Splitters should be made of materials such as aluminum or stainless steel in thickness that can handle substantial force without bending. Snow splitters should also be anchored to building framing using multiple stainless-steel fasteners.

4.8 Vent Connector Piping

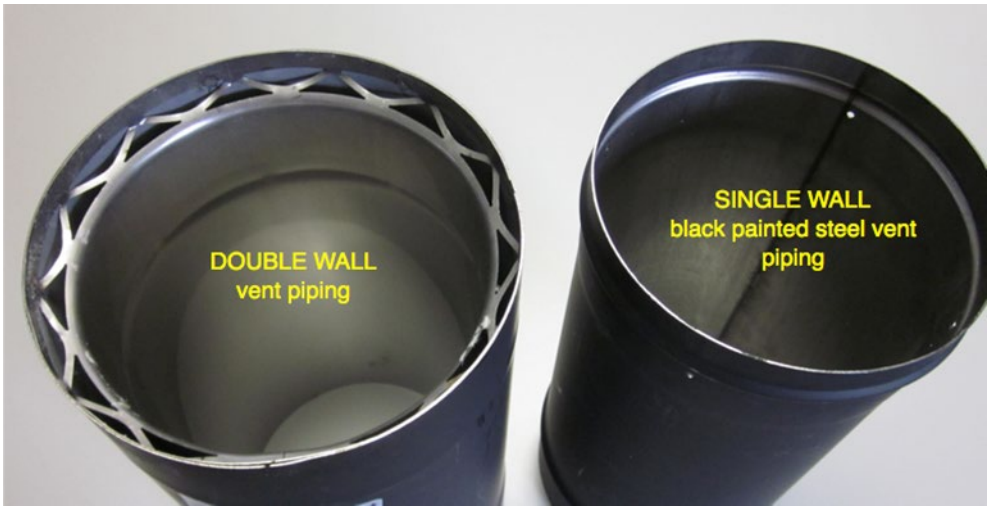
The piping used between the boiler's flue collar and the chimney is called vent connector piping. Figure 4-8 shows this piping in relationship to the boiler and chimney. It also shows two common NFPA requirements for the vent connector piping: (1) it cannot be longer than 50% of the height of the chimney above where the vent connector piping joins the chimney, and (2) it must have a minimum upward rise toward the chimney of one-quarter inch per foot of horizontal travel.

Figure 4-8. Vent connector piping connecting the boiler to the chimney, and associated code dimensions



Some mechanical codes allow vent connector piping that is equivalent in corrosion resistance to 24-gauge galvanized steel vent piping. However, this manual does not recommend galvanized vent connector piping for use with biomass boilers. One concern is leakage through the snap-lock longitude seams and crimped ends often used on galvanized vent connector piping. Another concern is long-term corrosion resistance. Instead, this manual recommends 22-gauge welded seam, single-wall, black steel stovepipe, or 22-gauge stainless steel, double-wall stove pipe. Figure 4-9 shows both types of pipe.

Figure 4-9. Examples of 22-gauge welded seam, single-wall, black steel stovepipe and 22-gauge stainless steel, double-wall stovepipe



Twenty-two gauge, black-painted, single-wall stove pipe is available from many suppliers in a range of sizes and with associated fittings such as elbows, tees, and caps. This pipe is swaged on one end, allowing sections to be joined without crimping. The swaged end of the pipe should always be installed up, to allow any condensate within the pipe to remain within the pipe as it drains downward.

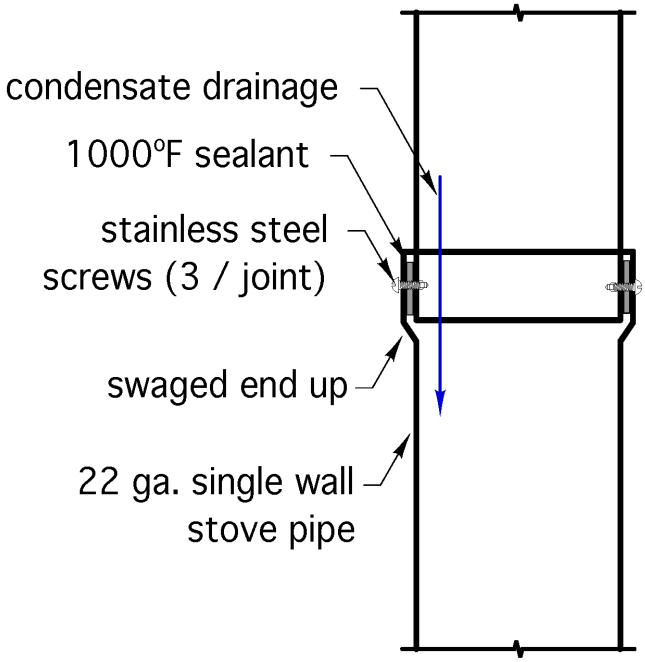
All joints in single-wall vent connector piping must be made using stainless steel screws that provide corrosion resistance. All joints in vent connector piping should also be sealed using a high-temperature sealant specifically made for sealing joints in venting systems. The sealant should be applied around the interior perimeter of the swaged pipe end so that the other section of pipe will slide through it when inserted.

Figure 4-10 shows how fly ash produced by a pellet boiler can leak through unsealed joints in single-wall vent connector piping. Ash leakage also means that flue gases, including carbon monoxide, have leaked through the joint, presenting a health and safety hazard. This leakage can be eliminated by proper sealing in combination with proper draft regulation of the venting system. Figure 4-11 shows the joint details just discussed, including piping orientation, sealant, and fasteners.

Figure 4-10. Fly ash leaking through unsealed joints in a single-wall vent



Figure 4-11. Joint details including piping, orientation, sealant and fasteners



Most codes require single-wall vent connector piping to be at least 18 inches away from any combustible materials. NFPA standards allow clearance distance reductions when specific types of thermal shielding are used.

Vent connectors can also be made using double wall piping. The inner wall of the pipe is 304- or 316-grade stainless steel. The outer wall is black painted steel. The inner and outer walls are separated by a three-eighths inch air space. That space significantly reduces the temperature of the outer pipe surface. It also keeps the inner stainless-steel wall warmer, and thus less prone to flue-gas condensation or creosote formation. The inner wall of double wall piping is also swaged on one end. As with single-wall pipe, the swaged end of double-wall pipe should always be installed facing up to allow any condensate to remain within the pipe.

All joints in the inner wall of double-wall piping should also be sealed to prevent flue-gas or ash leakage. Double-wall piping and fittings are joined using black painted screws that are usually supplied with the pipe and fittings. These screws only penetrate the outer wall and are not exposed to flue gases. Each joint in the outer pipe should be fasted with three screws passing through the predrilled holes.

Excessive draft pulls significantly more air through the boiler's combustion chamber than necessary for efficient combustion. Heat that would otherwise be useful is pulled out of the boiler and up the chimney by the higher air flow rate.

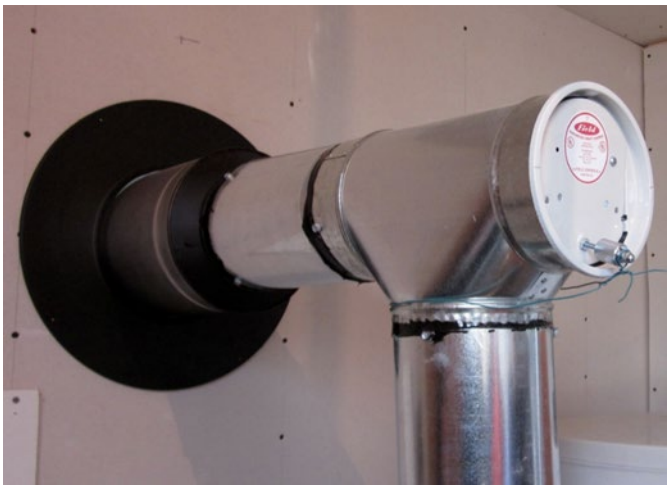
Most codes require double-wall vent connector piping to be at least six inches away from any combustible materials. Double-wall piping is more expensive than single-wall piping but provides superior performance in terms of resistance to flue-gas condensation and corrosion, as well as cooler outer wall temperatures.

4.9 Draft Regulation

All chimneys must provide sufficient draft to safely carry flue gases out of their associated building. It's also important that excessive chimney draft be avoided. A tall chimney on a cold, windy day and operating at normal flue-gas temperatures can develop much higher negative draft than is required by a biomass boiler. Some estimates claim that a negative draft pressure over 10 times higher than required can develop under certain conditions.

Excessive draft pulls significantly more air through the boiler's combustion chamber than necessary for efficient combustion. Heat that would otherwise be useful is pulled out of the boiler and up the chimney by the higher air flow rate. Highly excessive draft can also create uncontrolled combustion in the boiler—a situation that must be avoided from a safety standpoint. The classic solution to draft regulation in residential and light commercial boiler systems is to install a barometric damper, such as the unit shown in Figure 4-12.

Figure 4-12. Barometric damper installed in a vent connector between a pellet boiler and chimney



The barometric damper has a hinged circular plate that normally hangs vertically to cover the opening into the venting system. The hinged plate has an adjustable weight fastened to it. The position of this weight on its mount determines the negative pressure within the venting system at which the hinged damper plate swings partially or fully open. The more the plate swings open, the greater the amount of room air that enters the vent connector to reduce what would otherwise be excessive negative draft pressure.

To properly set the weight, a draft gauge is inserted through a hole in the vent connector piping near the boiler's flue collar. A draft reading is taken with the boiler operating at or close to steady state conditions. Most boiler manufacturers specify the acceptable range for this "breaching" draft pressure. Typical values range from -0.04 to -0.08 inches of water column. The weight is adjusted with the draft gauge in place until the draft is stable within the boiler manufacturer's specified range. Once set, the weight is secured in position.

The photo of the barometric damper in Figure 4-12 was taken when that damper was newly installed in a pellet boiler system. Figure 4-13 shows the same regulator after several months of operation.

Figure 4-13. Barometric damper showing signs of exhaust gas and ash ejection



Notice the fly ash accumulation around the perimeter of the damper as well as behind the joint where the damper meets the vent connector pipe. This ash is visible evidence of leakage that occurs due to positive pressure in the venting system. Ash ejection means that unseen flue gases, including carbon monoxide, are also being ejected from the venting system. This is likely the result of poor chimney draft at cold start conditions, combined with pressure created by the induced draft blower in the pellet boiler. Ash and flue-gas ejection can also occur from a positive pressure "percussion" effect caused by delayed ignition of pyrolytic gases within the boiler. Although such leakage is usually temporary, it is undesirable from an aesthetic as well as safety standpoint.

The solution to this problem is not to omit a draft regulator from the venting system. Doing so makes the venting system subject to excessive draft that waste heat and potentially could cause uncontrolled combustion in the boiler. The solution is to use a draft regulator that can seal tightly when there's positive pressure in the venting system. Two examples of draft regulators that can seal shut under positive pressure are shown in Figure 4-14.

Figure 4-14. Examples of draft regulators that can seal against positive pressure in vent connector piping



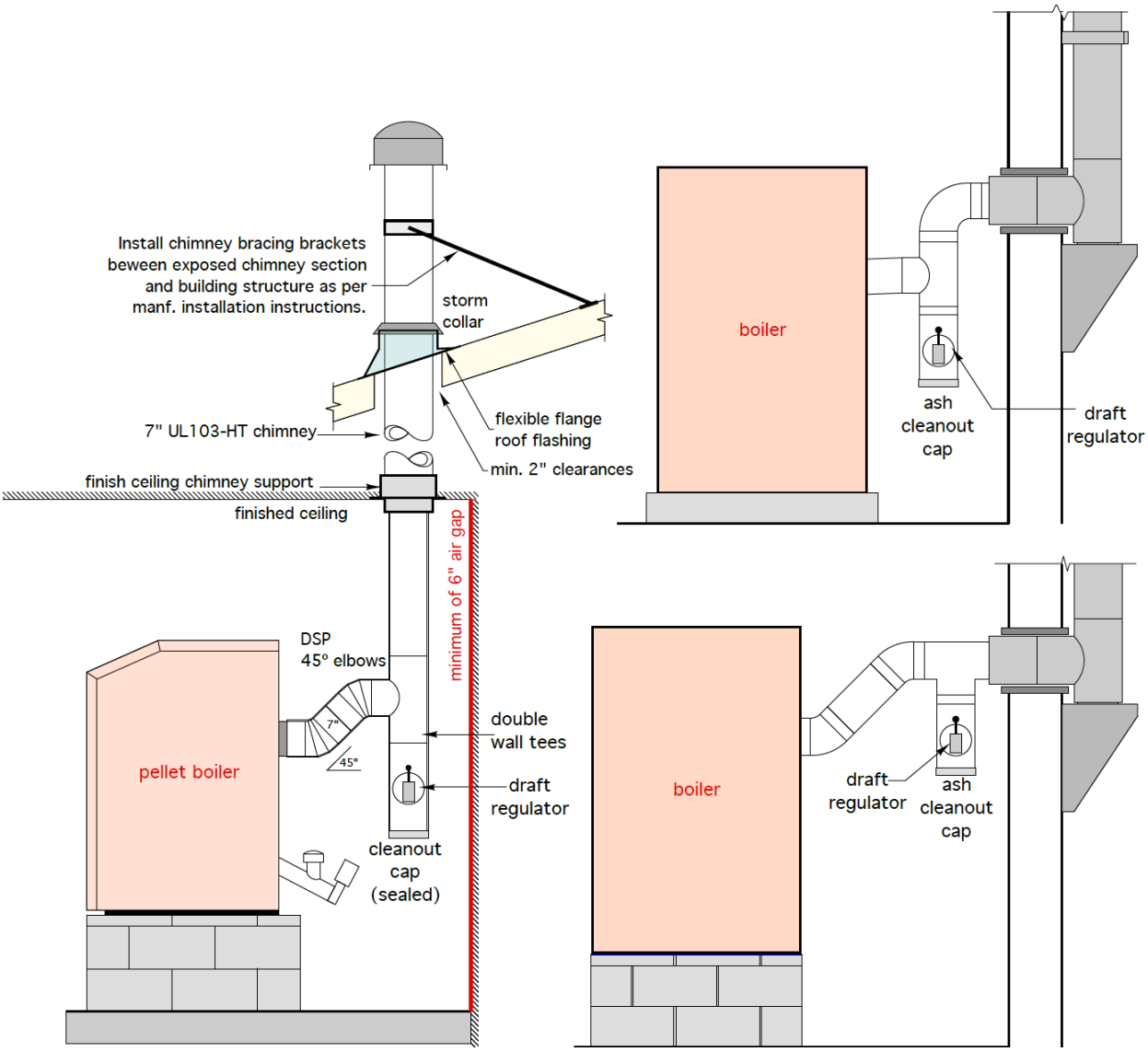
These draft regulators have a gasket around the perimeter of the opening against which the hinged damper plate can press when there is positive pressure in the vent system. This greatly reduces the potential for ash or flue-gas leakage. Like a barometric damper, each of these draft regulators has an adjustable weight that determines when the rotating plate opens to control normal (negative) draft. Both draft regulators shown in Figure 4-14 are constructed of stainless steel to minimize any potential corrosion.

As of this writing, neither of the dampers shown in Figure 4-14 is UL listed as a stand-alone product. One is Underwriters Laboratories (UL) listed as part of a supplied assembly with a specific boiler. Efforts are underway to get a UL listing on one of these draft regulators as a separate component. That damper has been approved by some local inspectors and state agencies for use in specific projects.

4.10 Draft Regulator Location

Based on European practices, installation manuals from biomass boiler suppliers, and field experience, the preferred location for the draft regulator is under the point where the vent connector piping changes from horizontal to vertical, as shown by the examples in Figure 4-15.

Figure 4-15. Three possible (and preferred) locations for a draft regulator in a biomass boiler venting system



The positive pressure sealing draft regulator is installed in the side port of a tee that's below the tee connecting the boiler to the vertical portion of the vent connector. This places the damper below the direct stream of flue gas, which is trying to move upward due to its buoyancy. This arrangement minimizes the potential for flue gases to be present directly behind the draft regulator, keeping the regulator cooler, but still allowing it to stabilize negative pressure in the venting system. A removable cap is installed at the bottom of the lower tee to allow periodic removal of any accumulated fly ash.

Figure 4-16 shows a positive pressure, sealing draft regulator installed in this manner, in a system using double-wall vent connector piping.

Figure 4-16. Positive pressure sealing draft regulator installed in tee below the tee connecting a horizontal vent connector from boiler to a vertical vent connector that rises to chimney



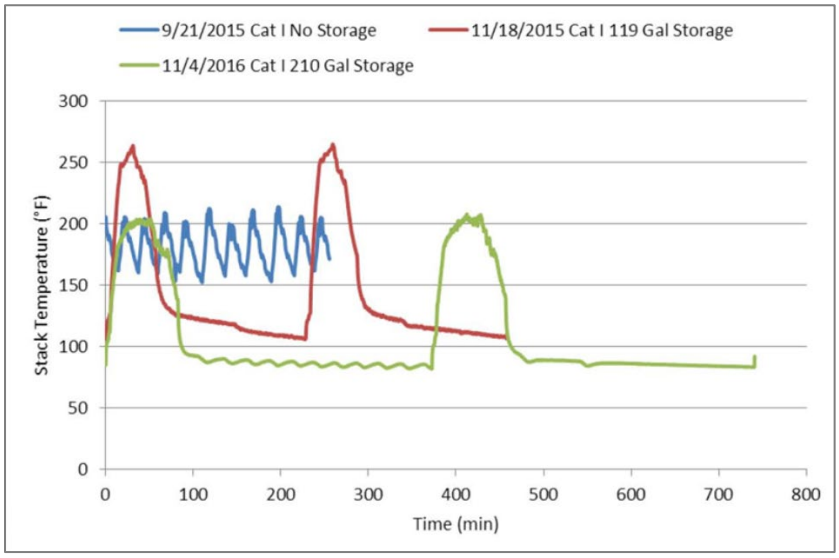
5 Thermal Storage

Previous sections have stressed the need for thermal storage in systems using cordwood gasification and wood pellet boilers. This section will provide further evidence of the importance of thermal storage and discuss installation details.

Figure 5-1 is based on pellet boiler testing conducted at Brookhaven National Laboratory. It illustrates the beneficial impact of using thermal storage for a 25 kW (85,300 Btu/hr) pellet boiler responding to a load of 15% of the boiler's rated output or less over several hours.

Figure 5-1. Comparison of pellet boiler cycling with and without thermal storage, and subjected to a load of 15% of the boiler's rated output

Source: Brookhaven National Laboratory



The low-load condition represented in Figure 5-1 occurs for a minimum of 54% of the operational hours for a home in upstate NYS, and more typically 62% of the operational hours. The blue line shows the flue gas temperature of the pellet boiler without thermal storage as it cycles on and off to meet the load without overheating. The boiler cycles approximately 10 times over four hours. The boiler on-cycles are only about 10 minutes long. These operating conditions result in low thermal efficiency and promote flue-gas condensation within the combustion chamber and in the stack. Over time this flue gas condensation can reduce the heat transfer rate of the boiler's heat exchanger, cause severe corrosion, and shorten the life of the boiler. With the addition of the 119-gallon thermal storage tank (red line) the boiler cycle is extended to approximately every 3.5 hours, with the boiler firing for about 30 minutes during each cycle. With 210 gallons of thermal storage the boiler cycle extends to about once every six hours.

5.1 Unpressurized Thermal Storage Tanks

Thermal storage tanks can be categorized as unpressurized or pressurized. Unpressurized tanks are designed to withstand the static pressure of water within them, but not any additional pressurization from the overall system. The top of the tank is vented to the surrounding air, which implies there will always be zero-gauge pressure at the surface of the water within the tank.

Most unpressurized thermal storage tanks are shipped disassembled in a "knock down" configuration. This allows the components that eventually form the tank to be moved through standard doorways or along stairs that would not accommodate the size of the assembled tank. This is a major benefit in many retrofit situations. Figure 5-2 shows a sequence of photos on how an unpressurized tank is assembled.

Figure 5-2. Assembly of an unpressurized thermal storage tank

Courtesy of HydroFlex Corporation



Unpressurized tanks can also accommodate the thermal expansion of the water they contain, assuming that an adequate air space is provided at the top of the tank. This eliminates the need for a separate expansion tank, which is required in systems with pressurized tanks. Another benefit of unpressurized tanks is that they usually cost less on a dollar per gallon basis compared to pressurized tanks.

The disadvantages of unpressurized tanks include:

The liners used to contain water in pressurized tanks have temperature limitations. The tank supplier should provide a specification on the maximum allowed water temperature. A common rating is a maximum continuous temperature of 175°F. When such tanks are used with cordwood gasification or pellet
oilers, controls must be in place to prevent the tank from exposure to temperatures above their rating. Pressurized tanks made of steel can usually be operated at significantly higher temperatures.

There will always be some evaporation of water from the vented tank over time. This requires the water level in the tank to be periodically checked and maintained.

Because unpressurized tanks are vented to the atmosphere, the water in the tank can absorb and release oxygen as it changes temperature. When water cools it absorbs oxygen molecules from the atmosphere. This dissolved oxygen will be carried to other parts of the system that are piped directly to the tank. If water containing significant dissolved oxygen makes contact with ferrous metal in the system (e.g., carbon steel or cast iron) it causes corrosion. Over time this corrosion can cause failure of components such as circulators. Because of this, unpressurized tanks should never be directly connected to steel or cast-iron boilers, or to portions of the system containing cast-iron circulators, valves, air separators, or other components made of ferrous metals. This rules out direct connection of
an unpressurized tank to a biomass boiler with a carbon steel heat exchanger. Some type of stainless-steel or copper heat exchanger must be used between steel biomass boiler and any unpressurized thermal storage tank.

Unpressurized tanks should never be directly connected to steel or cast-iron boilers, or to portions of the system containing cast-iron circulators, valves, air separators, or other components made of ferrous metals.

Vented/unpressurized tanks can, under some conditions, support biological growth leading to slime in the tank. Biocides are commercially available to minimize this condition.

Unpressurized tanks directly connected to distribution systems in which piping rises above the water level in the tank (i.e., to a second-floor level of a house) will create negative pressure in the elevated piping (e.g., the pressure in the piping will be less than the surrounding atmospheric pressure) when the circulator is off. This could allow air into the piping at any location where the system is not sealed against pressure differentials. Common locations for
air ingress include air vents, loose packings on valves, or poorly sealed circulator flange gaskets. If a hydronic distribution system is directly connected to an unpressurized tank, care should be taken to ensure that areas of possible air ingress are eliminated. Negative pressure in piping can also cause water at temperatures below 212°F to flash into steam, which can create loud knocking sounds in piping. The greater the negative pressure in the piping, the lower the water temperature at which steam flash can occur.

5.2 Heat Exchanger Options for Unpressurized Thermal Storage Tanks

Heat exchangers are commonly used to separate water in an unpressurized tank from the water in a steel biomass boiler, as well as from water a pressurized hydronic distribution system.

The two types of heat exchangers commonly used are (1) internal helical coils made of copper or stainless-steel tubing, and (2) brazed plate stainless-steel heat exchangers mounted outside the tank.

Internal coil heat exchangers operate with forced convection heat transfer along the coil's inner surface, and natural convection heat transfer along the coil's outer surface. Natural convection heat transfer is caused by buoyancy induced flow of the tank water surrounding the coil. It is a much weaker form of convective heat transfer relative to forced convection, which is created by much higher water flow rates inside the coil. The rate of heat transfer between the fluid inside the coil heat exchanger and the tank water is almost always limited by natural convection along the outer surface of the coil.

The rate of heat transfer between the fluid inside the coil heat exchanger and the tank water is almost always limited by natural convection on the outer surface of the coil.

To compensate for this limitation, internal coil heat exchangers require relatively large surface areas compared to brazed plate heat exchangers, which operate with forced convection heat transfer on both sides of the heat exchanger. In some systems, multiple coils are connected in parallel to a common header system, as seen in Figure 5-3.

Figure 5-3. Multiple heat exchanger coils connected in parallel to a common header system within a unpressurized thermal storage tank

Courtesy of HydroFlex

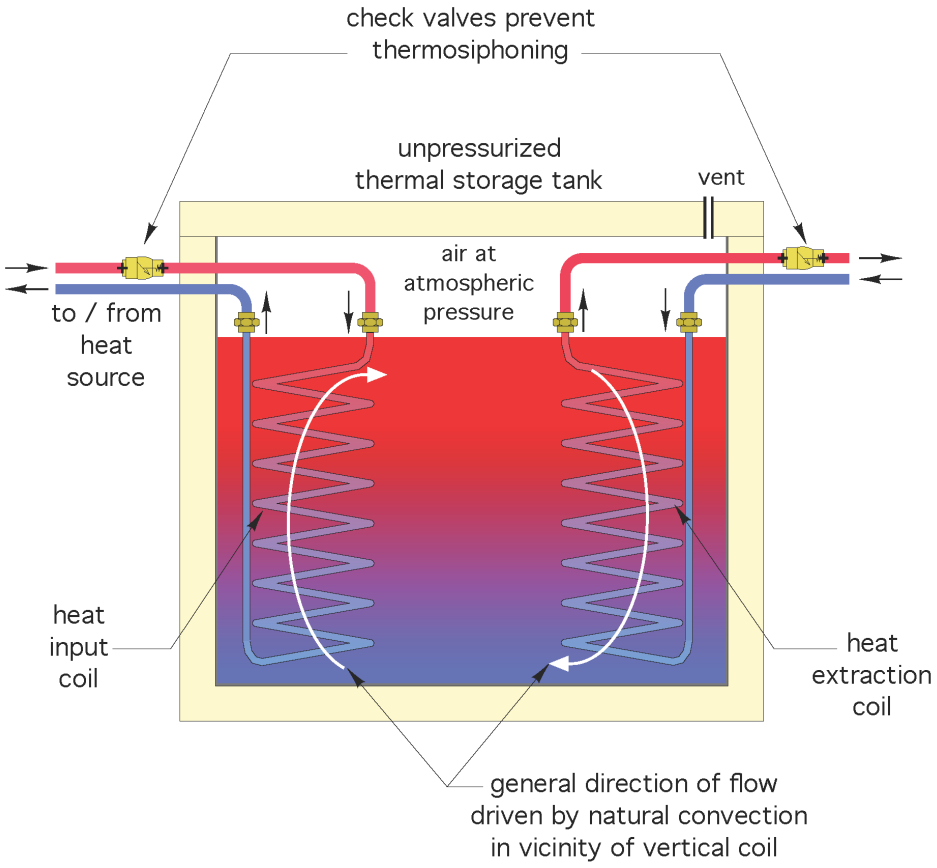


The thermal performance of coil heat exchangers is dependent on many variables including coil material, pipe diameter, coil height, diameter, flow rate, properties of the fluid flowing through the coil, and temperature stratification within the tank. Attempting to accurately calculate the theoretical heat transfer rates associated with natural convection can be very complex. For this reason, it is best to obtain heat transfer rate performance directly from the tank manufacturer.

It is also important to pipe coil heat exchangers to create "counterflow" between the fluid flowing through the coil and the direction of water movement inside the tank due to buoyancy forces. The movement of the water in the tank should always be opposite the direction of fluid movement through the coil. This is illustrated in Figure 5-4.

It is very important to pipe coil heat exchangers to create "counterflow" between the fluid flowing through the coil and the direction of water movement inside the tank.

Figure 5-4. Coil heat exchangers configured for counterflow



The coil on the left delivers heat from the biomass boiler to the tank. Water inside this coil flows from top to bottom, as tank water rises due to buoyancy as it absorbs heat. The coil on the right supplies heat from the tank to the load. Water within this coil flows from bottom to top as water in the tank descends due to increasing density as the water cools.

5.3 Temperature Limitations of Unpressurized Thermal Storage Tanks

Most unpressurized thermal storage tanks consist of a shell that provides structure against static water pressure as well as insulation, and a flexible liner that fits within the shell and holds the water. Tank liners are commonly made of ethylene propylene diene monomer (EPDM) rubber or polypropylene. Both of these materials have upper temperature limits that must be respected. Typical upper temperature limits are in the range of 170–175°F for continuous service.

Many biomass boiler systems are capable of producing water at temperatures above the upper temperature limit of tank liners. Systems using unpressurized thermal storage tanks with liners must include safety devices and controller settings that do not allow water to exceed the temperature limit of the liner as specified by the tank manufacturer.

5.4 Pressurized Thermal Storage Tanks

Nearly all pressure-rated tanks used in biomass boiler systems are constructed of carbon steel. They can be supplied with or without insulation, the latter being more common. Figure 5-5 shows an example of a 210-gallon, pressure-rated, uninsulated steel thermal storage tank.

Figure 5-5. ASME-certified, uninsulated steel thermal storage tank (210-gallon)

Courtesy of Hydronic Specialties Corporation



This tank has flat top and bottom plates that are restrained against buckling due to internal pressure by a grid of steel stay rods running from top to bottom inside the tank. The tank is supported on four steel legs, which allow placement of insulation under the tank shell. Four, two-inch FPT threaded piping connections are located on opposite sides of the tank wall, two near the top and two near the bottom. These connections allow the tank piping to be configured several ways depending on the design of the system. The five, three-quarter FPT tappings seen along the height of the tank are typically used to mount temperature sensor wells, thermometers, or other instrumentation. The tank also has a three-quarter inch FPT tapping in the top plate to accommodate an air vent. Any unused piping connections can be easily closed with a threaded iron plug.

Figure 5-6 shows a 350-gallon, American Society of Mechanical Engineers (ASME)-rated thermal storage tank constructed with semi-elliptical top and bottom bells.

Figure 5-6. ASME-certified thermal storage tank (350-gallon)

Courtesy of Troy Boiler Works, Inc.

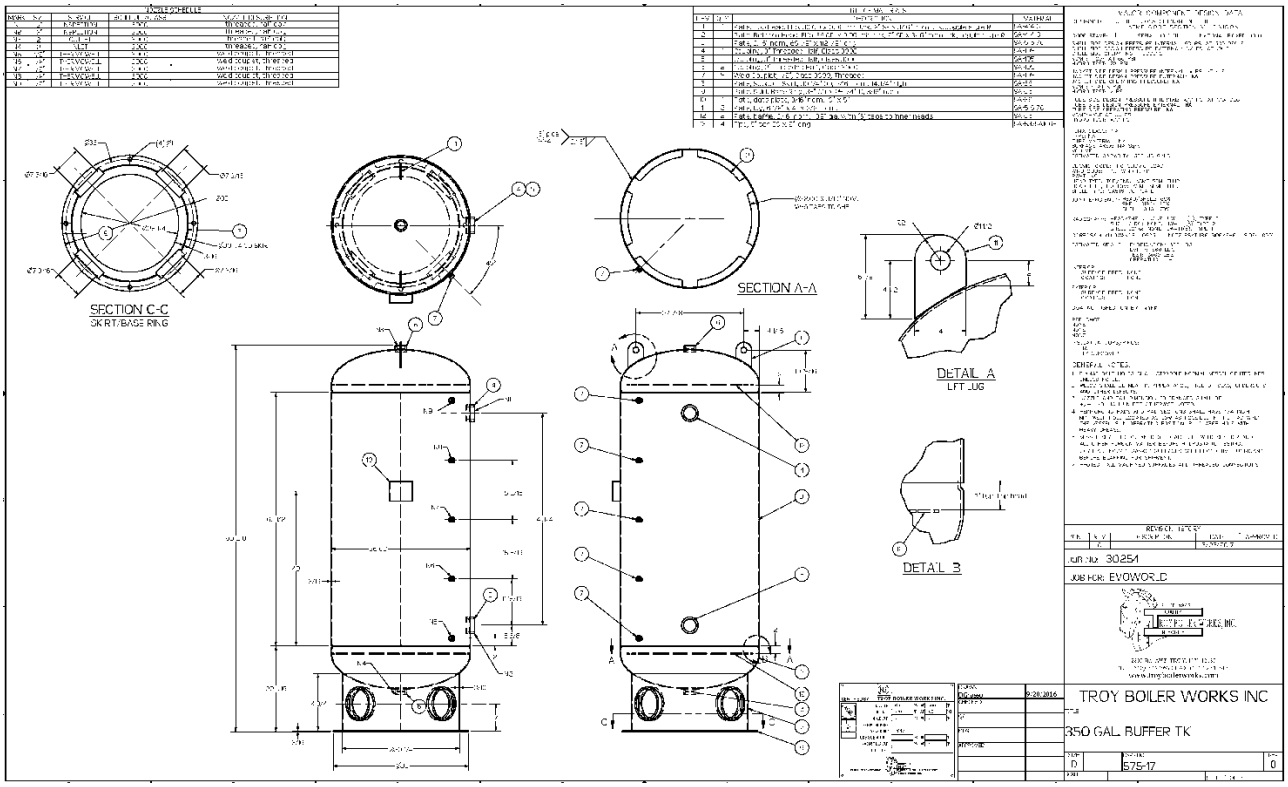


The tank is 35 inches in diameter and approximately 100 inches tall, and weighs about 660 pounds. The tappings seen on the side of the tank are used for mounting temperature sensor wells. It has two, three-inch FPT tappings near the top and bottom of the cylindrical shell, as well as a two-inch FPT tapping at the very top and bottom of the tank. The metal primer finish prevents surface oxidation.

Tanks of this design are typically fabricated to specific project requirements including volume, dimensions, tappings, pressure ratings, and lifting locations. These requirements are typically documented as a shop drawing, such as shown in Figure 5-7. The tank is fabricated after the designer has reviewed and approved the shop drawing.

Figure 5-7. Shop drawing of a 350-gallon ASME-certified thermal storage tank

Courtesy of Troy Boiler Works, Inc.



Pressurized thermal storage tanks also have strengths and limitations.

Their strengths include:

The ability to directly connect to pressurized closed loop hydronic systems without use of heat exchangers. The elimination of heat exchangers generally improves system performance and may also reduce installation cost.
The ability to operate at higher temperatures than most unpressurized tanks.
They do not lose water due to evaporation.

The limitations of pressurized tanks include:

Large tanks present logistical issues for handling, especially in passing through standard doorways, or being installed in limited height spaces. Many of the pressurized tanks used in residential biomass heating systems weigh several hundred pounds and require careful planning for handling on the job site. Figure 5-8 shows a 360-gallon tank with flat ends that just barely fits within the height of an older basement. Careful measurements must be made to ensure that the tank can be moved into the space and properly positioned.

Figure 5-8. ASME-certified 360-gallon thermal storage tank installed in basement with low ceiling clearance



Because of the water volume they add to the system, the system's expansion tank must be significantly larger than for an equivalent system without thermal storage. A starting estimate for the size of the expansion tank is 10% of the volume of the thermal storage tank. Floor mounted expansion tanks are typically used due to the required size and weight.

Pressurized thermal storage tanks with volumes over 119 gallons usually need to be certified as ASME pressure vessels. The requirements for this ASME certification may vary with local codes and the type of building in which the tank is located. Buildings subject to public occupancy or occupied by employees almost always require that pressurized tanks over 119 gallons be constructed in conformance with ASME pressure vessel code, which includes inspections during fabrication and final testing. Tanks built to ASME pressure vessel codes usually cost significantly more than similar size non-ASME tanks.

5.5 Thermal Storage Tank Insulation

All thermal storage tanks used in biomass boiler systems will, at times, contain water at relatively high temperatures. These tanks also have large surface areas. These characteristics create a high potential for heat loss into surrounding spaces. Such heat loss compromises system performance and can significantly overheat the mechanical room. It must be minimized through adequate insulation on all tank surfaces.

All thermal storage tanks used in systems funded by NYSERDA's Renewable Heat NY program must be insulated on all surfaces to a minimum of R-24 F•hr•ft^2/Btu.

The Renewable Heat NY requirements do not specify the type or thickness of insulation needed to meet this requirement. However, that insulation must be capable of withstanding the maximum temperature the tank could experience. The ability to withstand a temperature of at least 200°F is a suggested guideline—without degraded R-value over its projected service life.

The ability to withstand a temperature of at least 200°F is a suggested guideline—without degraded R-value over its projected service life.

Potential tank insulation materials include:

High density, semi-rigid fiberglass roll stock, specifically intended for insulating tanks.
Mineral fiber batt insulation
Spray-applied polyurethane insulation
Cellular glass foam insulation precut to fit the tank's shape.

Figure 5-9 shows three multi hundred-gallon pressurized thermal storage tanks installed in municipal pellet boiler systems.

Figure 5-9. Large (multi hundred-gallon) ASME-certified thermal storage tanks with insulation

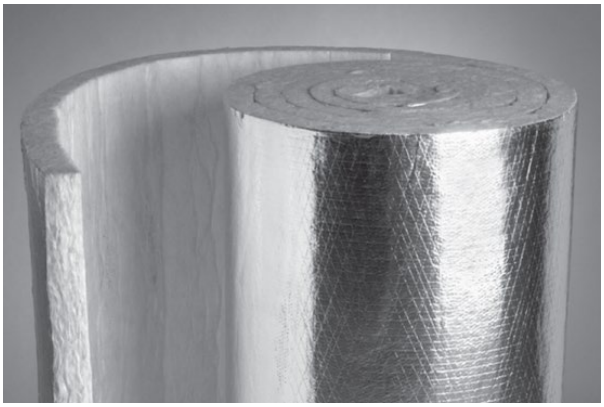


All three tanks have site-installed insulation. The tank on the left and in the center have reinforced fabric jackets to protect the insulation. The tank on the far right uses an aluminum sheet metal jacket to protect the insulation.

Some manufacturers offer pre-insulated and fully jacketed tanks, although not necessarily insulated sufficiently to meet the R-24 RHNY requirement. In such cases it's possible to add insulation to the tank so that the combined R-value is at least 24. Materials such as high-temperature resistant semirigid fiberglass blankets with a reinforced facing material are well suited for this purpose. Figure 5-10 shows an example of such a product that can withstand temperatures over 800°F (well above the temperature of any biomass heating system tank) and is available in a variety of thicknesses.

Figure 5-10. High-temperature rated semirigid fiberglass blanket with reinforced facing material

Courtesy of Johns Manville



Some insulation materials require a coating or cladding that protects the insulation against physical damage, and/or provides a flame resistance rating that meets local code requirements. The latter, known as an "intumescent" coating, is common for tanks insulated with sprayed polyurethane insulation.

Figure 5-11 shows an example of a 210-gallon, ASME-rated thermal storage tank that has been insulated with a minimum of 4 inches of spray polyurethane insulation to meet the R-24 requirement of Renewable Heat NY. The foam insulation has also been sprayed with an intumescent coating.

Figure 5-11. 210 Gallon ASME-certified thermal storage tank insulated with spray polyurethane insulation and finished with an intumescent thermal barrier coating

Courtesy of Hydronic Specialty Supply



The foam insulation has been held back at all piping connection points. This allows easier attachment of the piping as well as a "receptacle" to support the end of piping insulation. Any unused tappings on the tank can be plugged and then covered with insulation.

All piping used between the biomass boiler and thermal storage tank, as well as that used in conjunction with an auxiliary boiler should be insulated. In the absence of codes that require otherwise, insulation with a minimum of R-4 F•hr•ft^2/Btu should be used on piping. That insulation should also have a minimum service temperature rating of 200 °F.

5.6 Thermal Storage Tank Piping Configurations

The way in which a thermal storage tank is piped into the system can have profound implications on
how well it performs. A poorly performing thermal storage tank will inevitably lead to a poorly performing biomass heating system.

A well-stratified thermal storage tank contains more useful heat than a tank operating with internal mixing currents.

The following are desirable traits for a thermal storage tank:

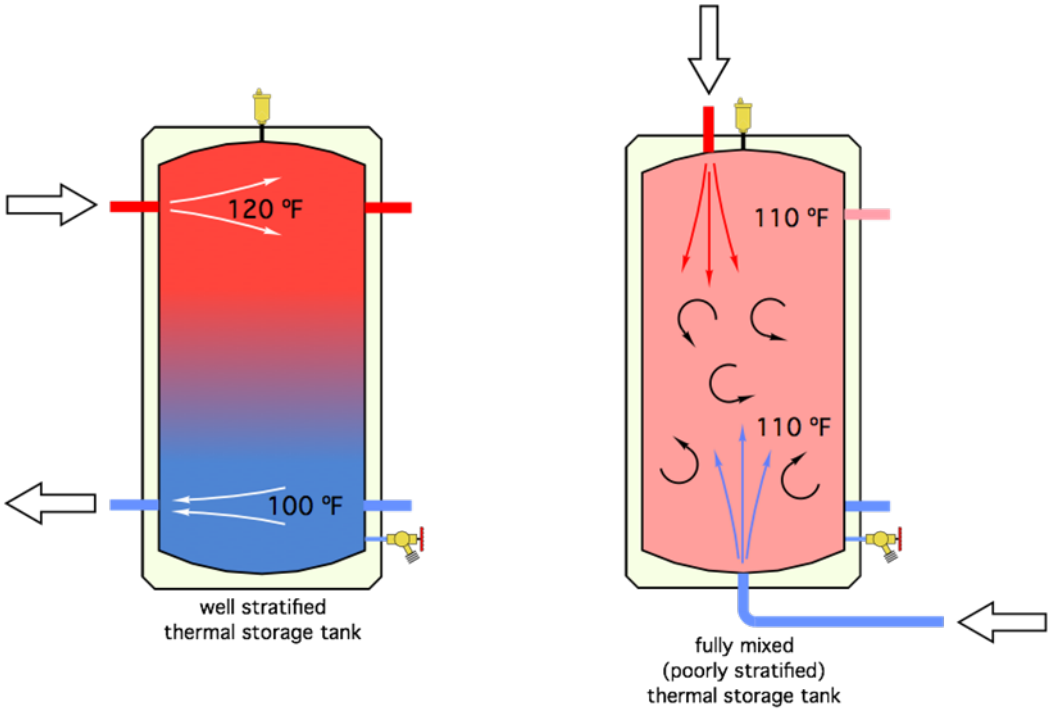
Develops and maintains good temperature stratification
along its height
Allows its full-water volume to participate in the thermal
exchange process
Minimizes heat loss though use of good insulation
Loses minimal heat due to forward or reverse thermosiphoning
through attached piping
Operates with a wide-temperature swing to reduce boiler cycling
Delivers the hottest available water to the load
Easily rids itself of air
Provides hydraulic separation of circulators in the boiler circuit and load circuit when
they operate simultaneously

These desirable traits will be discussed individually and then combined into piping layouts.

5.7 Temperature Stratification Within Thermal Storage Tanks

Temperature stratification is the ability to maintain the hottest water at the top of the tank and the coolest water at the bottom of the tank. A well-stratified thermal storage tank contains more useful heat than a tank of the same geometry operating with internal mixing currents. This is illustrated in Figure 5-12.

Figure 5-12. Comparison between a well-stratified thermal storage tank and one operating with internal mixing currents



Assume that both tanks are identical in volume, shape, and insulation. The tank on the left exhibits good temperature stratification. The water temperature at the top is 120°F, and the water temperature at the bottom is 100°F. Assuming a symmetrical temperature profile from top to bottom, the average water temperature in the tank is 110°F. The tank on the right has been subject to mixing such that the entire tank contains water at 110°F.

Based on average temperature, the amount of heat contained in both tanks is the same. However, consider which tank could supply water at 115°F, for a time, if needed by the load. Only the left tank could do so (through some type of mixing device). Consider which tank could supply water at 111°F, for a time, if required by the load. Again, only the tank on the left, with its well-developed stratification could do so. Thus, even though the total energy content of both tanks is equal, the *usefulness* of the energy in the well-stratified tank is greater than that in the fully mixed tank.

The usefulness of the energy can be quantified by a thermodynamic property called “exergy.” Although the mathematics associated with exergy are beyond the scope of this manual, the guidelines that enhance temperature stratification and thus maintain the exergy of the heat in the tank are not.

Well-insulated, vertically oriented thermal storage tanks with no forced water flow tend to develop good temperature stratification. However, any disturbance of the water in the tank causes internal mixing currents, which reduce and, in some cases, all but eliminate temperature stratification. To minimize mixing, water flowing into the tank should enter horizontally and as slow as practical. It should also enter at a location along the vertical height of the tank where the water inside the tank is the same temperature as the entering water. These constraints, if fully achieved, would allow water to enter the tank with very little turbulence, and at a location where there is no difference in density between the entering water and the water in the tank.

Avoid piping that allows water to enter vertically into a fully open tank shell. Vertically oriented incoming flows can greatly disturb temperature stratification.

It's not possible, at least with present technology, to create tanks that will always achieve these ideals. Nevertheless, details that approach these ideals are possible and will improve tank performance compared to tanks in which these factors are ignored.

Piping carrying water into a thermal storage tank should introduce that water horizontally. Avoid piping that allows water to enter vertically into a fully open tank shell (e.g., into a tank with no internal flow diffuser). Vertically oriented incoming flows can greatly disturb temperature stratification.

It is possible to introduce flow vertically into the top or bottom of a tank that's equipped with an internal detail that changes the direction of the entering water, allowing it to diffuse into the surrounding water in a horizontal direction and at a relatively low-flow velocity. This internal detailing is called a flow diffuser, and there are several ways to construct them.

5.8 Flow Diffusers

One of the simplest details for converting vertical flow to horizontal flow is a called a "plate diffuser." It consists of a round steel plate with reinforcing ribs that's welded into the upper and lower portions of the tank, typically near where the cylindrical portion of a tank joins the semi-elliptical end bells. Figure 5-13 shows an example of a plate diffuser that has been welded to an elliptical end bell.

Figure 5-13. Plate diffuser welded to an elliptical end bell during fabrication of thermal storage tank

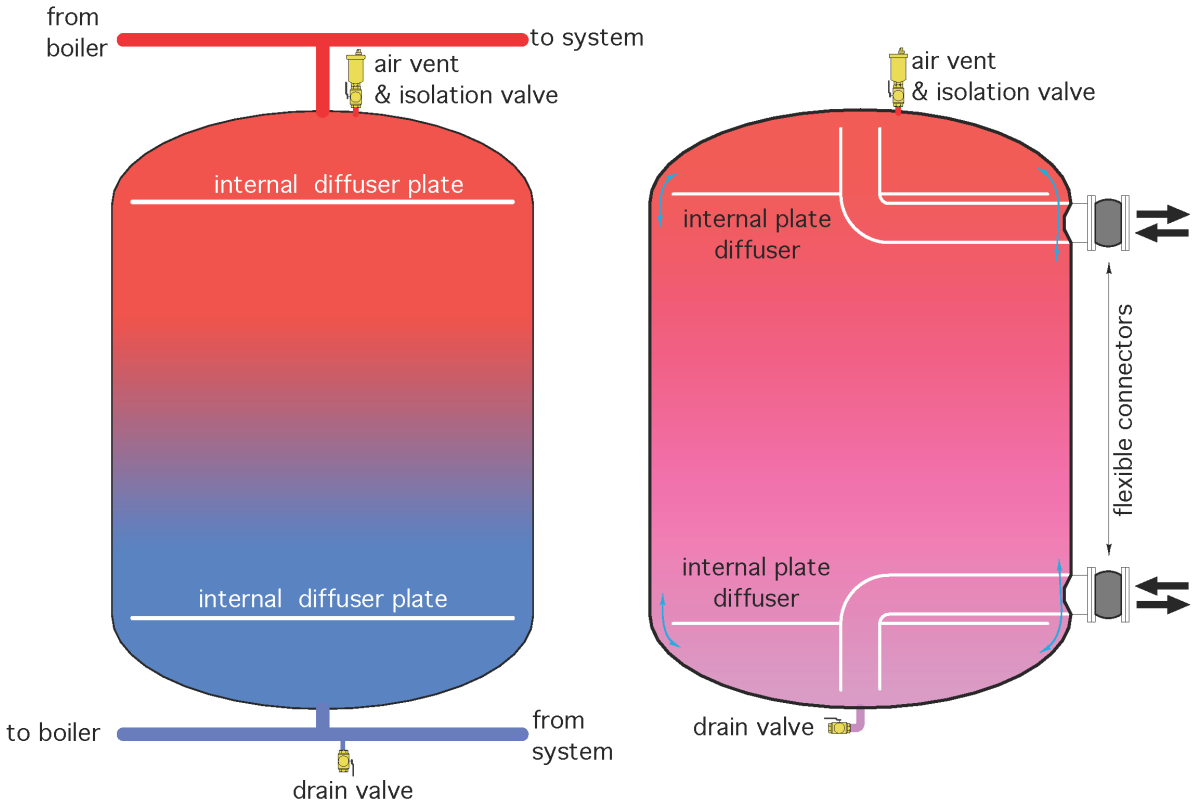
Courtesy of Troy Boiler Works



The diameter of the plate diffuser is typically 4 to 6 inches less than the internal diameter of the tank shell. This provides an annular gap of 2 to 3 inches between the tank shell and the perimeter of the plate diffuser. Depending on the diameter of the tank, the cross-sectional area of this annular space is many times greater than the cross-sectional area of the pipe carrying water into the tank. Thus, the average flow velocity through the annular space will be greatly reduced relative to the flow velocity entering the tank shell through the piping. Lower velocity reduces turbulence in the main portion of the tank which reduces mixing and enhances temperature stratification.

Plate diffusers can be used in both the upper and lower portions of a tank. Figure 5-14 shows two internal details that allow plate diffusers to be combined with piping as it enters the tank vertically or horizontally.

Figure 5-14. Cut away illustration of upper and lower plate diffusers combined with piping options

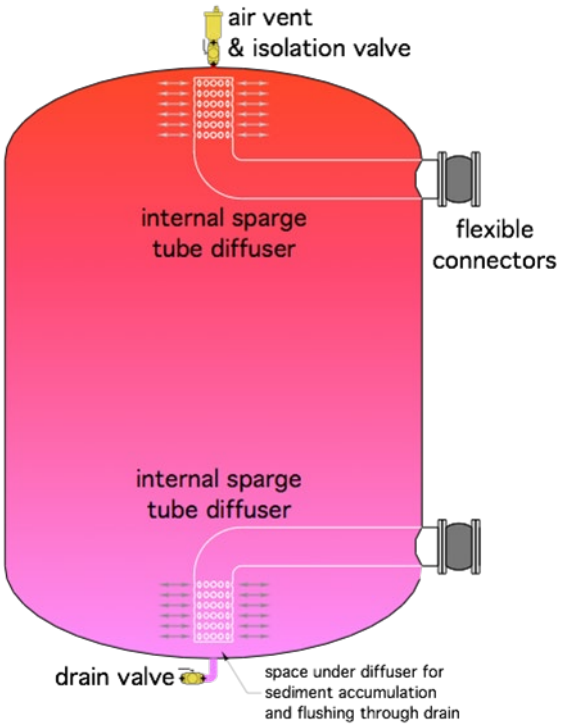


When the piping enters the side of the tank, it continues to an internal elbow that goes through the center of the plate diffuser. The flow impinges against the top of the elliptical end bell and spreads out symmetrically along its inner surface, eventually passing through the annular gap formed by the plate diffuser.

The same pipe that carries flow into the upper portion of the tank can also extract the hottest water from the tank and send it to the load when needed. Note that an air vent with an isolation valve should also be located at the top of the tank. A similar diffuser detail can be used in the lower portion of the tank. A drain connection should be provided either directly to the tank shell or tapped into the pipe entering the bottom of the tank.

It's also possible to spread flow horizontally within the upper and lower portions of a tank using sparge tube diffusers, as shown in Figure 5-15.

Figure 5-15. Illustration of sparge tube diffusers spreading flow horizontally near top and bottom of thermal storage tank



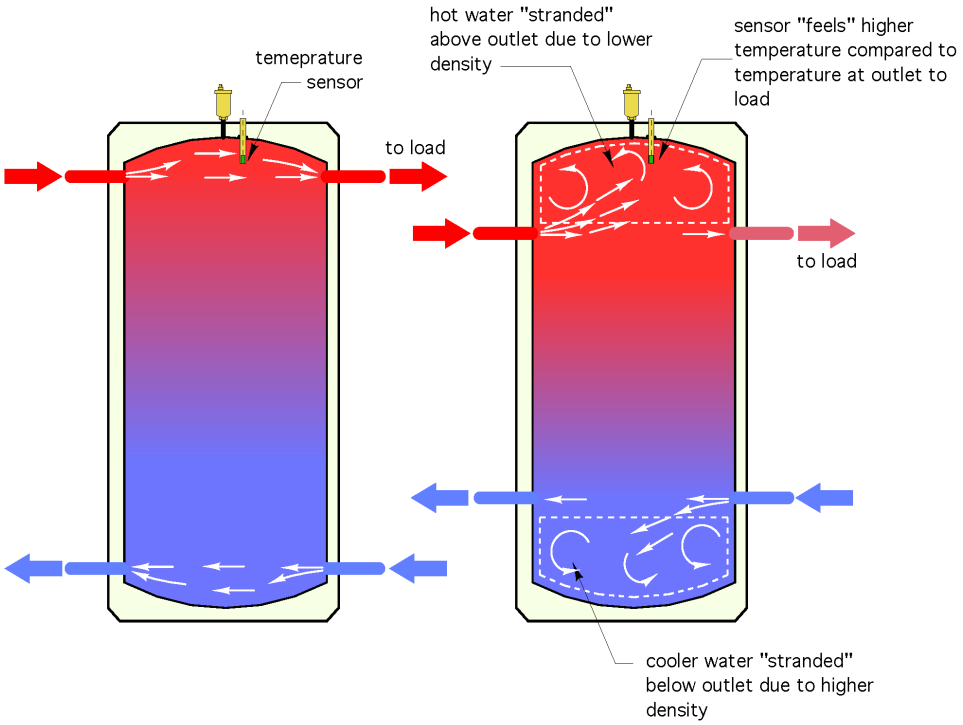
Sparge tubes have a closed end with a symmetrical array of holes around their perimeter. The total cross-sectional area of these holes should provide for low-average flow velocity.

Of the two, plate diffusers are generally easier to fabricate and provide lower pressure drop through the thermal storage tank. The latter is important as it provides hydraulic separation between multiple circulators in the system.

5.9 Full Participation of the Tank's Water Volume

To achieve the maximum benefit from a thermal storage tank, it's important that all the water in the tank "participate" in the energy exchange. The locations at which water enters or leaves the tank, in combination with temperature stratification, will play a role in determining the degree to which this participation is achieved. Consider the two tanks shown in Figure 5-16.

Figure 5-16. Comparison of flow within tanks with different sidewall connection locations



The tank on the left has sidewall connections that are very close to the top and bottom of the inner tank shell. This allows the hot water entering the tank from the biomass boiler to be placed at the hottest location within the tank and permits the hottest water in the tank to be extracted and sent to the load. A similar placement of horizontal piping near the bottom of the tank allows the coolest water in the tank to return to the biomass boiler and permits what should be cool water returning from the distribution system to enter the coolest portion of the tank. This piping geometry minimizes the mixing of cooler water with the warmer water located higher in the tank. For the tank geometry shown, these piping attachment locations preserve temperature stratification.

The tank on the right in Figure 5-16 has the same shell size as the tank on the left, but the piping connections have been moved down from the top of the tank and up from the bottom. The upper left connection introduces hot water from the biomass boiler lower in the tank. If this water is significantly warmer than the water where it enters the tank, it's buoyancy will create mixing currents that interfere with temperature stratification in the upper portion of the tank. The mixing will reduce the water temperature available to the outlet pipe on the upper right side of the tank.

In situations where there has not been flow through the tank, temperature stratification should reestablish. However, when water is extracted from the upper right connection, the hottest water in the tank will remain stratified near the top, and thus the hottest water in the tank will not be delivered to the load. Similarly, the coolest water in the system will not be returned to the boiler.

Problems have also occurred in systems where a temperature sensor located near the top of the tank is reporting a temperature several degrees warmer than the water temperature being sent to the load. This inadvertently provides misinformation to the controller that determines when the pellet boiler should fire based on tank temperature. Although this situation could be remedied by moving the temperature sensor close to where the piping leaves the tank, it would be better to move the piping connection closer to the top, and thus closer to the hottest water.

In a four-pipe tank configuration, all the energy flowing from the biomass boiler to the load must pass through the thermal storage tank.

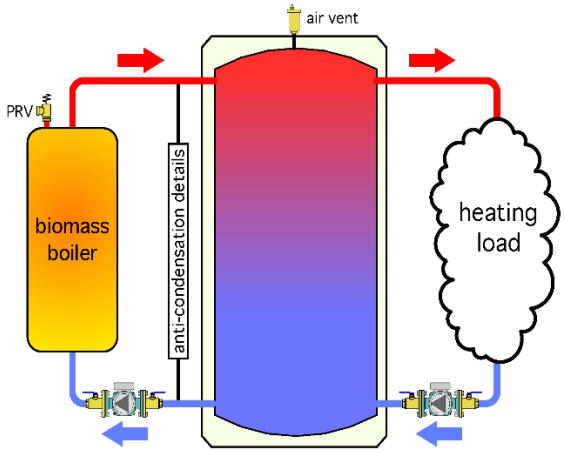
5.10 Tank Piping Configurations

There are several ways to pipe thermal storage tanks that respect the details just described. The method selected for a given project will depend on the hardware that's available, as well as the characteristics of the loads supplied from the thermal storage tank. In most cases, each possible piping configuration will be a compromise between ideals such as maintaining good temperature stratification, how the tank would be fabricated, cost, and constraints imposed by the space in which the tank is to be located.

5.11 Four-Pipe Tank Configuration

The classic method of piping a thermal storage tank uses four primary piping connections. Two pipes attach to the upper sidewall of the tank on opposite sides and two pipes attach to the lower sidewall, again on opposite sides. The tank shown in Figure 5-5 has these piping connections, similar to the tank represented in Figure 5-16. Figure 5-17 shows how a biomass boiler and load are connected for a four-pipe tank configuration.

Figure 5-17. Four-pipe tank configuration connecting the biomass boiler and heating load



4-pipe tank configuration

In a four-pipe tank configuration, all the energy flowing from the biomass boiler to the load must pass through the thermal storage tank. The hotter water entering the tank from the boiler tends to stay in the upper portion of the tank, although there will be some mixing which is counterproductive to good temperature stratification. The cooler water returning from the load tends to stay in the lower portion of the tank.

The flow rates in the boiler circuit and load circuit can be different. For example, if the flow rate in the boiler circuit is 10 gallons per minute (gpm), and the flow rate in the load circuit is 7 gpm, the difference between these flow rates (10-7 = 3 gpm) will flow vertically downward through the tank. If the flow rate from the biomass boiler was only 4 gpm, and the load circuit flow rates was 9 gpm, the difference between these flow rates (9-4 = 5 gpm) would flow upward through the tank. The total flow into and out of the tank must always be the same.

5.12 Hydraulic Separation

A tank piped in a four-pipe configuration can provide excellent hydraulic separation between the boiler circulator and the load circulator(s). Hydraulic separation is a very desirable characteristic in any hydronic system with multiple circulators that may operate simultaneously. In systems with good hydraulic separation, the flow and pressure dynamics created by one circulator will not interfere, to any consequential extent, with the flow and pressure dynamics created by the other circulator(s). Each circulator operates *as if* it were in a stand-alone circuit, completely unaffected by the other circulators. Maintaining hydraulic separation with other thermal storage piping configurations is important.

All pellet-fueled boilers and cordwood gasification boilers need to be protected against sustained flue-gas condensation.

5.13 Anti-condensation Details

All pellet-fueled boilers and cordwood gasification boilers need to be protected against sustained flue-gas condensation. This condition develops when the water temperature entering the boiler is below the dew point of the flue gases. There are several hardware details that can be used to provide the necessary protection. They are discussed later in this manual. For now, the “anti-condensation details” graphics simply represent that these details need to be present regardless of how the thermal storage tank is piped.

5.14 Characteristics of Four-Pipe Tank Configurations

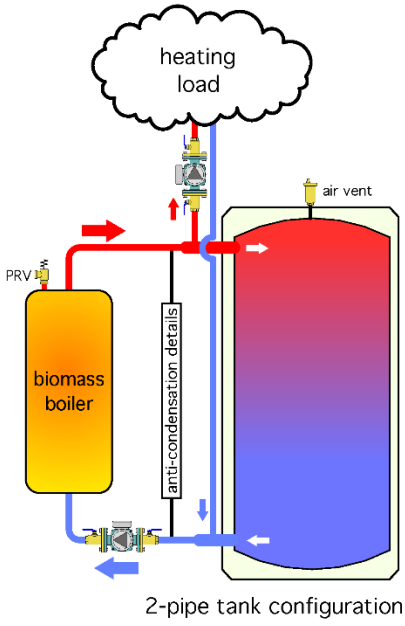
One characteristic of four-pipe thermal storage tanks it that the full-flow rate from the biomass boiler must pass into the upper inlet connection and return to the biomass boiler from the lower left connection. Likewise, the full load flow rate must pass out of the upper right connection and come back into the tank through the lower right connection. The higher these flow rates are, the greater the disturbance of temperature stratification within the tank. Other piping configurations, specifically the two-pipe configuration, reduce the flow rates entering the tank under certain conditions, and thus reduce disturbance of temperature stratification.

Another characteristic of four-pipe tank configuration is that some of the thermal mass of the tank will always be "online" with energy flow from the biomass boiler to the load. For example, if the tank has cooled significantly below its normal operating temperature range, the water in the upper and lower portions of the tank will interact with heat transfer between the biomass boiler and load causing a temporary reduction in the water temperature supplied to the load. The degree to which this interaction occurs depends on the location of the piping connections and the flow rates involved. However, in all cases this characteristic will delay the transfer of energy from the biomass boiler to the load when both are operating simultaneously.

5.15 Two-Pipe Tank Configurations

In a two-pipe tank configuration, the load is tapped into a header located between the biomass boiler and thermal storage tank, as shown in Figure 5-18.

Figure 5-18. Two-pipe tank configuration



The two-pipe tank configuration holds two significant advantages relative to a four-pipe tank configuration.

The first advantage applies when the biomass boiler and load are operating at the same time. Under this condition the flow rate into or out of a 2-pipe thermal storage tank will only be the difference between the boiler flow rate and the load flow rate. For example, if the flow rate from the boiler is 10 gallons per minute (gpm), and the flow rate to the load circuit is 7 gpm, the difference between these flow rates (10-7 =3 gpm) will flow into the tank. This flow would pass vertically through the tank, at a very low flow velocity, and eventually out of the tank at the lower connection. The very low vertical flow velocity within the tank creates minimal disturbance of temperature stratification.

Similarly, if the flow rate from the heat source was 4 gpm, and the load flow rate was 9 gpm, the difference between these flow rates (9-4 = 5 gpm) would flow *upward* through the tank and out at the upper connection. Again, low vertical flow velocities inside the tank help preserve temperature stratification.

One potentially undesirable characteristic of a two-pipe configuration is that some of the flow returning from the load could, under certain circumstances, pass through the heat source when it is not operating.

Another benefit of the two-pipe configuration is that some or all of the flow from the heat source can pass directly to the load without having to first pass through the tank. This is helpful in situations where the tank is cooler than the water coming from the heat source. The time required to deliver useful heat output from the boiler to the load is reduced because that heat does not have to first interact with the potentially cooler thermal mass of the storage tank, as it would with the four-pipe tank configuration.

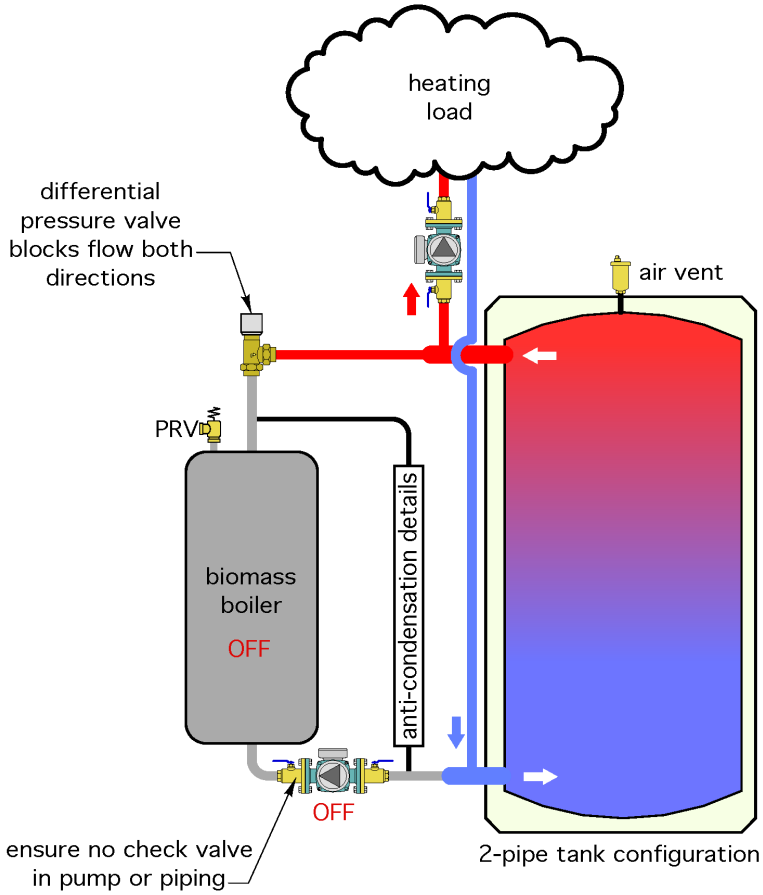
To maintain good hydraulic separation between the boiler circulator and load circulator, the tees that connect the load circuit to the upper and lower tank headers should be as close to the tank as possible. This minimizes the pressure drop through the common piping which in this case is from the upper tee through the tank to the lower tee. The lower this pressure drop, the better the hydraulic separation characteristic of the tank.

One potentially undesirable characteristic of a two-pipe configuration is that some of the flow returning from the load could, under certain circumstances, pass through the heat source when it is not operating. This is undesirable from two standpoints. First, heated water passing through an unfired boiler creates heat loss though the boiler's jacket, as well as convective air currents that move heat from the boiler up the chimney. Biomass boilers do not have motorized flue dampers to reduce the latter. Secondly, the water passing through an unfired boiler cools due to heat loss and eventually mixes with flow coming from the thermal storage tank at the upper header—reducing the water temperature supplied to the load. The extent of this temperature reduction depends on the relative flow rates coming from the

boiler and tank, as well as the temperature drop of the water flowing through the unfired boiler. However, any water temperature reduction due to mixing at this point in the system is undesirable.

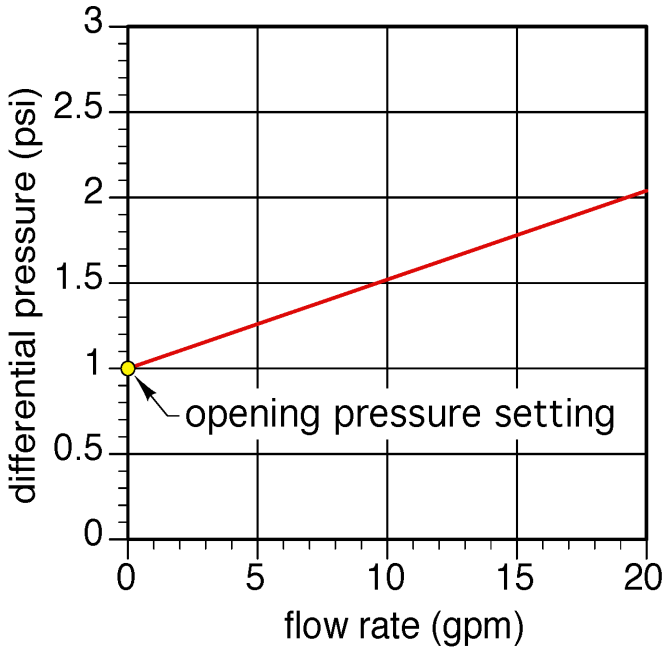
There are several ways to detail a two-pipe tank to prevent flow through the heat source when it is off and the load is active. Figure 5-19 shows the use of a spring-loaded differential pressure valve (a.k.a. ΔP valve) installed between the boiler and tank.

Figure 5-19. Using a spring-loaded differential pressure valve on a 2-pipe tank configuration to prevent forward or reverse flows when boiler circulator is off



The differential pressure valve can be set to a low forward opening pressure in the range of 1–1.5 psi. This provides sufficient blocking force to prevent flow returning from the load from passing through the boiler when the boiler circulator is off. When the boiler circulator turns on, it immediately creates sufficient pressure to open the ΔP valve. Most differential pressure valves have a relatively flat ΔP versus flow rate curve, as shown in Figure 5-20.

Figure 5-20. Differential pressure (psi) versus flow rate (gpm) for a specific differential pressure bypass valve

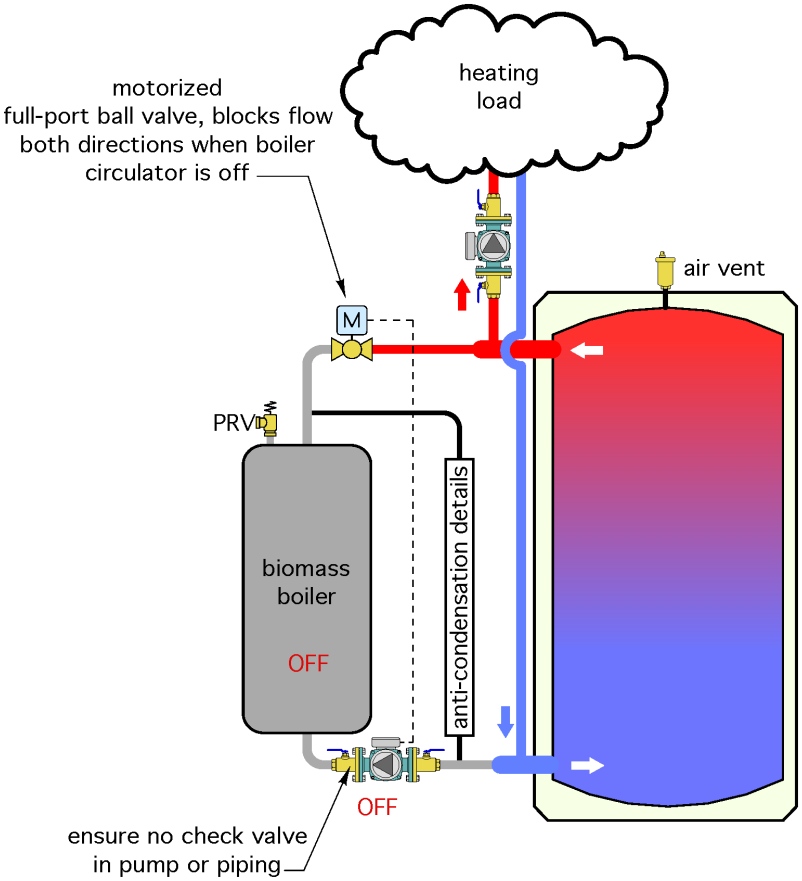


This characteristic allows the valve to have sufficient forward opening resistance, as well as maintains relatively low-head loss through the valve when the boiler circulator turns on. A differential pressure valve used in this manner closes as soon as the boiler circulator turns off. This prevents undesirable reverse thermosiphoning between the thermal storage tank and boiler. It also eliminates the need for a check valve in the boiler circuit.

Differential pressure valves are commonly available in four piping sizes of three-quarter inch, 1 inch, and 1.25 inch. The larger size valves have lower head loss versus flow rate characteristics compared to smaller valves and can also be set for relatively low-opening differential pressures in the range of 1–1.5 psi.

Another method of preventing flow through an unfired boiler used with a two-pipe tank configuration is a motorized ball valve installed between the boiler and tank, as shown in Figure 5-21.

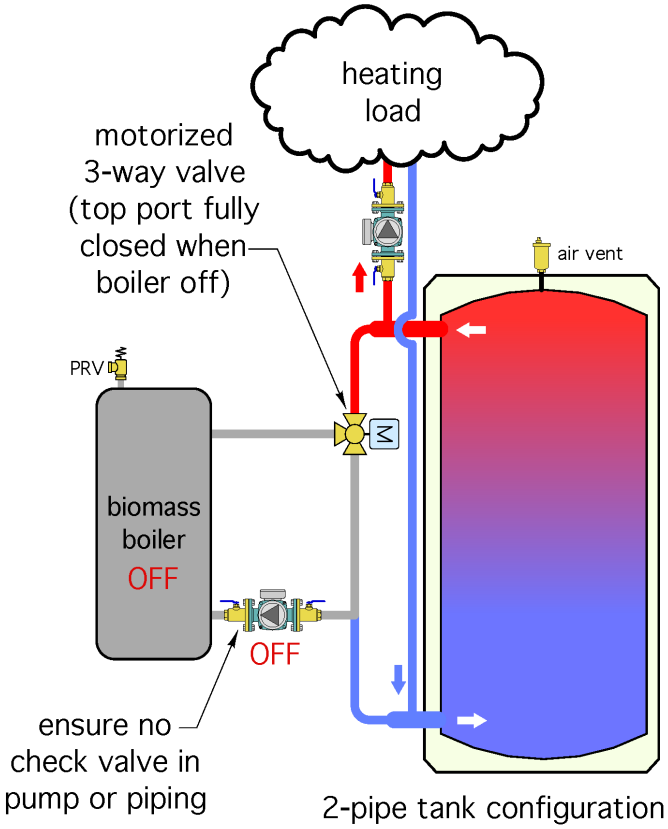
Figure 5-21. Motorized ball valve installation between boiler and thermal storage tank



The motorized ball valve is wired in parallel with the boiler circulator. It opens as soon as this circulator turns on. Its spring-loaded actuator closes the valve as soon as the boiler circulator turns off. Use of a motorized full-port ball valve, with a high Cv value, minimizes head loss in the boiler circuit whenever the valve is fully open.

One other method is to provide control logic that can operate a motorized three-way mixing valve, which is used for anti-condensation protection on some pellet boilers, so that the valve moves to the "full bypass" position whenever the boiler circulator is off. This detail is shown in Figure 5-22.

Figure 5-22. Specialized control of a motorized three-way mixing valve to prevent thermal migration through biomass boiler when it is off



When either the motorized ball valve or the three-way motorized valve is used to prevent flow through the unfired boiler, it's essential for the water in the boiler to have pressure communication with the balance of the system, especially with the system's expansion tank. This communication occurs through the piping between the boiler inlet piping and the lower tank connection. This path should not be blocked by a check valve that prevents flow from the boiler into the lower tank connection. If a check valve were present, and either type of motorized valve was fully closed, any pressure increase in the boiler would cause water to discharge from the boiler's pressure relief valve.

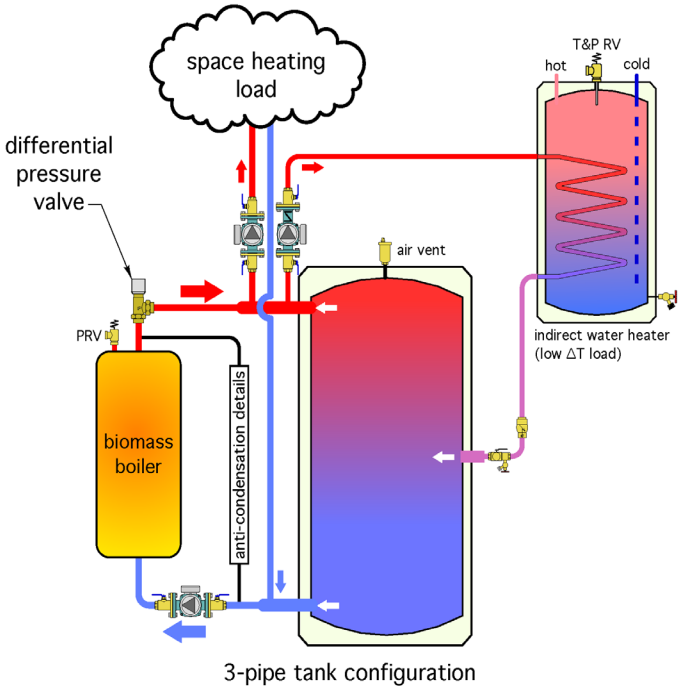
5.16 Three-Pipe Tank Configuration

Another potential issue with two-pipe tank configurations comes into play in specific circumstances; for example, when (1) the biomass boiler is operating, and (2) a load with a relatively small temperature drop is operating. Under these combined conditions the water returning from the load may only be a few degrees Fahrenheit cooler than the water supplied to the load. When the boiler circulator is on, this relatively hot return water is drawn into the boiler, causing the boiler temperature to rise quickly. The internal temperature limit controller in the boiler shuts off the boiler based on the temperature rise, and the length of the boiler operating cycle is cut short.

Domestic water heating using an indirect water heater is an example of a load that has caused this situation in some biomass boiler systems—this is especially true when the heat exchanger in the water heater has a small surface area or the heat exchanger is heavily scaled from mineral deposits. The higher the domestic water temperature is maintained, the lower the rate of heat transfer from the internal coil heat exchanger, and the lower the temperature drop (ΔT) across the coil.

One way to accommodate such a load is by piping the buffer tank in a three-pipe configuration, as shown in Figure 5-23.

Figure 5-23. Thermal storage tank piped in a three-pipe configuration for use with indirect water heater



The three-pipe configuration supplies both space heating and indirect water heater loads from the upper tank header. The space heating return pipe connects to the lower tank header the same as with a two-pipe tank configuration. However, the return from the indirect water heater (representing a lower ΔT load) connects to a mid-height tapping on the thermal storage tank.

Ideally, the temperature difference between the top of the thermal storage tank and the return connection from the low ΔT load would match the temperature drop across the low ΔT load. This would return water to the tank at a location where the entering water was about the same temperature as the water in the tank, and thus reduce mixing. However, the temperature drop across low ΔT loads will vary as the load operates, as the heat exchanger in the load accumulates scale and as the water temperature supplied from the thermal storage tank to the low ΔT load changes.

Although it's possible to have a thermal storage tank custom built with the return piping connection at any specified location, custom building often increases cost relative to using a standard tank. Some standard thermal storage tanks have a mid-height connection. To minimize mixing, the size of that connection should limit the entering flow velocity to no more than 2 feet per second.

Keeping the return pipe from the low ΔT load at or above mid-height allows cooler water returning from the space heating system to interact with the lower portion of the tank, as in a two-pipe system.

5.17 Multiple Thermal Storage Tank Configurations

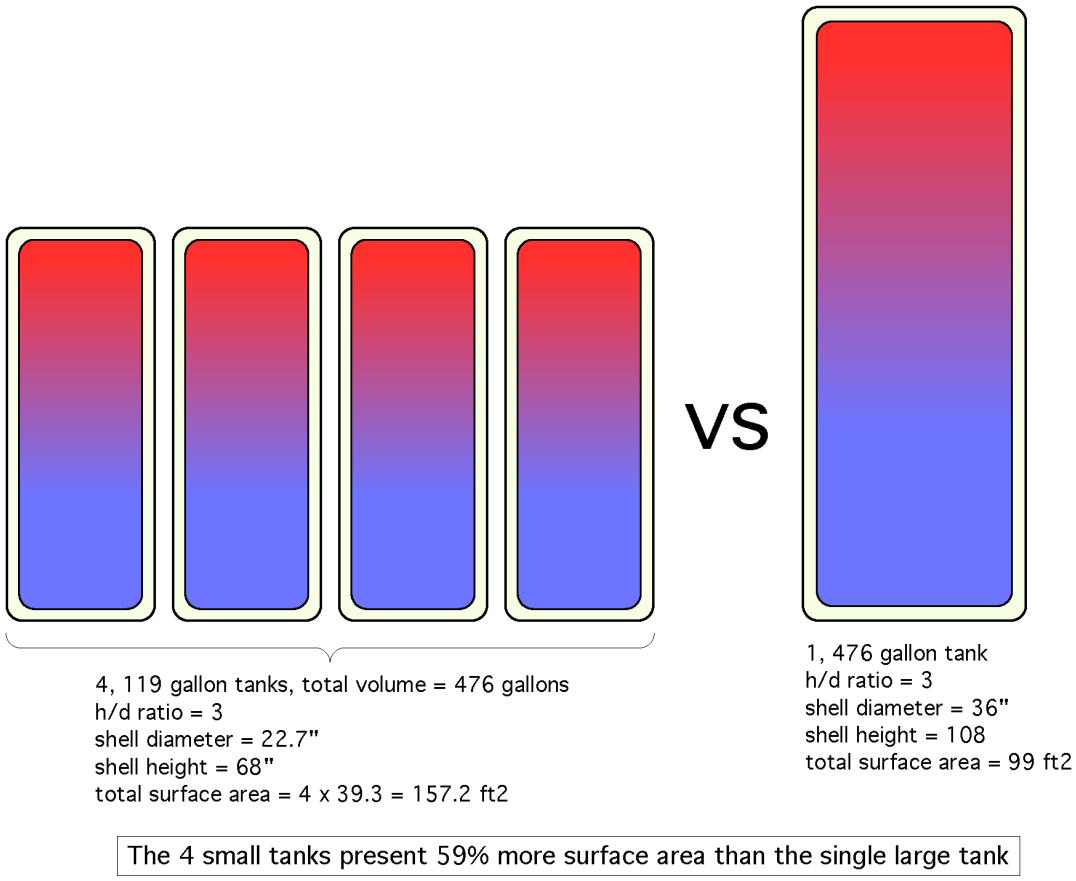
In some applications, it may be necessary to use multiple smaller thermal storage tanks rather than a single larger tank. The constraint may be the size of doors, width of stairs, or mechanical room dimensions. Another possibility is that multiple non-ASME tanks (up to 119 gallons each) are readily available and are often cost competitive with a single larger tank.

The decision to use multiple smaller tanks should consider the surface-to-volume ratio of multiple smaller tanks relative to that of a single larger tank. Multiple smaller tanks will have significantly more surface area per unit of volume compared to a single larger tank with the same height to diameter ratio. Higher surface to volume ratios result in higher heat loss from the thermal storage system relative to those from a single larger tank, assuming equal insulation R-value.

Multiple smaller tanks will have significantly more surface area per unit of volume compared to a single larger tank with the same height to diameter ratio.

Consider a comparison between four 119-gallon thermal storage tanks (total 476 gallons), and a single 476-gallon tank. All tanks are assumed to have the same height-to-diameter ratio of 3. The situation is shown in Figure 5-24.

Figure 5-24. Comparison of surface area to volume ratio of multiple 119-gallon thermal storage tanks versus a single 476-gallon tank. All tanks have 3:1 height to diameter ratio



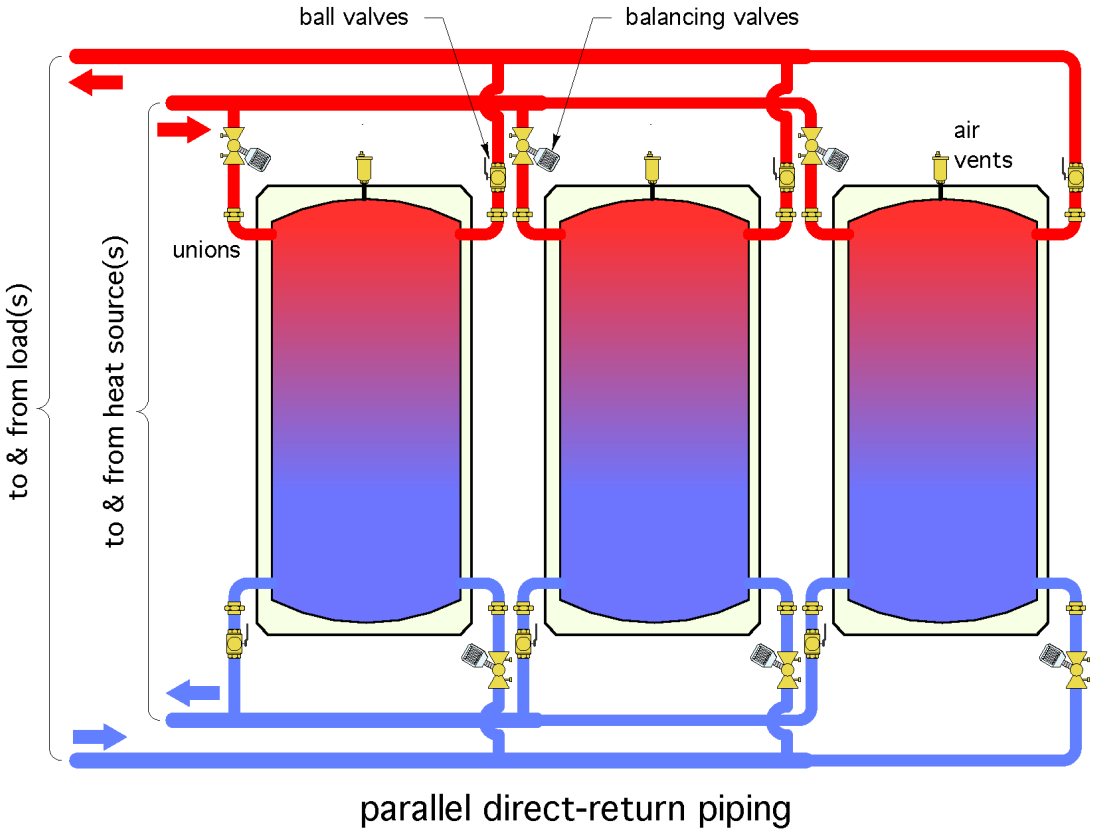
For mathematical simplicity, assume all tanks are flat-ended cylinders. Simple calculations show that the combined surface area of the four smaller tanks is 59% greater than the surface area of the single larger tank. If all tanks had identical insulation, and identical surrounding temperatures, the heat loss from the four smaller tanks would be approximately 59% greater than from the single larger tank. This could potentially be corrected by using high R-value insulation on the smaller tanks, but that could add significant cost.

It's also important to consider the area required for the thermal storage unit(s). Multiple smaller tanks will usually require significantly more floor space in mechanical rooms, especially when service clearances for each tank are factored in.

5.18 Piping Options for Multiple Thermal Storage Tanks

Most multiple tank systems connect the tanks in parallel, with the goal of dividing flow equally between the tanks. Two classic piping methods for achieving approximately equal flow through each tank are (1) parallel direct-return piping, and (2) parallel reverse return piping. Figure 5-25 shows three identical tanks piped in a parallel direct-return configuration.

Figure 5-25. Three thermal storage tanks piped in parallel direct-return configuration



The pathways the fluid follows through each tank have different lengths. Through the left tank the pathway is the shortest, longer in the center tank, and longest through the right side for both the boiler circuit and load circuit.

To achieve approximately equal flow rates through the tanks, it's necessary to install a balancing valve for the boiler and load circuit at each tank. Most balancing valves have a means of indicating flow rate. Some have a direct flow rate scale, others require the use of a manometer to infer flow rate based on the pressure drop through the valve. The individual balancing valves can also be fully closed to serve as an isolating valve.

The piping shown in Figure 5-25 allows any of the tanks to be fully isolated from the system by closing two balancing valves and two ball valves. The unions connecting the piping to the tanks can be opened to disconnect the piping from any tank. With proper space planning these piping details allow any tank to be isolated and removed from the system for repair or replacement.

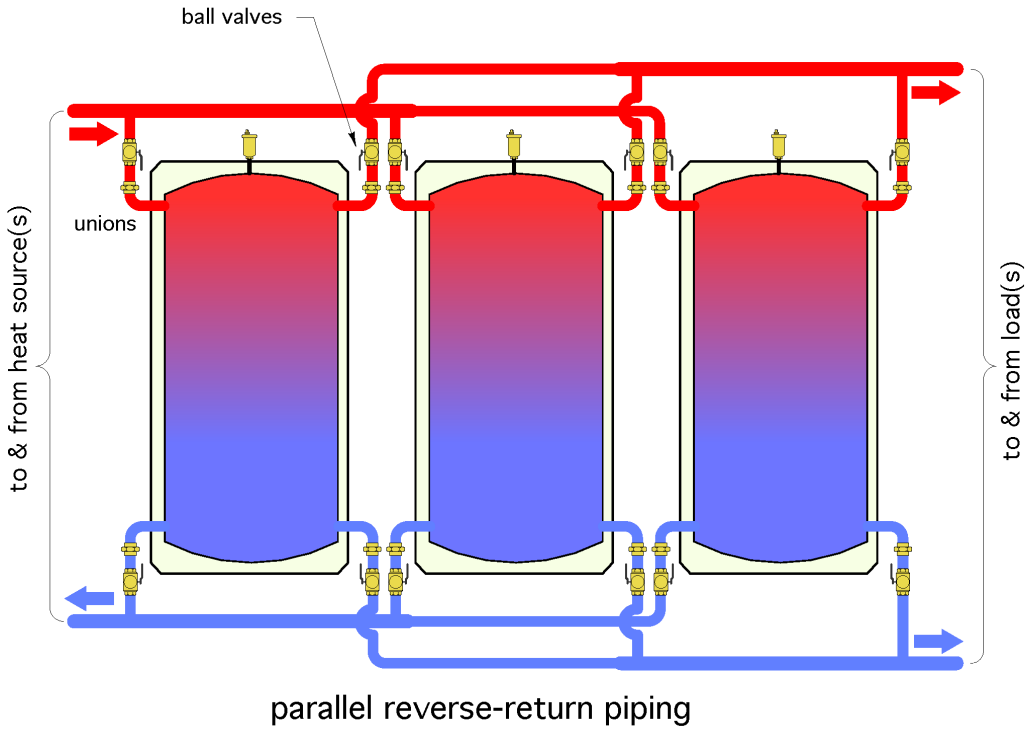
The need to isolate and possibly remove an individual tank in a multiple tank system should be established or dismissed based on project constraints. While the concept of being able to isolate and remove/replace any tank seems beneficial, the likelihood of having to do so is small, especially with high-quality, ASME-certified tanks. The piping, fittings, and valves required to isolate each tank can add significant cost to the system.

If the design condition is to allow isolation and potential removal of each tank, it's critically important that piping placement relative to the tanks, and tank placement relative to other equipment in the mechanical room, allows each tank to be removed without disruption of piping or other equipment in the system or mechanical room. This requires careful planning and adequate space allowances.

It's critically important that piping placement relative to the tanks, and tank placement relative to other equipment in the mechanical room, allows each tank to be removed without disruption of piping or other equipment in the system or mechanical room.

Parallel direct return piping is useful when the tank array is *not* located between the boiler(s) and loads. Figure 5-26 show a parallel reverse-return piping configuration of three thermal storage tanks.

Figure 5-26. Three thermal storage tanks with a parallel reverse-return piping configuration



Reverse-return piping creates *approximately* equal flow rates through the tanks. If the designer wants assurance of exactly equal flow rates, two balancing valves should be substituted for two ball valves at each tank, one in the boiler circuit and the other in the load circuit. Balancing valves are typically more expensive than ball valves. The pipe sizes used for the headers connecting the tanks should be "stepped" to give approximately equal head loss per unit of length.

Parallel reverse-return piping lends itself to situations where the tank array is between the boiler(s) and the load. If the design goal is to isolate and possibly remove any tank from the array, the same piping and tank placement considerations discussed for direct-return systems apply.

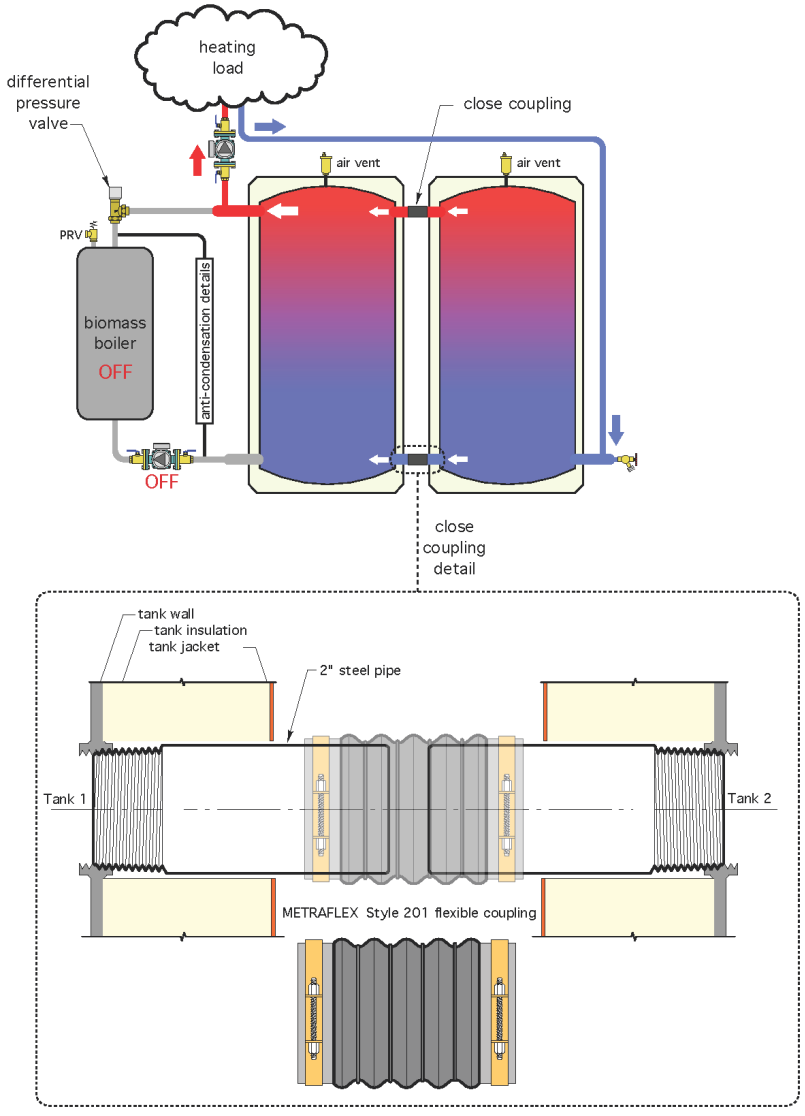
5.19 Close-Coupled Multiple Tank Systems

If design constraints do not require that each tank can be isolated and removed, it's possible to greatly simplify the piping involved in a multiple-tank system. Figure 5-27 shows an example of a close-coupled, multiple-tank array.

The schematic in Figure 5-27 is for joining two or more identical tanks that have threaded upper and lower sidewall connections. The upper sidewall connections that face each other are fitted with a short length of steel pipe that's threaded on one end. The opposite ends of these pipe segments are joined using a reinforced (Metraflex Style 201) coupler. The coupler must have a temperature and pressure rating that exceeds and temperatures and pressures the system could develop. The coupler is tightened to each pipe segment, and the flexibility of this coupler allows slight compensation for piping connections that may not have the exact same centerline.

The tanks should be positioned as close to each other as possible. This minimizes the pressure drop through the coupled connections and allows the tank assembly to provide good hydraulic separation between the biomass boiler circulator and the load circulator.

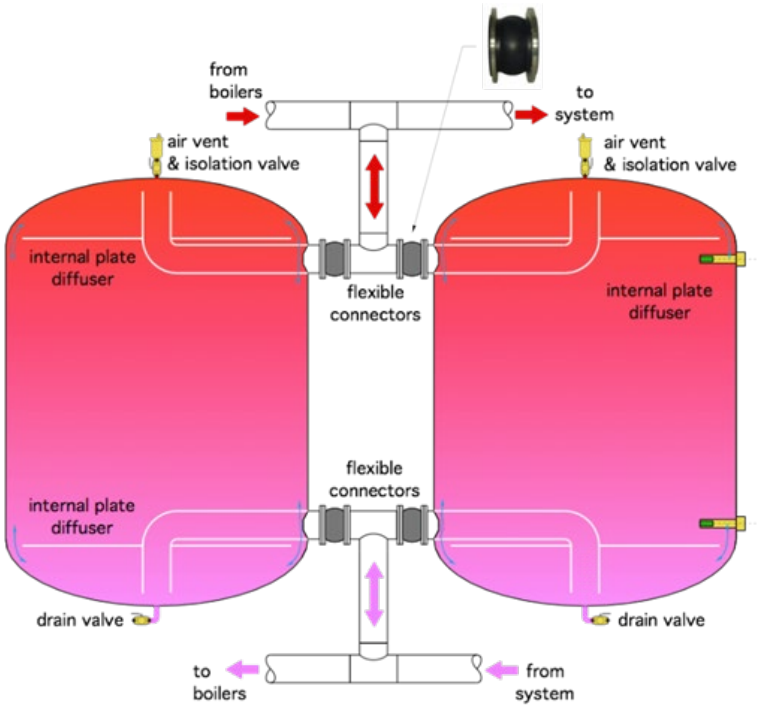
Figure 5-27. Close-coupled, multiple-tank array using a flexible coupling between tanks



The coupled tanks shown in Figure 5-27 are a close approximation of the two-pipe configuration described earlier. The flow rate passing through the tanks will always be the difference between the boiler flow rate and the load flow rate. This tank configuration is significantly less expensive than previous discussed configurations but does not allow each tank to be isolated and serviced.

Figure 5-28 shows a concept for how two larger thermal storage tanks, each with sidewall connections and internal detailing for flow diffusion, can be combined into a storage assembly that functionally operates as a two-pipe tank configuration.

Figure 5-28. Configuration for two large thermal storage tanks that forms a two-pipe tank array



The large tanks in Figure 5-28 each have flanges at their two main sidewall connections. Threaded openings are provided for small piping, valves, or instrument.

The main connections are joined to flanged tees using flexible connectors. The latter are commonly available in a wide range of pipe sizes. They are commonly used as vibration isolators on the inlet and outlet of large circulators. In this application, they provide a slight amount of flexibility to compensate for minor misalignment of the main sidewall connections. That slight misalignment may be due to fabrication tolerances in what are assumed to be identical tanks or slightly uneven concrete floors supporting the tanks. Both tanks have internal plate diffusers to minimize vertical flow velocity in the main portion of the tank. The internal piping shown also assures that hot water is delivered to and taken from the very upper portion of the tank, and that the cooler water is routed to or from the very lowest portion of the tank.

5.20 Boiler-to-Storage Flow Rate

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. A suggested maximum flow rate is one that will yield a nominal 20°F temperature rise across the biomass boiler when it is operating at full capacity.

Even higher temperature rises of 25–30°F are preferred if allowed by the biomass boiler manufacturer. The higher the temperature rise across the boiler, the lower the required flow rate between the boiler and thermal storage tank. Lower flow rates entering thermal storage tanks reduce mixing and help preserve temperature stratification. The relationship among boiler capacity, temperature rise, and flow Formula 5-1:

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

Where:

f = boiler flow rate (gpm)
Q = rated boiler output (Btu/hr)
ΔT = temperature rise across boiler (°F)
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°F temperature rise (e.g., difference between inlet and outlet temperature) in a water system would require a flow rate of the following.

Formula 5-2:

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

This is a low-flow rate that could be accommodated using 1-inch piping and a relatively small hydronic circulator.

6 Heat Emitters and Heating Distribution Systems

The heat produced by biomass boilers is usually carried throughout the building by a hydronic distribution system. It is then dissipated into each space by heat emitters. This section describes the type of hydronic distributions systems and heat emitters that work well with biomass boilers. It also describes how to include domestic water heating into systems supplied by pellet boilers and offers an example of how to deliver heat from thermal storage to a forced air distribution system.

6.1 The Importance of Low-Temperature Systems

Section 5 described the importance of thermal storage in biomass boiler systems. Thermal storage allows pellet boilers and cordwood gasification boilers to operate for several hours each time they are fired. This improves overall thermal efficiency and reduces emissions.

In order for thermal storage tanks to store large amounts of heat they must undergo a significant temperature rise from when the biomass boiler is first fired to when it turns off. The heat stored in any size tank is dependent on and directly proportional to this temperature rise.

The amount of *useful* heat stored in a tank can be calculated using the following formula.

The temperature at which no more useful heat is available from thermal storage is highly dependent on the heat emitters used in the system.

Formula 6-1:

$$Q=8.33(v)(\Delta T)$$

Where:

Q = amount of heat stored (Btu)
8.33 = heat capacity of water (Btu/gallon/°F)
v = volume of water in tank (gallons)
ΔT = drop in average tank temperature from its fully charged state to its minimum useful temperature state (°F)

The last term in Formula 6-1 (ΔT) deserves further explanation. The term refers to the change in the *average* temperature of the tank (averaged between top and bottom temperature) when the biomass boiler stops adding heat to the tank, minus the *average* tank temperature when no more useful heat can be extracted from the tank by the heating distribution system.

The temperature at which no more useful heat is available from thermal storage is highly dependent on the heat emitters used in the system. The fin-tube baseboard found in many existing residential and light commercial buildings that have oil-fired or gas-fired boilers is usually sized to deliver design load output at average water temperatures of 180°F or higher. Because these temperatures are close to the upper temperature limits of biomass boilers, thermal storage tanks have a very limited temperature cycling range in these systems under design load conditions. This is a significant limitation, and one that must be addressed to produce acceptable operating circumstances for the biomass boiler.

A recommended guideline is to design or modify all hydronic distribution systems so that they can deliver design load output using supply water temperatures no higher than 120°F.

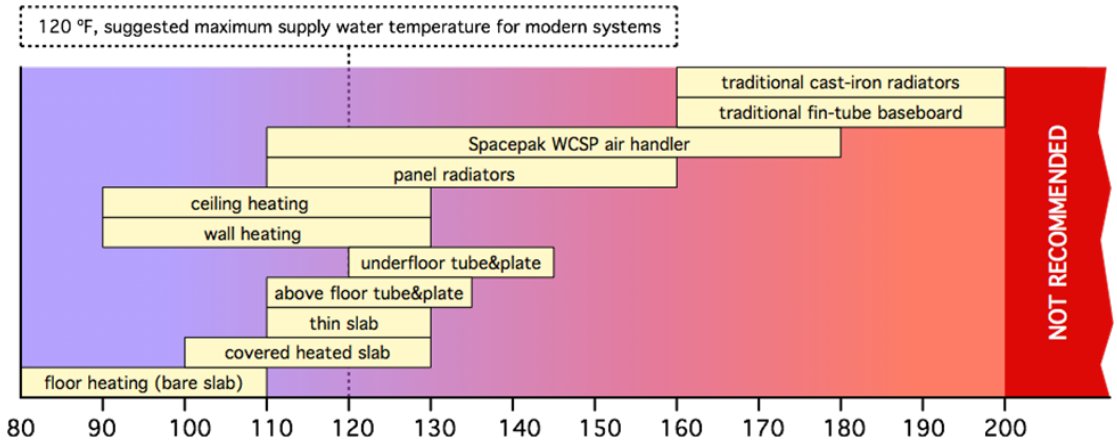
For example, on a cold winter day, a thermal storage tank heated to an average temperature (top to bottom) of 175°F, may only be able to drop to an average temperature of perhaps 165°F before the baseboard heat emitters in the building begin to fall short of delivering sufficient heat to maintain comfort. The latter situation must be avoided, and thus, in this situation, the thermal storage tank is constrained to a very narrow 10°F temperature swing between "boiler on" on "boiler off" conditions. Such shallow cycling is undesirable from the standpoints of both thermal efficiency and emissions.

To avoid this circumstance, it is necessary to have heat emitters that can deliver design heating load output at much lower water temperatures. The lower the better. A recommended guideline is to design or modify all hydronic distribution systems so that they can deliver design load output using supply water temperatures no higher than 120°F.

The previous recommendation is a major departure from common practices. It's also a necessary and highly beneficial aspect of achieving good performance from biomass boilers. This section describes several types of heat emitters that can meet this recommended guideline as well as ways of modifying existing (high temperature) hydronic distribution systems to reduce their supply water temperature requirements.

Figure 6-1 shows the traditional water temperature range for several types of hydronic heat emitters. A vertical line shows the suggested supply water temperature limit of 120°F. Notice that there are several heat emitter options that can be used to stay within the recommended range of supply water temperature.

Figure 6-1. Traditional water temperature ranges for hydronic heat emitters

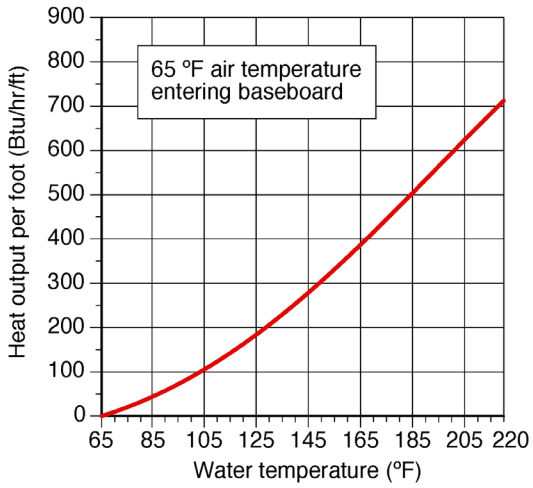


6.2 Low-Temperature Heat Emitter Options

Finned-tube baseboard was originally developed for the high-water temperatures available from conventional boilers. Baseboards were (and often continue to be) sized based on supply water temperature of 180°F or higher. Such high temperatures severely limit the temperature cycling range of thermal storage systems.

Finned-tube baseboard can operate at reduced water temperatures but its heat output drops. Figure 6-2 can be used to estimate the heat output of standard residential finned-tube baseboard at reduced average water temperatures.

Figure 6-2. Heat output of residential finned-tube baseboard per foot (Btu/hr/ft) versus average water temperature (°F)



The average water temperature referenced in figure 6-2 is the average between the supply and return water temperature. The temperature drop across a baseboard circuit can vary widely depending on how the baseboard is piped. When several baseboards are piped in series, the temperature drop across the entire series circuit is typically in the range of 15–20°F.

At an average water temperature of 180°F, a typical residential fin-tube baseboard element releases about 475 Btu/hr/ft. If the average water temperature is reduced to 115°F, the same element releases about 140 Btu/hr/ft. Both outputs are based on 65°F air entering the fin-tube baseboard at floor level. At low water temperatures, the constraining factor for standard fin-tube baseboard is usually the necessary wall space.

At low-water temperatures, the constraining factor for standard fin-tube baseboard is usually the necessary wall space.

6.3 Low-Temperature Fin-Tube Baseboard

New products recently introduced in North America are aimed at eliminating the high temperature limitation of standard baseboard. The finned-tube element shown in Figure 6-3 has much greater fin area compared to a standard finned-tube element. It also has two tubes passing through the fins. This allows significantly higher heat output at reduced water temperatures. The rated output of this element when both pipes operate in parallel is 290 Btu/hr/ft at an average water temperature of 110°F and a total flow rate of one gallon per minute.

Figure 6-3. Example of a finned-tube element with a greater fin area compared to standard finned-tube elements

Courtesy of Emerson Swan, Inc.



6.4 Panel radiators

Although their origins are in Europe, panel radiators are now widely available in North America. Figure 6-4 shows a typical panel radiator equipped with a nonelectric thermostatic valve to regulate heat output independently of other radiators in the system.

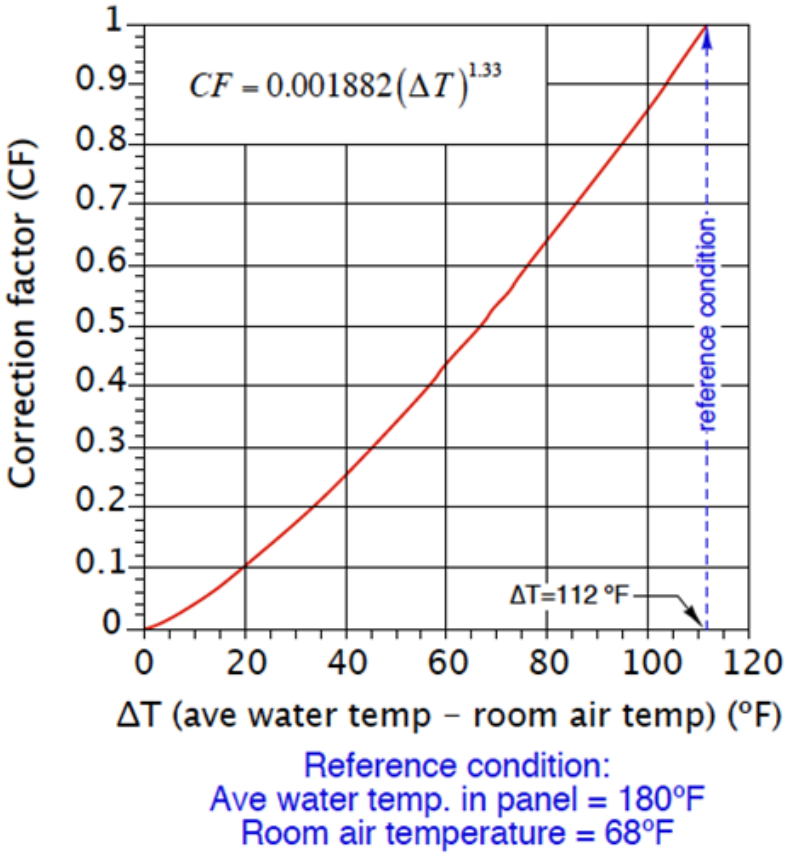
Figure 6-4. Typical panel radiator equipped with a nonelectric thermostatic valve for room temperature control



Most of the panel radiators sold in North America are constructed of steel, and as such must be use as closed-loop hydronic systems. Panel radiators have relatively low-thermal mass, allowing them to quickly increase or decrease heat output as the water passing through them changes temperature. They are available in different heights, widths, and thicknesses to provide a reasonable match between panel output and room heating load, while also fitting radiators into constrained spaces such as below windows or in alcoves.

The *rated* output of panel radiators is often based on high average water temperatures, such as 180°F. Most manufacturers provide correction factors such as those shown in Figure 6-5 to adjust for low-average water temperatures.

Figure 6-5. Correction factors for estimating heat output of panel radiators at low average water temperatures



If panel radiators are to be selected based on a supply water temperature of 120°F, the average water temperature used to establish the correction factor should be approximately 110°F (assuming the panel operates with a nominal 20°F temperature drop under design load conditions). As a guideline, the heat output of a panel radiator operating at an average water temperature of 110°F is about 25% of its heat output when operated at an average water temperature of 180°F. Panel radiators sized to provide a given heat output while operating at relatively low average water temperatures must be larger than panels operated at significantly higher average water temperatures.

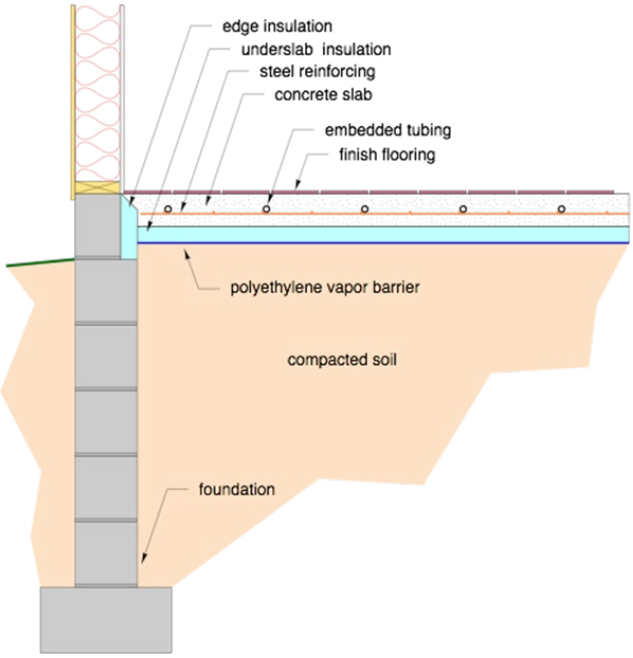
6.5 Radiant Panels

Radiant panels represent another category of low-temperature heat emitters. This category includes radiant floor heating as well as radiant wall and radiant ceiling heating. There are several variations within each category. For example, radiant floors can be integrated into slab-on-grade construction or into wood-framed floor construction. Some radiant panels can operate at supply water temperatures under 100°F, even under design load conditions. These low-temperature radiant panels allow for wide temperature changes in thermal storage and are ideal for use with biomass boilers.

6.6 Heated Floor Slabs

Heated floor slabs with relatively close tube spacing and low-finish floor resistances are ideally suited for use with biomass boilers. Figure 6-6 shows the cross section of such a floor. The tubing has been placed at mid-depth within the slab, and the underside and edge of the slab are well insulated with extruded polystyrene. Both details are important in achieving good low-temperature performance.

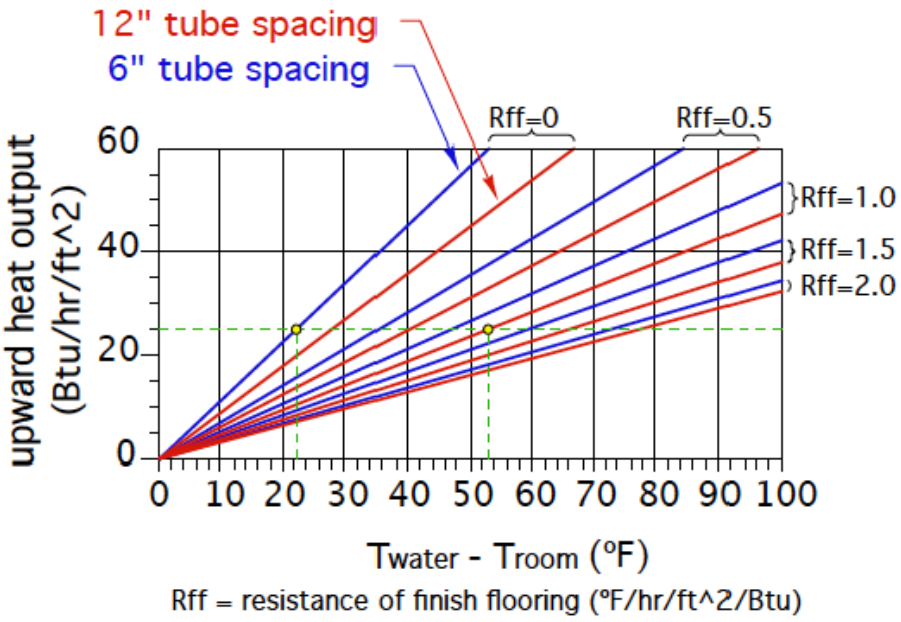
Figure 6-6. Cross section of a heated floor slab



The graph in Figure 6-7 shows upward heat output from a heated slab based on tube spacing of six inches and 12 inches and for finish floor resistances ranging from 0 to 2.0 (°F•hr•ft^2/Btu).

For example, to achieve an upward heat output of 20 Btu/hr/ft^2 from a slab with no covering (e.g., Rff = 0) and six-inch tube spacing requires the "driving ΔT" (e.g., the difference between average water temperature in tubing and room air temperature) to be 17.5°F. Thus, in a room maintained at 70°F, the average water temperature in the circuit needs to be 87.5°F. The supply water temperature to the circuit would likely be in the range of 95–98°F. This is a relatively low-supply water temperature and should allow thermal storage to supply the load for a long boiler-off cycle.

Figure 6-7. Comparison of upward heat output from a heated slab based on tube spacing of 6 and 12 inches and different finish floor resistances (Rff)



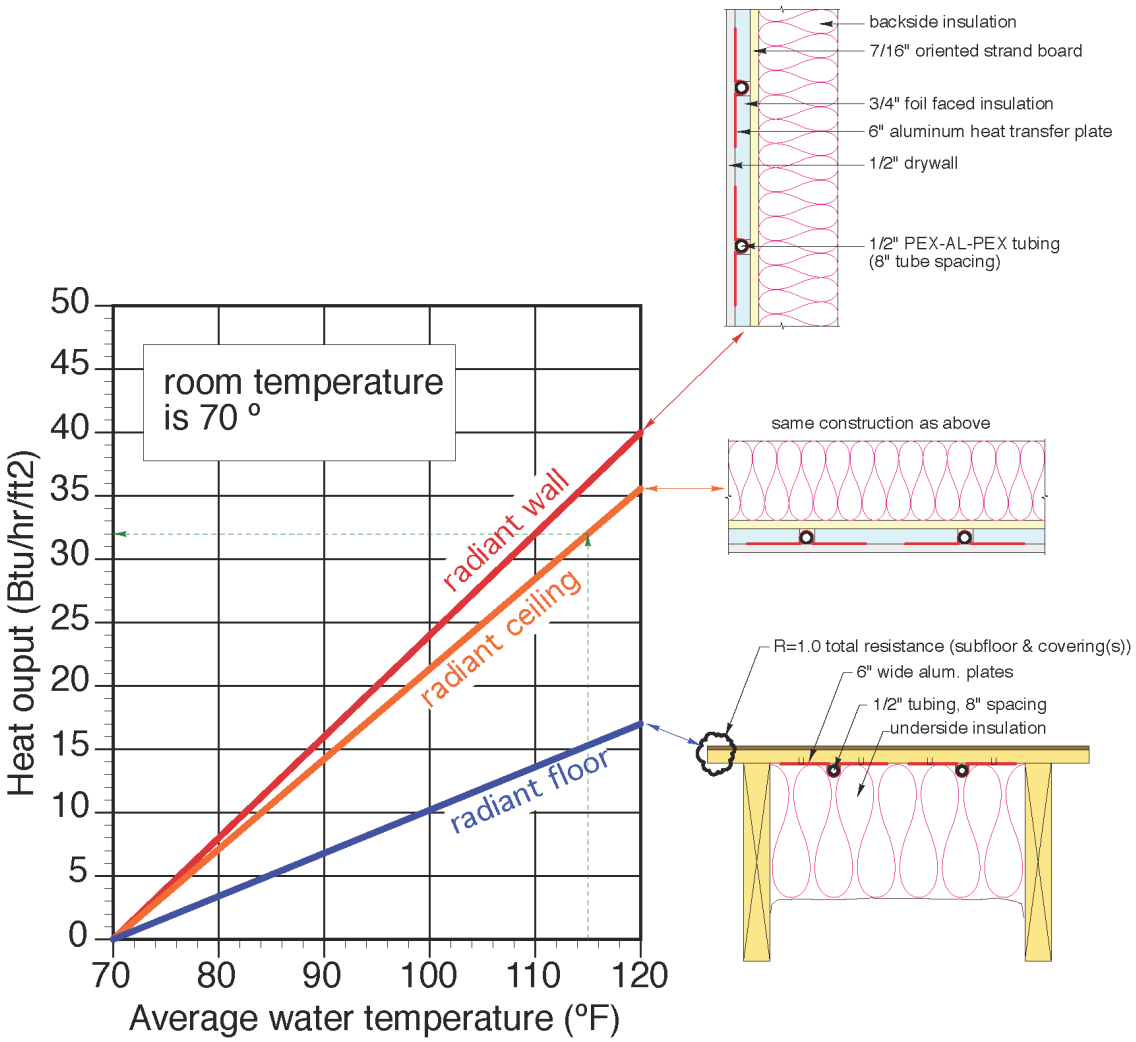
For comparison, consider supplying the same 20 Btu/hr/ft^2 load using a heated floor slab with 12-inch tube spacing and a finish floor resistance of 1.0°F•hr•ft^2/Btu. The driving ΔT must now be 42.5°F. The average circuit water temperature required to maintain a room temperature of 70°F would be 70 + 42.5 = 112.5°F and the supply temperature would be likely in the range of 120–123°F. This higher temperature limits the temperature swing of thermal storage relative to the previous example and thus yields short boiler-off cycles.

Figure 6-8 shows the room-side heat output of three specific types of low-thermal mass radiant panels:

bottom-side tube and plate radiant floor panel
radiant wall panel
radiant ceiling panel

These outputs are specific to the construction details for each panel. Panels with different construction and tube spacing will have different outputs. The operating water temperature required for any of these panels makes them good choices for use with biomass boilers.

Figure 6-8. Room-side heat output for three types of low-thermal mass radiant panels



The room-side heat output of each radiant panel represented in Figure 6-8 is given in Btu/hr/ft^2. For example, the radiant ceiling panel releases approximately 22 Btu/hr/ft^2 into a 70°F room below when operated at an average water temperature of 100°F. Under the same conditions, the radiant wall panel releases about 24 Btu/hr/ft^2 and the radiant floor panel represented releases about 10 Btu/hr/ft^2. The total heat output of the panel is determined by taking the Btu/hr/ft^2 output and multiplying by the total area of the panel.

It's also possible to use fan-coils or air handlers in combination with biomass boilers and thermal storage. Figure 6-9 shows and example of a small horizontal air handler that's designed to connect to a forced air duct system.

Figure 6-9. Example of small horizontal air handler designed to connect to a ducting system

Courtesy of SpacePak



The air handler should be selected to provide the require design load heat output while operating at a supply water temperature of not more than 120°F.

Space heating can also be delivered using fan-coil units located in different areas of a building. Figure 6-10 shows an example of a wall-mounted fan coil. Again, these units should be selected to provide design load heating requirements using a supply water temperature no higher than 120°F.

Figure 6-10. Example of a wall-mounted "console" fan coil unit

Courtesy of SpacePak



One potential benefit of using air handlers or fan-coils is that certain models are equipped with condensate drain pans. Those units can provide cooling through chilled water, assuming that a source of chilled water is available.

6.7 Reducing Supply Water Temperature for Existing Systems

Biomass boilers are often retrofitted to systems in which the existing heat emitters were designed to operate at high-water temperature. The performance of the biomass boiler can be significantly improved if the existing hydronic distribution system is modified to operate at lower water temperatures.

There are two fundamentals ways to reduce the supply water temperature of any hydronic heating system: (1) reduce the design load of the building envelope through improvements such as added insulation, better windows, and reduced air leakage; and (2) add heat emitters to the existing system. A combination of these two approaches is also possible.

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

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

Formula 6-2:

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

Where:

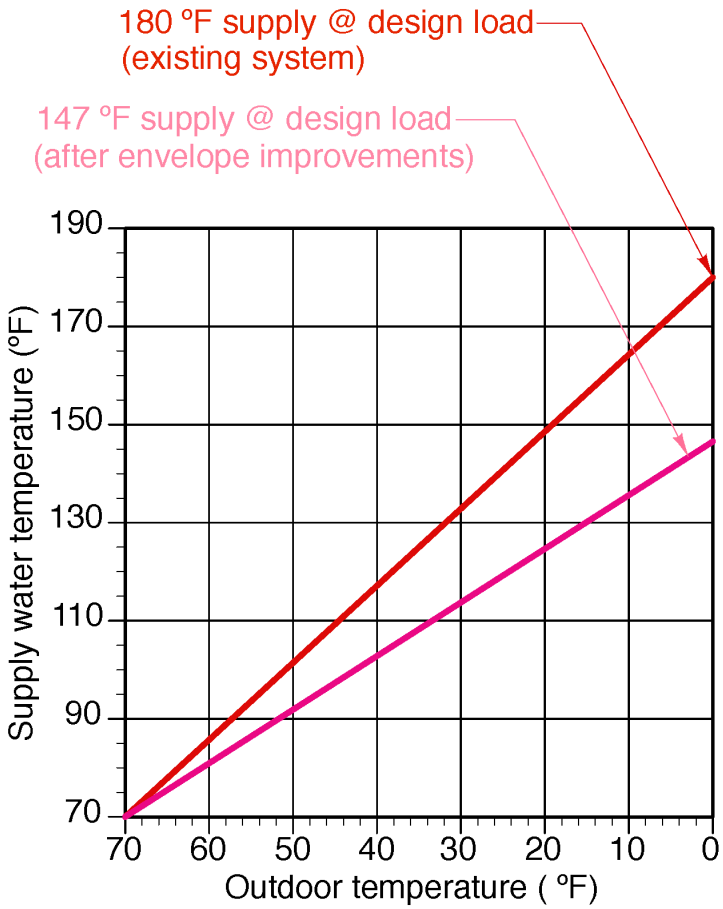
T_{new} = supply water temperature at design load after building envelope improvements (°F)
T_{in} = desired indoor air temperature (°F)
Q_{new} = design heating load after building envelope improvements (Btu/hr)
$Q_{existing}$ = existing design heating load (before improvements) (Btu/hr)
T_{De} = existing supply water temperature at design load (before improvements) (°F)

For example, assume an existing building has a design heating load of 100,000 Btu/hr, based on maintaining an interior temperature of 70°F. The existing hydronic distribution system uses standard fin-tube baseboard and requires a supply water temperature of 180°F at design load conditions. Also assume that improvements to the building envelope will reduce this design load from 100,000 Btu/hr to 70,000 Btu/hr. The new supply water temperature to the existing distribution system under design load conditions can be estimated using Formula 6-2:

$$T_{new} = 70 + \left(\frac{70{,}000}{100{,}000}\right) \times (180 - 70) = 147°\text{F}$$

Figure 6-11 shows a graph of the supply water temperature versus outdoor temperature for both the existing buildings (e.g., with design load of 100,000 Btu/hr) as well as after envelope improvements which reduced the design load to 70,000 Btu/hr.

Figure 6-11. Comparison between supply water temperature before and after building envelope improvements



In this example, reducing the design heating load from 100,000 Btu/hr to 70,000 Btu/hr reduced the required supply water temperature under design load conditions from 180°F to 147°F. Although this is certainly an improvement, it is still substantially above the previously suggested design criteria of 120°F supply water temperature at design load.

6.8 Adding Heat Emitters to Lower Supply Water Temperature

If reducing the building's design heating load does not lower the required water temperature to the desired value, it will be necessary to add heat emitters to the system.

Any of the previously discussed heat emitters could potentially be added. For example, an existing high-temperature baseboard system could potentially have more baseboard added to it, assuming sufficient wall space is available. Another option might be to change out some existing baseboard emitters with new baseboard that has high-heat output ratings.

Other options include adding a different type of heat emitter to the system. An example would be adding panel radiators to the existing baseboard. Another example would be adding some area of radiant panel heating (floor, wall, or ceiling) to the existing design.

The type of heat emitter to add will depend on several factors, including the following:

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

6.9 Adding More Finned-Tube Baseboard

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

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

Step 1: Accurately determine the building's design heat load using Manual J or equivalent procedures.

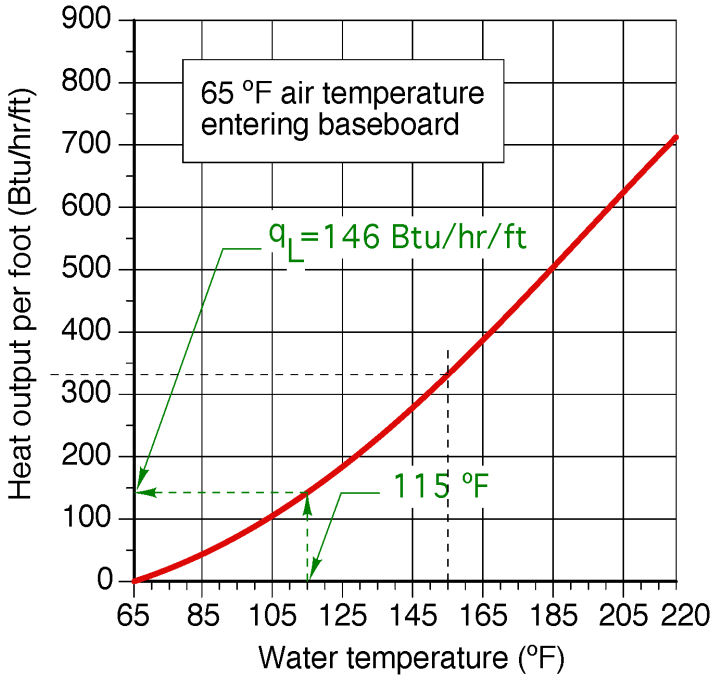
Step 2: Determine the total length of finned tubing in the existing distribution system. Do not include the length of tubing without fins. The existing finned-tube length will be designated as L_e.

Step 3: Determine the desired (lower) supply water temperature for which the system is to supply design load output. A suggested value is 120°F.

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

Step 5: Find the new average temperature for the circuit water on the horizontal axis of the graph in Figure 6. Draw a vertical line up from this point until it intersects the red curve. Draw a horizontal line from this intersection to the vertical axis of the graph and read the heat output of the finned-tube at the lower average circuit water temperature. This number is designated as q_L. The green lines and numbers in Figure 6-12 show how q_L is determined for an average circuit water temperature of 115°F.

Figure 6-12. Determining the value of q_L for an average circuit water temperature of 115°F



Step 6: Determine the length of baseboard to be added using Formula 6-3.

Formula 6-3:

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

Where:

L_{added} = length of finned-tube of same make/model baseboard to be added (feet)
design load = design heating load of building (Btu/hr)
q_L = output of baseboard at the lower average circuit water temperature (Btu/hr/ft)
L_e = total existing length of baseboard in system (feet)

Example 1: Assume a building has a calculated design load of 40,000 Btu/hr with a distribution system that contains 120 feet of standard residential finned-tube baseboard and is currently heated by a conventional cast iron boiler. The goal is to reduce the supply water temperature to 120°F at design conditions using more of the same baseboard. Assume the temperature drop of the distribution system is 10°F. To determine the amount of baseboard that must be added perform the following the steps:

Solution

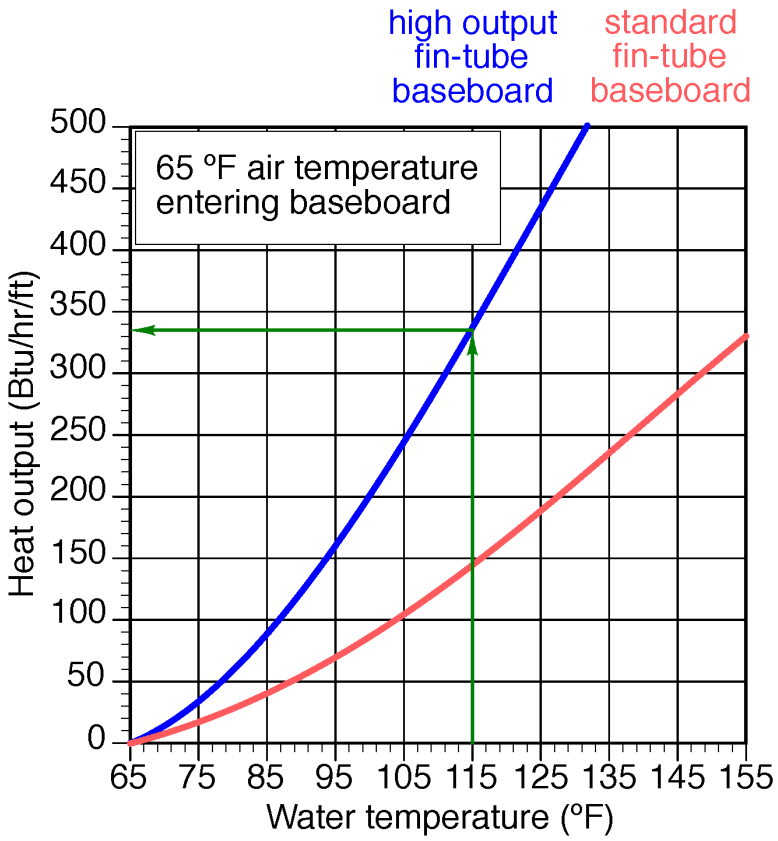
Step 1: The design load has been calculated as 40,000 Btu/hr.
Step 2: The total amount of finned-tube in the system is 120 feet.
Step 3: The lower supply water temperature at design load will be 120°F.
Step 4: The lower *average* circuit water temperature will be 120 - (10/2) = 115°F.
Step 5: The output of the finned-tube at an average circuit water temperature of 115°F is determined from Figure 6-12 as 146 Btu/hr/ft.
Step 6: The required additional length of baseboard is now calculated using Formula 2:

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

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

One option is to consider adding “high-output,” finned-tube baseboard rather than standard baseboard. Figure 6-13 shows the heat available from a specific high-output baseboard (shown as the blue curve) and for comparison, standard residential baseboard (shown as the red curve).

Figure 6-13. Heat available from high-output, finned-tube baseboard compared to standard baseboard



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

Steps 1-4: Same

Step 5: Determine the output of high-output baseboard at the average circuit water temperature using Figure 6-13 (or manufacturer’s literature for a specific make and model).

Step 6: The required length of high-output baseboard to add to the system is found using Formula 6-4.

Formula 6-4:

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

Where:

L_{ho} = length of high-output, finned-tube baseboard to be added (feet)
design load = design heating load of building (Btu/hr)
q_L = output of existing baseboard at the lower average water temperature (Btu/hr/ft)
L_e = total existing length of baseboard in system (feet)
q_{ho} = output of high-output baseboard at the lower average water temperature (Btu/hr/ft)

Example 2: Assume a building has a calculated design load of 40,000 Btu/hr with a distribution system that contains 120 feet of standard residential finned-tube baseboard. The goal is to reduce the supply water temperature under design load to 120°F. Additional high-output baseboard will be added to allow this lower water temperature operation. Assume that the temperature drop of the distribution system at design load is 10°F, and this existing baseboard has the same output as in the previous example (146 Btu/hr/ft at average circuit water temperature of 115°F). Determine the amount of high-output baseboard required established by the performance shown in Figure 6-13.

Solution

Step 1: The design load has been calculated as 40,000 Btu/hr.
Step 2: The total amount of finned-tube in the system is 120 feet.
Step 3: The new lower supply water temperature at design load will be 120°F.
Step 4: The new lower average circuit water temperature will be 120 - 5 = 115°F.
Step 5: The output of high-output finned-tubing at an average water temperature of 115°F is determined from Figure 6-13 as 335 Btu/hr/ft.
Step 6: The required length of high-output baseboard to add to the system is found using Formula 6-4:

$$L_{ho} = \frac{design\ load - (q_L)(L_e)}{q_{ho}} = \frac{40{,}000 - (146)(120)}{335} = 67ft$$

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

If the added length of high-output baseboard cannot be accommodated, another option is to raise the supply water temperature constraint from 120 to 130°F under design load conditions. This would reduce the amount of added high-output baseboard in second example to 40 feet.

6.10 Other Heat Emitter Options

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

The fundamental concept is given in Formula 6-5.

Formula 6-5:

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

Where:

Q_n = required heat output of the new heat emitters at lower supply water temperature (Btu/hr)
design load = the design heating load of the building (Btu/hr)
Q_e = heat output of existing heat emitters at the lower supply water temperature (Btu/hr)

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

The goal is to select a grouping of new heat emitters with a total heat output that's approximately equal to the value of Q_n in Formula 6-5.

Example 3: Assume a building has a calculated design load of 40,000 Btu/hr with a distribution system that contains 120 feet of standard residential finned-tube baseboard. The goal is to reduce the supply water temperature to 120°F under design load conditions. Panel radiators are available in the 24-inch x 72-inch size that can release 4,233 Btu/hr when operated at an average water temperature of 115°F in rooms with 70°F interior temperature. How many of these radiators are necessary to meet the design load?

Solution: First, use Formula 6-5 to determine the output required for the new radiators.

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

The number of radiators needed is then found as follows:

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

Discussion: The designer could either add six of these panel radiators or choose a slightly higher supply water temperature and use five radiators.

Another option is to use panel radiators of different sizes, provided that their total output at the lower supply water temperature can meet the value of Q_n. In this example the six new radiators would be combined with the 120 feet of existing baseboard to provide the 40,000 Btu/hr design load.

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

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

6.11 Piping for Supplemental Heat Emitters

There are several factors that could influence how the supplemental heat emitters are piped into the system. They include the following:

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

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

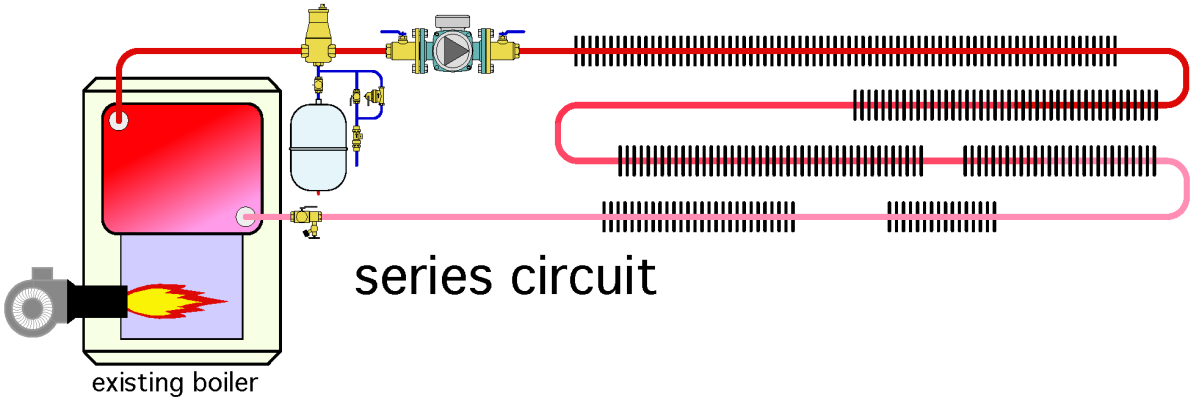
There is no one best approach. Every situation must be evaluated individually while weighing these factors to determine the best fit for that project.

6.12 Converting Series Loops to Parallel Branches

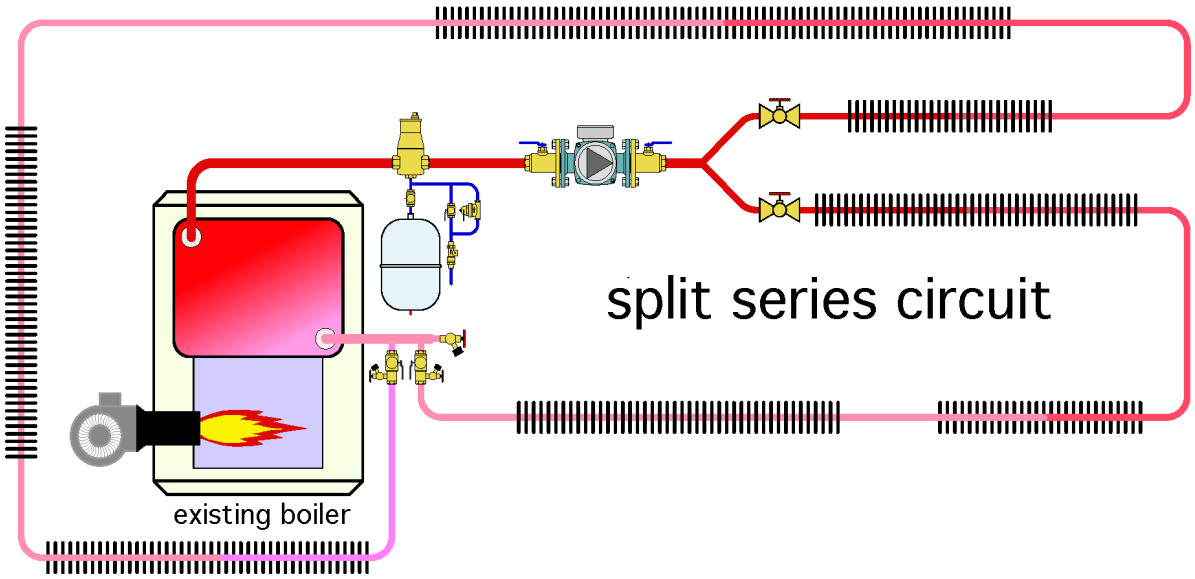
Many residential hydronic systems have finned-tube baseboards connected in series or “split-series” circuits, as shown in Figures 6-14a and 6-14b.

Figure 6-14. Common situations with finned-tube baseboards connected in series or split-series circuits

a)



b)

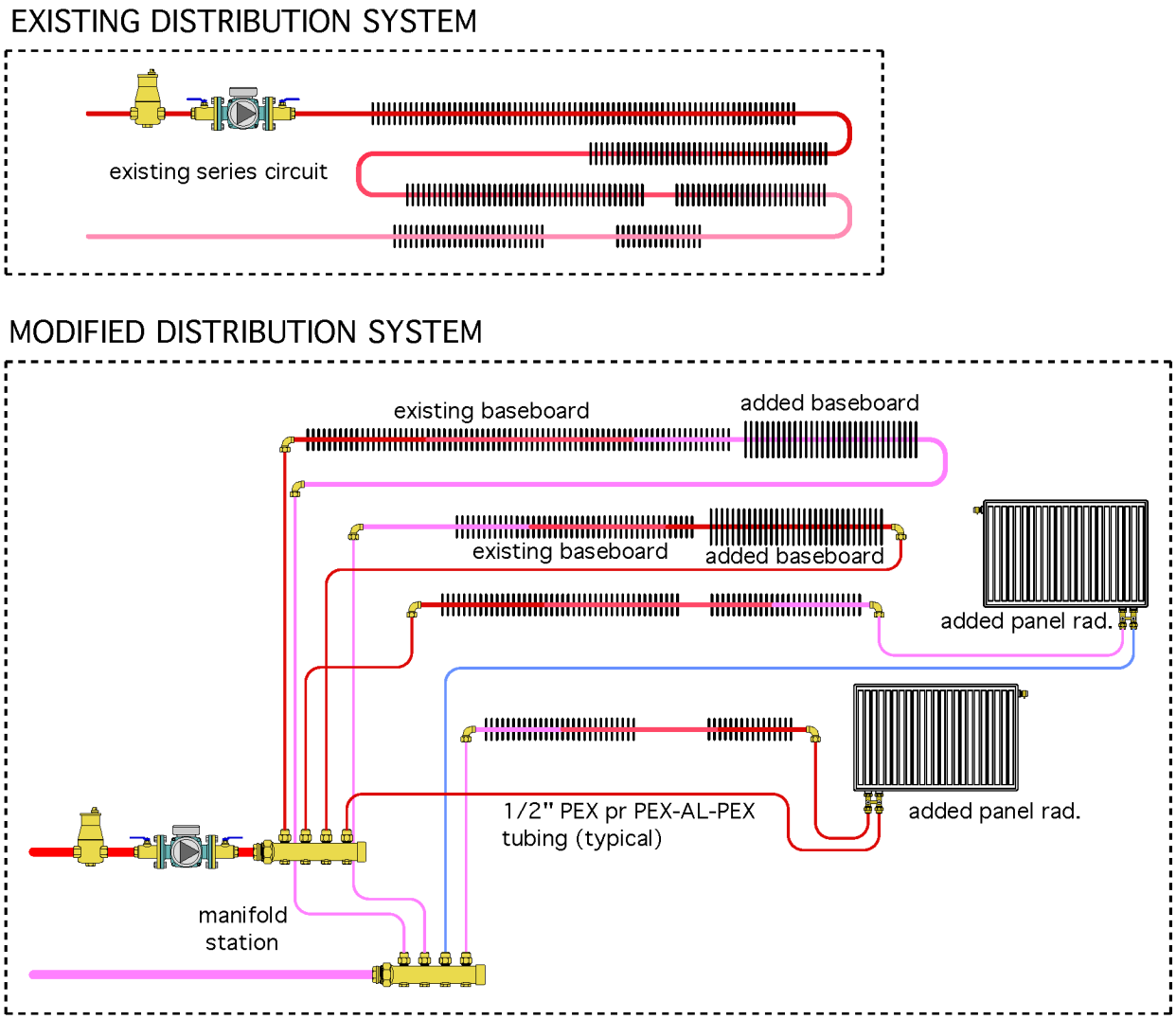


When several heat emitters are to be added to a system using series or split-series connected baseboards, they should not be simply cut into the series circuit. Doing so could substantially increase the flow resistance of that circuit, which reduces flow (assuming the same circulator is used). Adding heat emitters in series also increases the temperature drop of the circuit. This reduces the heat output of heat emitters near the end of the circuit, especially when the supply temperature to that circuit is lowered.

One possible approach is to make strategic cuts into the series circuit where it is easiest to access and reconnect the cut segments back into a parallel distribution system. These cuts could make each room a separate parallel circuit. The cuts could also be used to make a group of two or more rooms into a new single zone.

One of the easiest ways to divide an existing series loop or split-series distribution system into multiple parallel circuits is by creating a homerun distribution system. Each heat emitter or grouping of an existing heat emitter and a supplemental heat emitter is supplied by a separate circuit of PEX or PEX-AL-PEX tubing. This tubing is easy to route through cavities or along framing. The homerun circuits begin and end at a manifold station. This concept for converting a series baseboard system into a homerun system is shown in Figure 6-15.

Figure 6-15. Illustration for converting a series baseboard circuit into multiple homerun circuits



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

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

A parallel distribution system also supplies water at approximately the same temperature to each branch circuit, which is likely to boost the heat output of some existing baseboards.

The three-quarter-inch copper tubing in the existing circuit was cut at locations that preserved a reasonable amount of existing tubing, but also allow convenient transition to half-inch PEX or PEX-AL-PEX tubing. Adapter fittings for transitioning from three-quarter-inch copper to half-inch PEX or PEX-AL-PEX tubing are readily available from several suppliers. The half-inch PEX or PEX-AL-PEX supplies and returns are routed back to a manifold station. That manifold station should be equipped with individual circuit balancing valves that allow the flow rate through each of the new branch circuits to be adjusted.

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

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

6.13 Creating New Zones

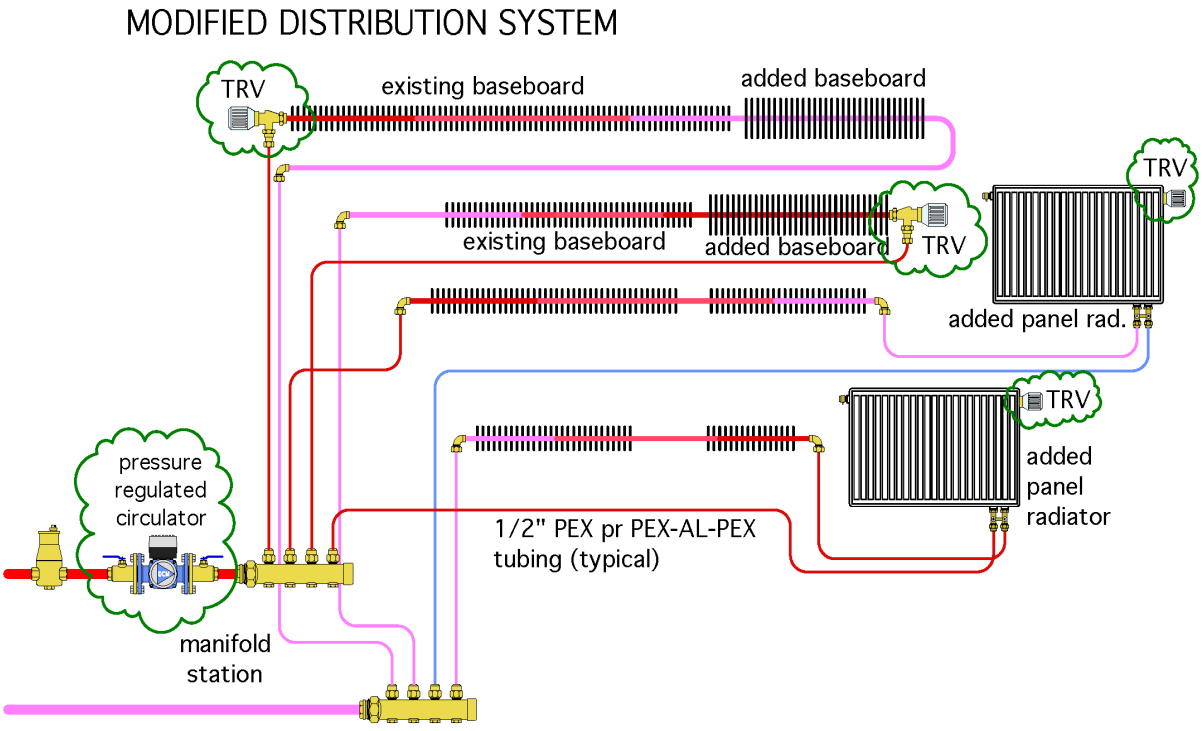
Another advantage of parallel distribution systems is the ease of creating multiple zones. If the existing series circuit is converted to multiple branches, each of those branches can be equipped with a thermostatic radiator valve. These nonelectric valves automatically modulate to vary the flow rate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

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

Another type of thermostatic radiator valve allows the valve body and actuator to be mounted within the baseboard enclosure, while the adjustment knob is mounted at normal thermostat height on the wall. The adjustment knob connects to the actuator using a capillary tube. It's also possible to use panel radiators with built-in thermostatic radiator valves.

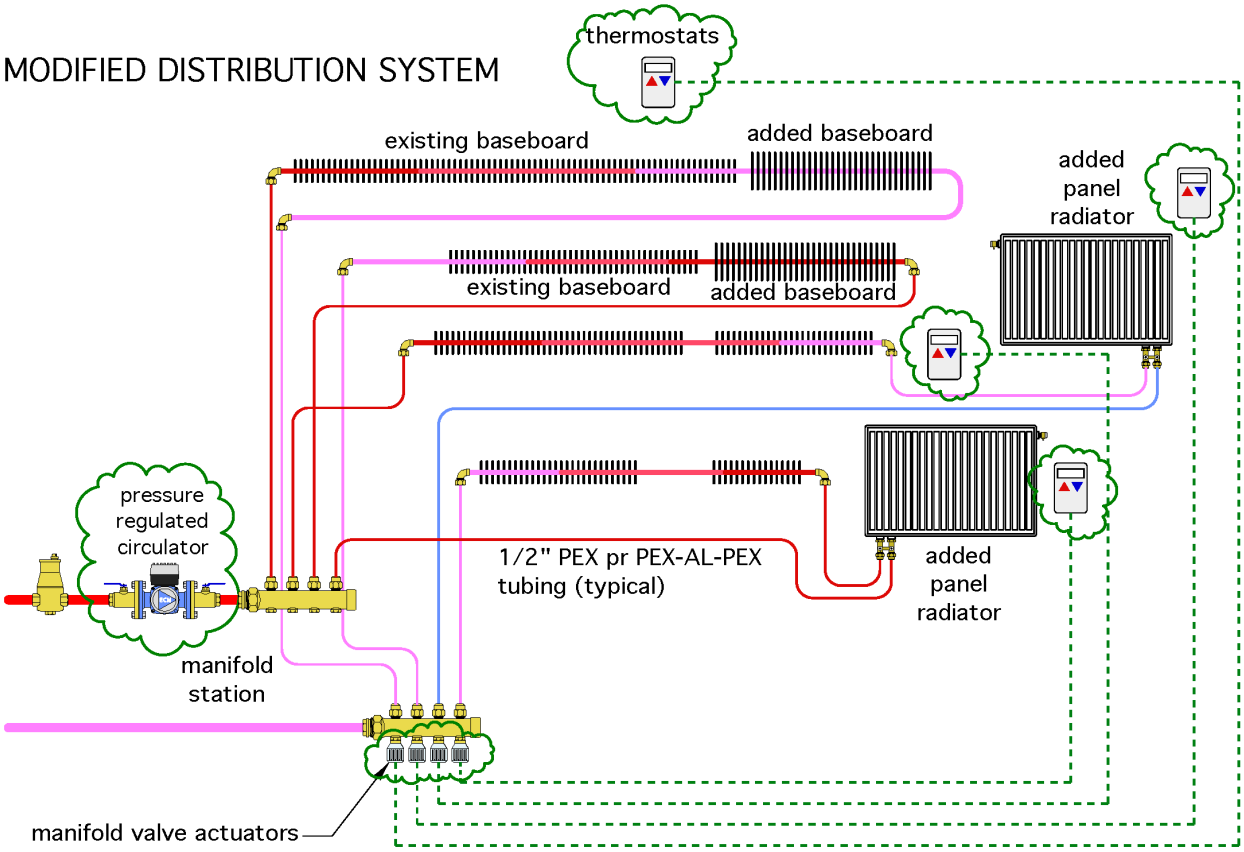
Figure 6-16 shows how the distribution system can be modified using thermostatic radiator valves to create a distribution system with four independently controlled zones. This adds flexibility for adjusting interior comfort conditions far beyond that of the original series-loop system.

Figure 6-16. Homerun distribution system using thermostatic radiator valves for zoning control



Another possibility is to install a low-voltage (24 VAC) manifold valve actuator on each circuit valve at the manifold station. These actuators are wired to four new thermostats, one for each zone. This option is shown in Figure 6-17.

Figure 6-17. Distribution system using low-voltage manifold valve actuators on each circuit



The systems shown in Figures 6-16 and 6-17 both use valves for zoning. In Figure 6-16, nonelectric thermostatic radiator valves are used. In Figure 6-17, low-voltage manifold actuators are attached to valves within the return manifold. In both cases, the original circulator has been replaced with a variable speed pressure regulated circulator. These circulators automatically adjust their speed and power input as the valves open, close, or modulate flow. This helps stabilize the differential pressure across the manifold station and helps maintain consistent flow rates within each zone circuit regardless of what other zones are operating.

6.14 Design Guidelines

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

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

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

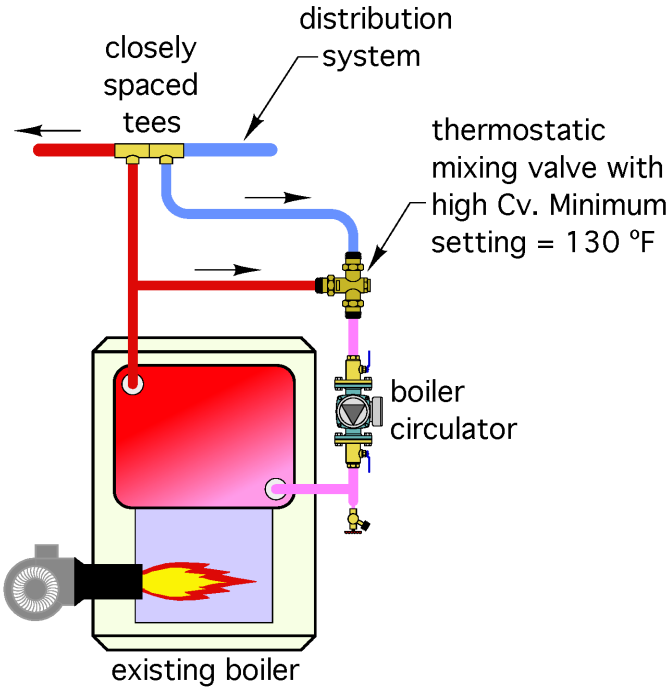
Always consider the benefit versus cost of creating new zones when modifying the existing system. For example, if two bedrooms are typically maintained at the same temperature, and the existing system has accomplished this, it's likely best to keep these two bedrooms together on the same zone after adding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

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

If the existing conventional boiler will be retained for use as a backup heat source for the low-temperature system, be sure the boiler is protected against sustained flue-gas condensation by installing a thermostatic mixing valve near the boiler, as shown in Figure 6-18.

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

Figure 6-18. Boiler protected against sustained flue-gas condensation by a thermostatic mixing valve



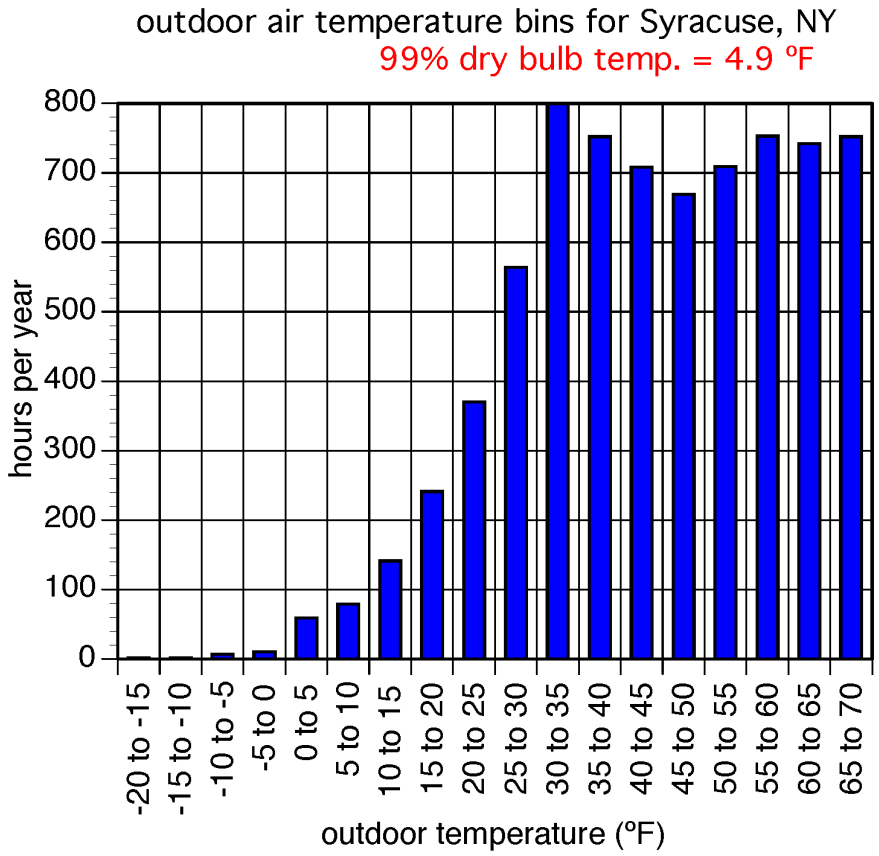
6.15 Outdoor Reset Control for Pellet Boiler Start Control

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

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

The graph in Figure 6-19 shows the frequency and range of outdoor temperature for a typical year in Syracuse, NY. Notice how many hours of partial load occur in comparison to the hours of design load, as defined by the 99% outdoor design temperature.

Figure 6-19. Frequency and range of outdoor temperature for a typical year in Syracuse, NY



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

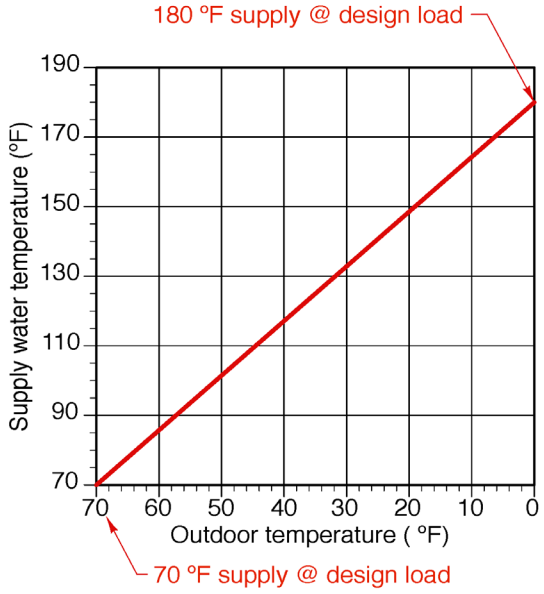
A second relationship that should also be considered is that the rate of heat output from any hydronic distribution system is approximately proportional to the difference between supply water temperature and room air temperature.

The supply water temperature to any hydronic distribution system can be reduced as the outdoor air temperature increases, while maintaining a stable indoor comfort temperature.

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

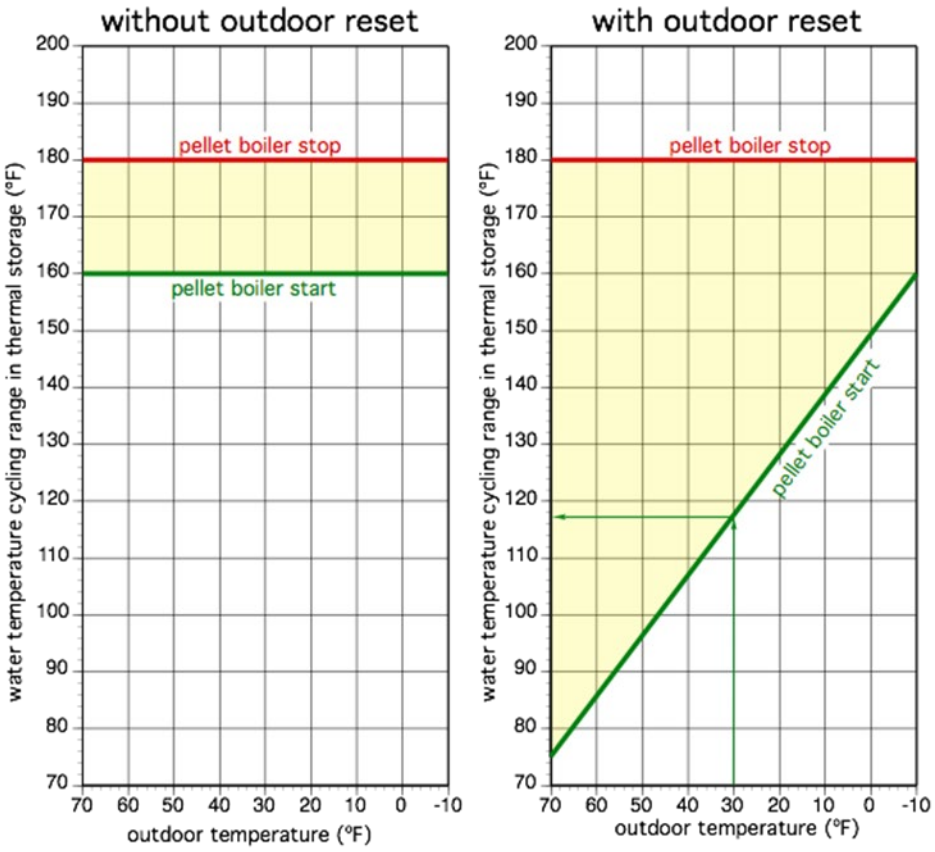
Figure 6-20 shows how the supply water temperature to a hydronic distribution system using standard finned-tube baseboard can be reduced, based on the current outdoor temperature. This graph assumes that the baseboard was sized to provide the design heating load of the building using a supply water temperature of 180°F.

Figure 6-20. Supply water temperature required versus outdoor temperature in a hydronic distribution system using standard finned-tube baseboard



Outdoor reset can be very useful in extending the temperature cycling range of thermal storage tanks used in biomass boiler systems under partial-load conditions. Figure 6-21 shows an example.

Figure 6-21. Comparison of water temperature cycling range in thermal storage based on systems with and without outdoor reset of the water temperature supplied to the heat emitters



The graph on the left represents a situation in which the pellet boiler starts as a sensor in the thermal storage tank drops to 160°F and continues to operate until the temperature at the sensor reaches 180°F. Neither of these temperatures change as the outdoor temperature changes.

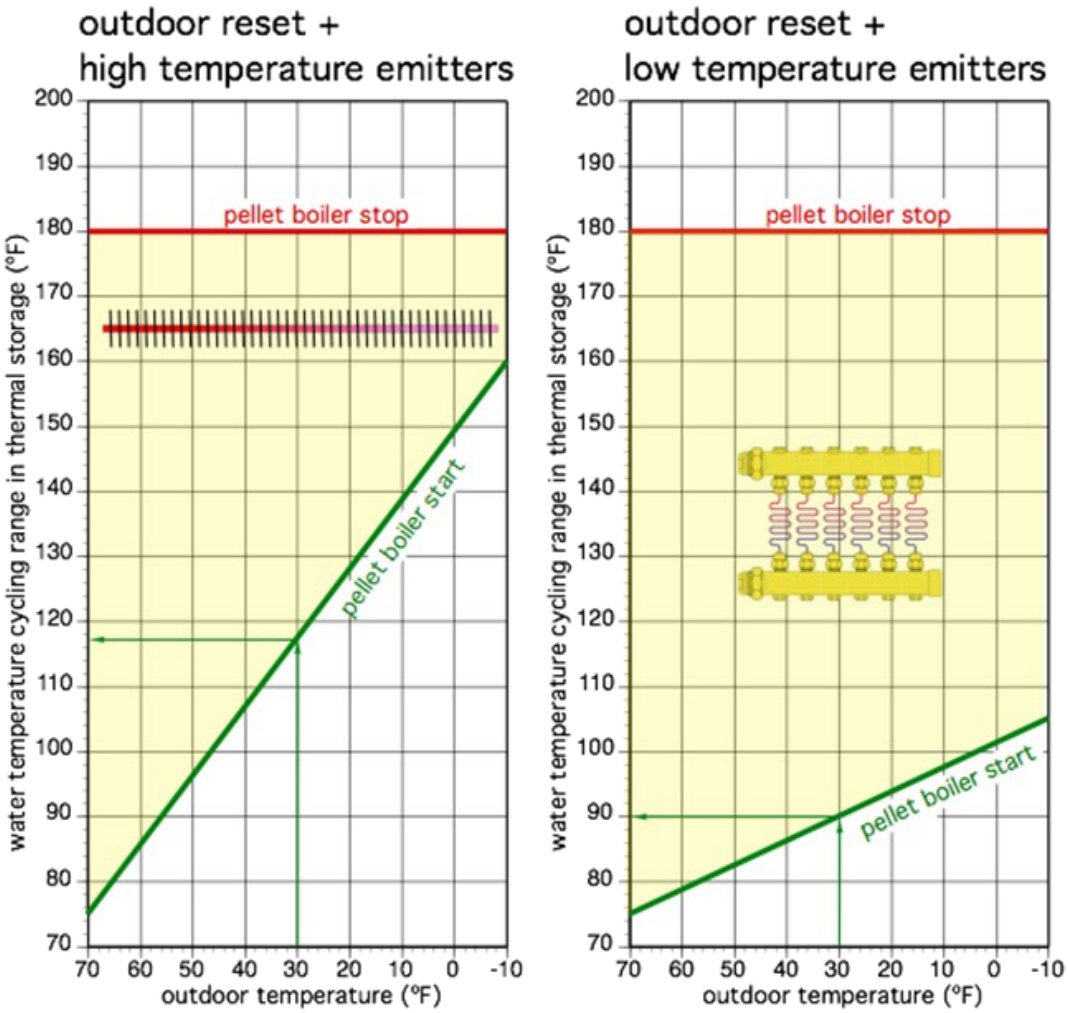
The graph on the right represents a situation in which the pellet boiler starts as the sensor in the tank drops to a calculated temperature based on outdoor reset, for example, when the outdoor temperature is 30°F, the calculated "boiler start" temperature is about 117°F (rather than 160°F). Once started the boiler continues to run until the sensor reaches the same high-temperature limit of 180°F. This scenario provides a wider temperature swing in thermal storage under partial-load conditions, while also maintaining stable indoor comfort.

The yellow shaded areas in Figure 6-21 indicate the relative utilization of the thermal storage available to the system. The graph on the right shows much better utilization. This leads to longer boiler operating cycles, higher thermal efficiency, and lower emissions.

Outdoor reset control is easy and inexpensive to implement. It is a very cost-effective strategy for improving the operation of pellet boiler systems connected to higher temperature distribution systems.

Figure 6-22 compares the thermal storage utilization concept between a high-temperature, finned-tube baseboard system using outdoor reset for the start criteria of a pellet boiler with that of a low-temperature heat emitter system also using outdoor reset for the boiler start criteria.

Figure 6-22. Comparison of thermal storage utilization between systems using high- and low-temperature heat emitters



Under design load conditions the high-temperature system starts the pellet boiler when the thermal storage temperature drops to 160°F. At the same outdoor temperature condition, the low-temperature system starts the pellet boiler when the tank temperature drops to 105°F. The low-temperature system provides a much wider temperature cycling range at design load conditions.

Both graphs show how outdoor reset is used to determine the pellet boiler start condition based on the outdoor temperature. At an outdoor temperature of 30°F, the high-temperature system starts the boiler when the tank temperature drops to 117°F. At the same outdoor temperature, the low-temperature system allows the tank temperature to drop to 90°F prior to starting the boiler. Again, the lower temperature distribution system provides a wider temperature cycling range and thus a greater utilization of thermal storage compared to the high-temperature system.

The concept of extending the utilization of thermal storage based on outdoor reset also applies to systems using cordwood gasification boilers. However, since the latter are manually started, outdoor reset can only provide an indication that heat input is needed from the boiler. The person tending the boiler would then have to load wood and start the fire.

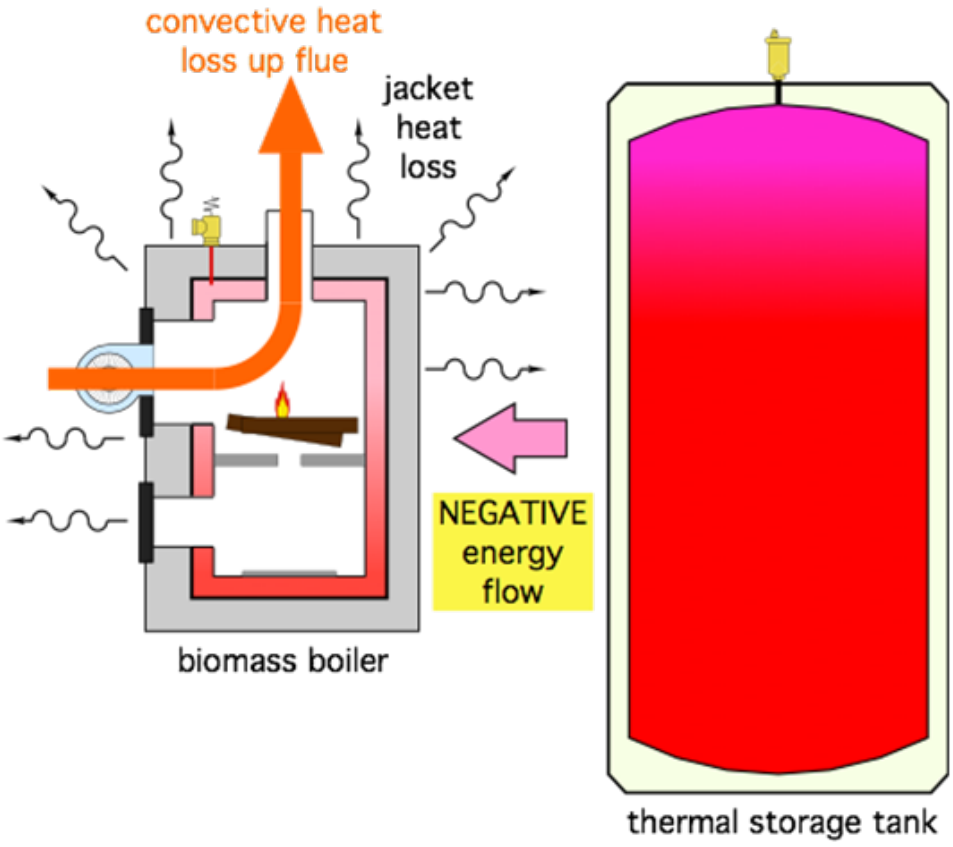
7 System Design Details

This section describes important design details that can make the difference between a system that provides optimal performance versus one that produces tolerable results. Many of these details have been developed based on experience with NYSERDA biomass-boiler research systems, as well as systems installed under NYSERDA biomass incentive programs. They are also based on state-of-the-art hydronics technology.

7.1 Preventing Negative Heat Flow from Storage to Boiler

Negative heat flow describes any unintentional heat flow from thermal storage to the biomass boiler. An example would be a system in which the boiler circulator operates continuously regardless of the boiler's firing status. When the boiler is not firing or has cooled to a temperature lower than that of the thermal storage tank, circulation between the tank and boiler allows the boiler and venting system to dissipate heat. Even the highest quality biomass boilers have far less insulation than a properly detailed thermal storage tank.

Figure 7-1. Negative heat flow



7.2 Boiler Circulator Control

Most biomass boilers have integral controllers that turn the boiler circulator on and off based on how the boiler manufacturer wants the circulator controlled. Some biomass boilers delay turning on the circulator until the boiler reaches a preset internal temperature.

The internal controller in some boilers might also keep the boiler circulator operating for a time during which the fuel load in the boiler is essentially burned out. This is called "post-purging" and is intended to scavenge heat from the thermal mass of the boiler and move it to thermal storage.

As a general guideline it is best to use the circulator control logic programmed into the boiler's internal controller whenever possible. However, there may be times when the boiler doesn't offer such control logic. In such cases, the circulator must be controlled based on some criteria developed by the system designer.

As a general guideline it is best to use the circulator control logic programmed into the boiler's internal controller whenever possible.

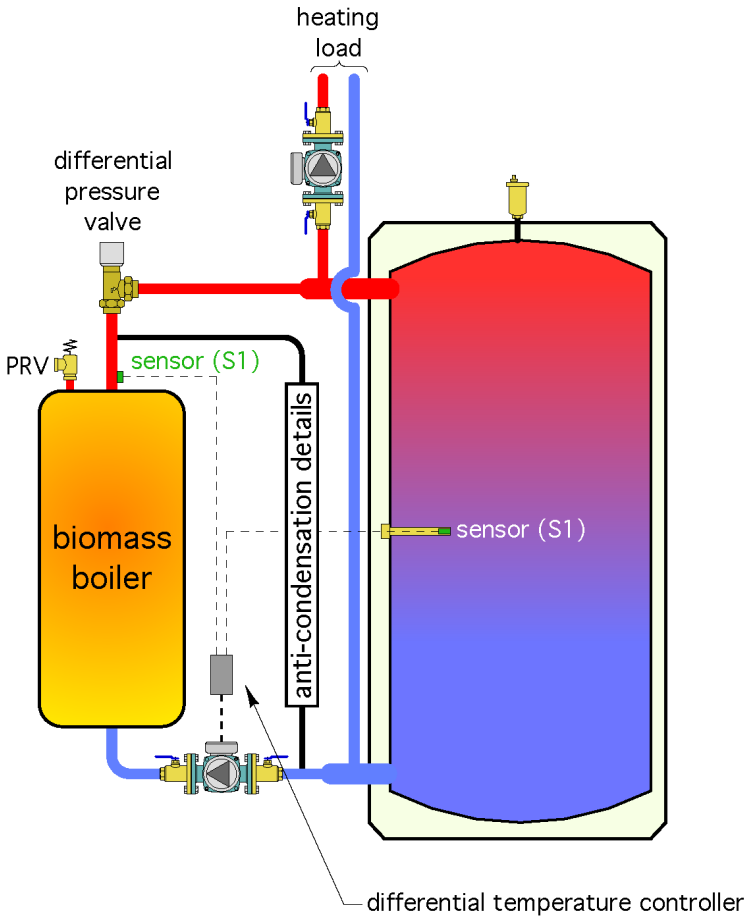
One such concept is differential temperature control. The boiler circulator is operated when the temperature at the outlet of the boiler is some user-set differential above the temperature measured in the thermal storage tank. Consider the system shown in Figure 7-2.

A standard differential temperature controller, such as used in solar thermal systems, compares the temperature at sensor S1 on the outlet of the boiler to the temperature sensor S2 at the mid-height of the thermal storage tank.

This controller would turn the boiler circulator on when the temperature at sensor S1 is higher than the temperature at sensor S2 by some user-set differential designated as ΔT_{on}. For example, if ΔT_{on} was set at 10°F and the temperature at the mid-height of the tank was 140°F, the boiler circulator would only operate when the boiler outlet temperature was 150°F or higher.

Once turned on, the circulator continues to operate until the temperature at sensor S1 drops to within some user-set differential designated as ΔT_{off} above the temperature at sensor S2. For example, if ΔT_{off} was set for 4°F, and the temperature at sensor S2 was 160°F, the boiler circulator would remain on until the boiler outlet temperature dropped to or below 164°F.

Figure 7-2. System using differential temperature controller to operate the boiler circulator when boiler temperature is higher than thermal storage temperature



Most modern differential temperature controllers allow the values for ΔT_{on} and ΔT_{off} to be adjusted over a wide range. Some also allow setting a minimum "on" temperature at the heat source temperature sensor (S1), and a maximum storage temperature at sensor S2. If the minimum "on" temperature is not established the circulator will not turn on regardless of the temperature difference between the two sensors. If the storage sensor S2 is above the maximum setting, the boiler circulator will not run regardless of the temperature difference between the sensors.

Designers need to assess the nature of the system in setting these control parameters. They should also consider how the differential temperature control concept would interact with other controllers in the system, such as boiler anti-condensation controllers (to be discussed), manual reset high-limit controllers (required by code on some hydronic systems), and the high-limit temperature setting on the boiler's internal controller.

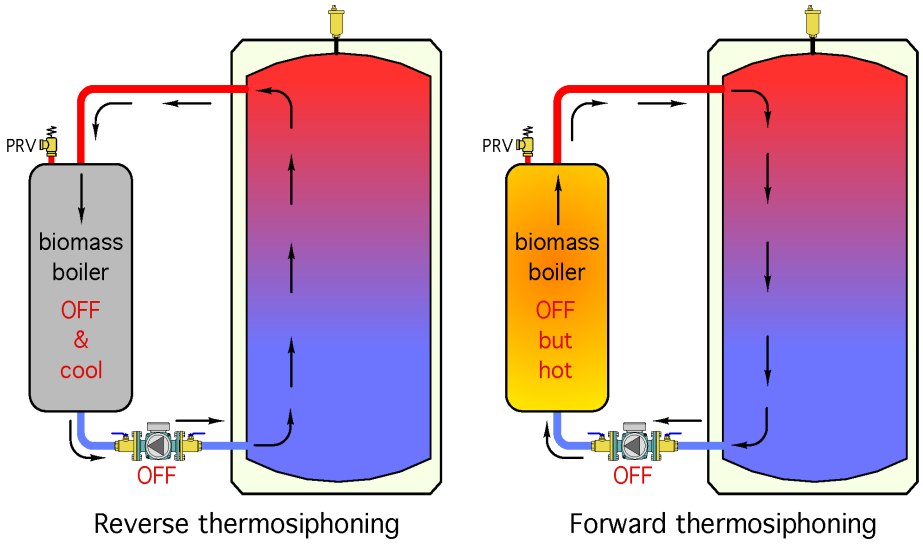
In all cases, it's imperative that the boiler circulator not be wired to operate continuously regardless of the boiler's firing status. Doing so will waste a substantial portion of the heat produced through piping heat loss, boiler jacket heat loss, and convective air currents in warm chimneys that draw surrounding air though the boiler's combustion chamber.

7.3 Thermosiphoning

Any hydronic circuit containing a source of heated water, a closed piping circuit with some vertical piping, and no "blockage" in that circuit will develop thermosiphon flow. This flow is caused by the lower density of hot water compared to cooler water. As water cools within a circuit its density increases relative to that of hot water in the thermal storage tank. The higher density cooler water attempts to move downward in the circuit, while the warmer water attempts to move upward. If there is nothing to prevent this movement a slow but persistent thermosiphon flow will develop in the circuit. This flow results in heat loss from piping or other components.

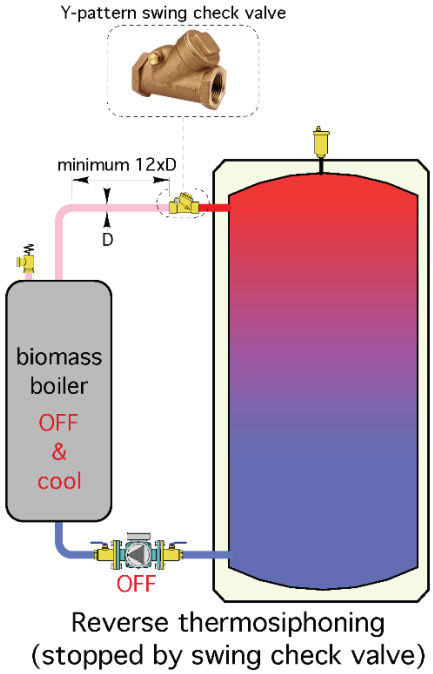
When thermosiphon flow is from thermal storage back through the boiler it is called "reverse thermosiphoning." When thermosiphon flow is from the boiler to the tank it is called "forward thermosiphoning." The latter is sometimes desirable because it can move heat from the boiler into thermal storage during a power outage. Figure 7-3 shows both concepts.

Figure 7-3. Examples of reverse and forward thermosiphoning



Reverse thermosiphoning can be stopped by installing a high-quality swing check valve in the piping near the upper tank connection. A "Y-patten" swing check valve, as shown in Figure 7-4, is recommended over swing check valves with vertical discs. The latter have, at times, demonstrated an inability to block reverse thermosiphon flow due to a slight gap between the valve's internal disc and its seat.

Figure 7-4. Placement of a Y pattern swing check valve to prevent reverse thermosiphoning



Swing check valves have minimal forward opening resistance. This is desirable because it allows them to pass forward thermosiphon flow, such as would develop if a power outage occurred and the boiler circulator was turned off while there was still wood burning in the boiler. This forward thermosiphoning is especially desirable in systems with cordwood gasification boilers due to the potentially high-residual fuel load in the combustion chamber when a power outage occurs.

Swing check valves should only be installed with their bonnet in an upright position, in a horizontal pipe, and with a minimum of 12 diameters of straight pipe upstream of the valve. The latter helps reduce turbulence that can cause the disc in some check valves to rattle.

Swing check valves are a good option to prevent reverse thermosiphoning in systems using four-pipe buffer tanks. Never use a spring-loaded check valve as a substitute for a swing check valve in situations where forward thermosiphon flow must occur. The forward opening resistance of the spring-loaded check could prevent forward thermosiphoning.

Reverse thermosiphoning can also be prevented using other hardware options, including a ΔP valve, motorized ball valve, or properly controlled three-way motorized mixing valve. These options, which are useful in two-pipe thermal storage tank configurations, can be seen in Figures 5-19, 5-21, and 5-22. All these methods also prevent forward thermosiphoning. When forward thermosiphoning is deemed necessary to dissipate residual heat from a biomass boiler during a power failure, other details and steps will be necessary to allow forward thermosiphoning to occur, which will be discussed later in this section.

7.4 Boiler Anti-condensation Protection

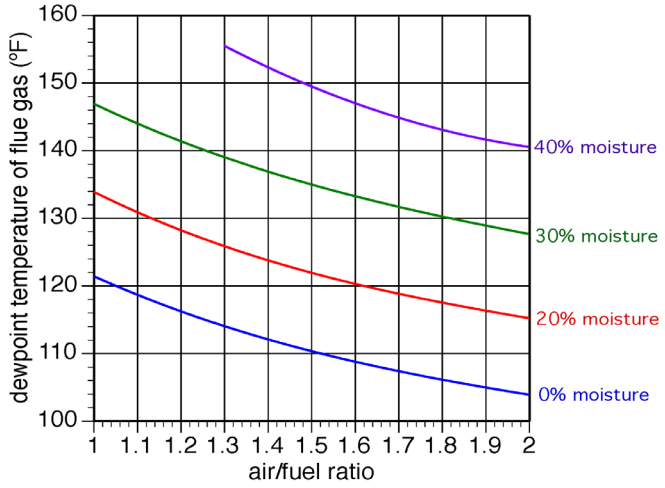
All boilers that burn hydrocarbon fuels (which includes wood) produce superheated water vapor as a byproduct of combustion. If the surfaces of the boiler's heat exchanger, flue vent piping, and chimney are sufficiently warm, the water remains in vapor form as it travels from the combustion chamber to the top of the chimney, where it's released to the atmosphere. As a vapor water does not corrode ferrous metal surfaces such as the steel-fire tubes in the boiler's heat exchanger, or steel vent connector pipe. However, if any of these surfaces are cool enough (e.g., below the dewpoint of the water vapor) condensation will occur on those surfaces. The resulting liquid can be very damaging to steel or iron components.

All boilers and flue-gas venting systems experience some amount of flue-gas condensation during cold start conditions, when the boiler's heat exchanger and venting system are well below the dewpoint of the water vapor in the exhaust stream. If the surfaces exposed to the flue gases quickly rise above the dewpoint temperature, any initial condensate quickly evaporates without causing any significant deterioration of ferrous metal surfaces. This phenomenon is called "intermittent flue-gas condensation" and it generally is of no concern.

However, if the surfaces exposed to the flue gases remain below the dewpoint for extended periods, perhaps even several hours in some systems, the situation is called "sustained flue-gas condensation." This is a situation that must be avoided to ensure safe operation and long service life.

The dewpoint temperature at which flue-gas condensation occurs depends on the moisture content of the wood as we all as the amount of air passing through the combustion chamber. Figure 7-5 shows the relationship.

Figure 7-5. Relationship between dewpoint temperature of the flue-gas (°F), moisture content of wood, and the air/fuel ratio



The air/fuel ratio is the ratio of the amount of air supplied to the combustion process divided by the "stoichiometric" minimum amount of air needed to completely burn the fuel. Supplying excess air to the combustion process creates a drying effect that lowers the dewpoint of the flue gases. However, as more air is supplied more heat is carried away in the exhaust stream.

The higher the moisture content of the firewood, the higher the dewpoint of the flue gases. Properly seasoned firewood should have a moisture content no higher than 20%. Lower flue-gas dewpoint temperatures are desirable because they allow the boiler to operate with lower jacket heat losses and higher thermal efficiency. Typical air fuel ratios used in wood-fired biomass boilers range from 1.2 to 1.6. A cordwood gasification boiler burning 20% moisture content wood at an air/fuel ratio of 1.3 would produce a flue-gas stream with a dewpoint temperature of approximately 126°F.

Flue-gas condensation is also partially determined by the design of the boiler's heat exchanger. Smaller heat exchangers that extract less heat from the combustion gases are less likely to experience flue-gas condensation relative to larger heat exchangers that extract more heat. Obviously, there's a tradeoff between extracting as much heat from the combustion process as possible, and thus increasing the thermal efficiency of the boiler, while at the same time avoiding sustained flue-gas condensation.

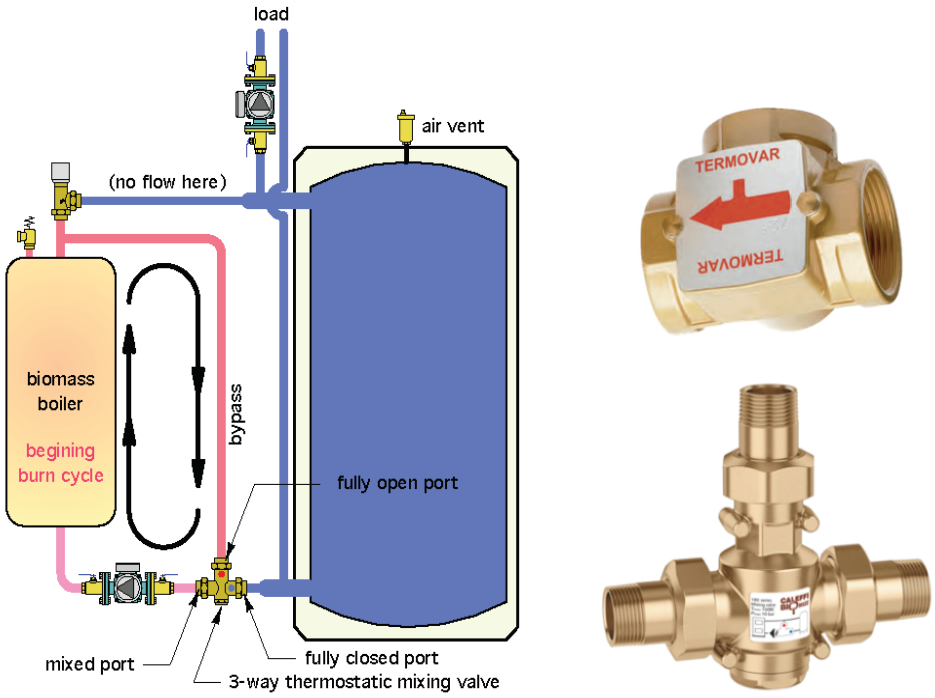
System designers are not able to alter the boiler's heat exchanger (with the exception of adjusting internal baffles on some boilers). However, they can influence the conditions at which the boiler operates. By taking steps to keep the boiler's inlet water temperature some margin above the dewpoint of the flue gases whenever possible, designers can minimize flue-gas condensation.

7.5 Anti-condensation Options

There are several ways to design systems that measure and react to boiler inlet water temperature to prevent sustained flue-gas condensation. In previous discussions these hardware options were simply represented by piping and a box labelled "anti-condensation details." They will now be examined in detail.

One approach uses a high-flow capacity (e.g., high Cv) thermostatic mixing valve between the boiler and thermal storage tank. This valve blends heated water from the boiler with cooler water returning from the load or thermal storage tank. The objective is to keep the water temperature entering the boiler above a minimum value, which is determined by the valve's setting. Figure 7-6 shows two examples of these valves and how they are placed in the system.

Figure 7-6. Use of a high-capacity thermostatic mixing valve between the boiler and the thermal storage tank to prevent sustained flue gas condensation, shown in full bypass mode



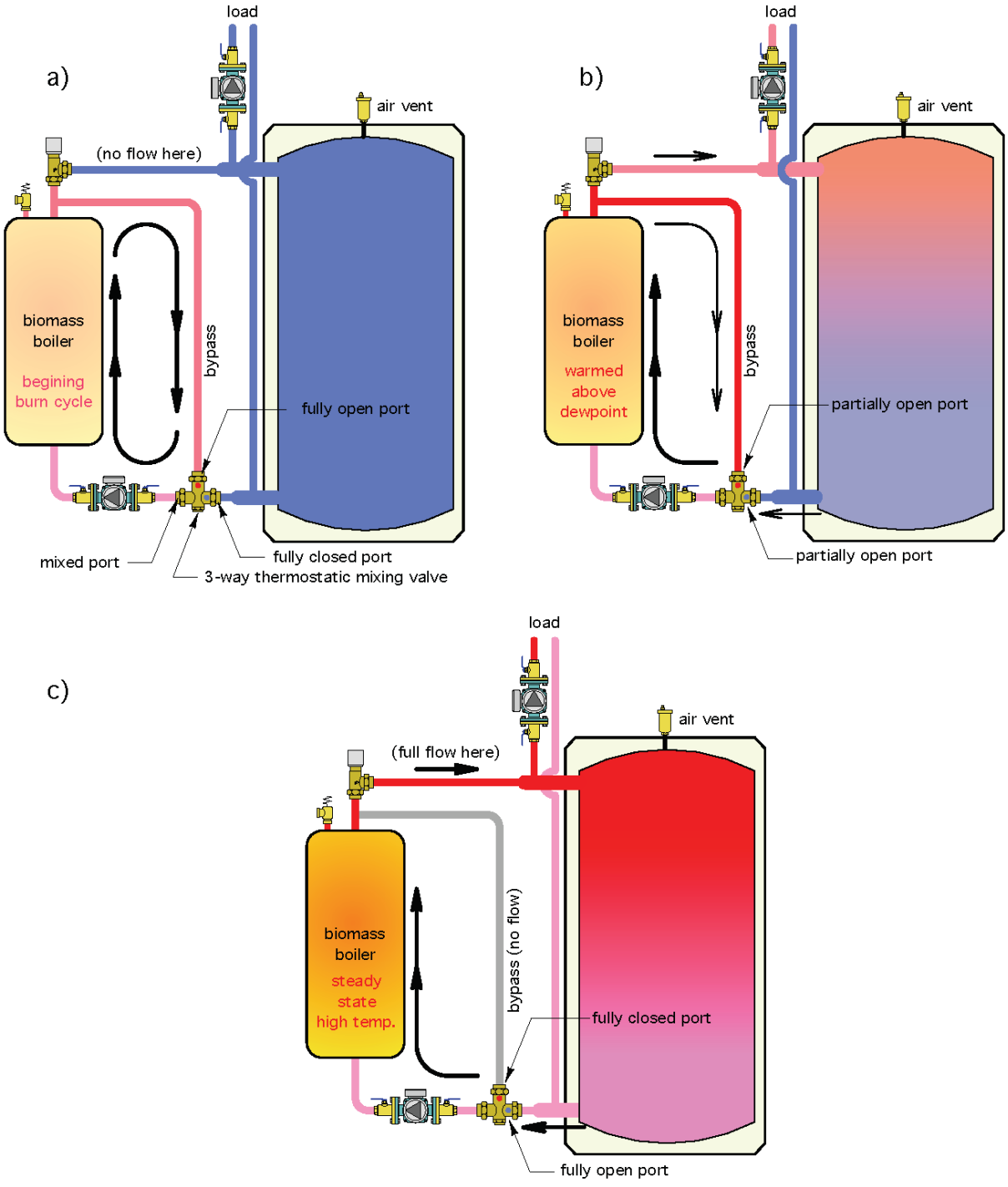
The mixing valve and bypass piping are installed between the biomass boiler and thermal storage tank. The boiler circulator must be installed between the mixing valve and the boiler, as shown in Figure 7-6.

When the boiler is cold fired, its water and metal content are well below the dewpoint of the flue gases. It's imperative to get the boiler up to temperature as quickly as possible to avoid sustained flue-gas condensation. Under this condition the "cold" port of the mixing valve is fully closed, and the bypass port is fully open. This forces water leaving the boiler to move through the bypass pipe through the mixing valve and back into the boiler. Minimal heat is dissipated from the water as it recirculates in this short piping circuit, which allows the boiler to warm up as quickly as possible.

As the water temperature leaving the mixing valve climbs above the valve's setting, the cold port begins to open as the bypass port begins to close. This allows some flow leaving the boiler to go to the load or thermal storage tank. An equal flow of cooler water from the load or thermal storage tank flows back into the cool port of the mixing valve where it blends with heated water coming down the bypass pipe.

When the water temperature leaving the valve is several degrees warmer than the valve's calibrated temperature (10°C or 18°F is common), the cold port of the mixing valve is fully open, and the bypass port is fully closed. All flow leaving the boiler now goes to the load or thermal storage tank, and all flow returning from the load or thermal storage tank goes directly into the boiler. There is no mixing under this condition. Figure 7-7 shows the described sequence.

Figure 7-7. Sequence showing the changes in water flows as boiler water temperature increases



This process works in reverse as the boiler's heat production rate decreases. The objective remains the same—to keep the boiler's inlet temperature warm enough to prevent sustained flue-gas condensation.

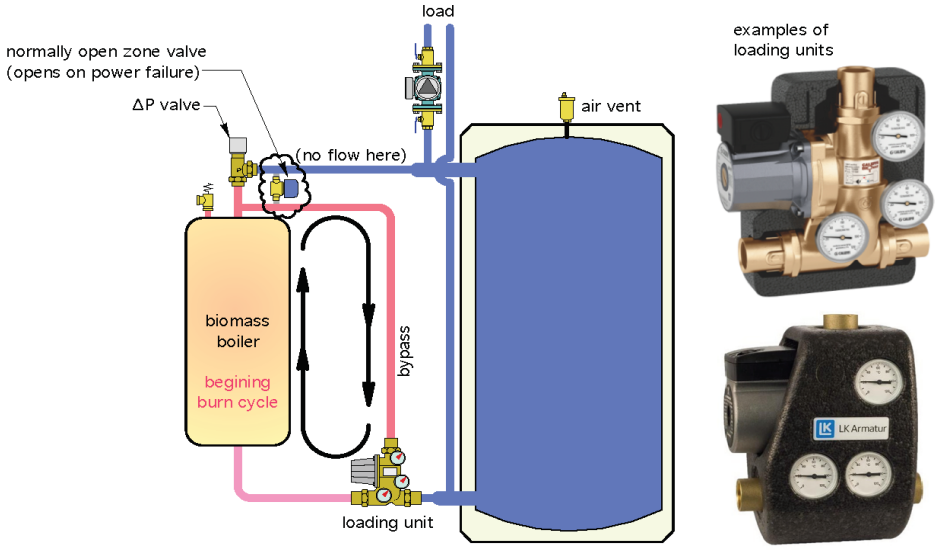
Some thermostatic mixing valves used in domestic water heating systems have adjustment knobs; however, the thermostatic mixing valves intended for this application do not. Instead, they are ordered with a specific actuating temperature setting at which the thermostatic element begins opening the valve's cold port. Common settings are 115°F, 130°F, 140°F, and 160°F. The only way to change the valve's actuating temperature is by changing the internal thermostatic cartridge.

Thermostatic mixing valves with low Cv values in the range of 2.5 to 9, which are intended for tempering domestic hot water, should not be used for boiler protection.

It's also important to understand that these valves are designed to handle the flow rates typical of residential and light commercial biomass boiler systems. Valves are typically available to fit pipe sizes of 1, 1.25, 1.5, and 2 inches. The smaller valves have Cv values (e.g., flow rate in gpm that creates 1 psi pressure drop through valve) of about 10. Larger valves have higher Cv values. Thermostatic mixing valves with low Cv values in the range of 2.5 to 9, which are intended for tempering domestic hot water, should not be used for boiler protection.

Another hardware option for anti-condensation control is called a loading unit. It combines the function of the high-flow capacity, three-way thermostatic valves just discussed with a circulator and a special check valve that allows forward thermosiphon flow between the boiler and thermal storage tank during a power outage. Figure 7-8 shows two examples of loading units and how they are installed between the boiler and thermal storage tank.

Figure 7-8. Loading unit installed between biomass boiler and thermal storage tank, and examples of loading units available in North America

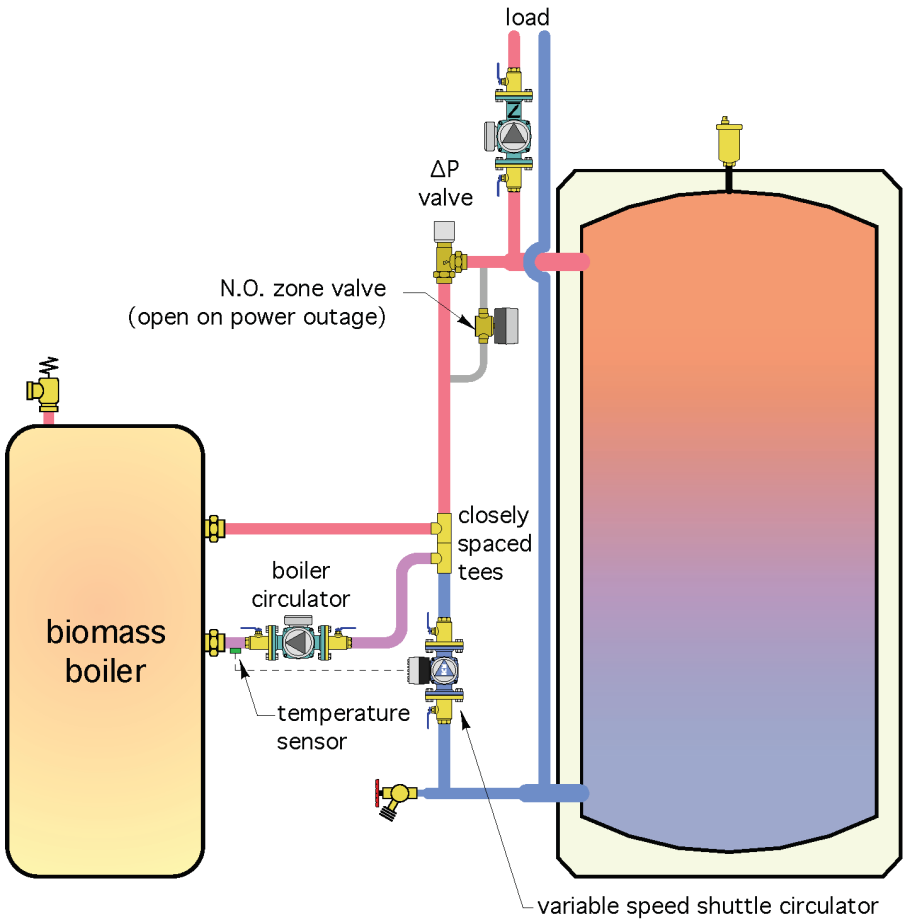


Loading units provide the same type of anti-condensation control as the previously described thermostatic mixing valve. They speed installation by combining the circulator and mixing valve into one assembly. They are also purchased with a specific actuating temperature setting. The actuating temperature can be changed by changing the thermostatic cartridge within the loading unit.

Loading units also provide an internal check valve that is closed during normal operation but opens when the boiler circulator is off. This check valve allows forward thermosiphon flow between the boiler and thermal storage tank during a power outage. For this check valve to operate properly there must be an unblocked circuit between the boiler and thermal storage tank. If a ΔP valve is used, there must be a normally open zone valve installed to provide a "detour" around the ΔP valve during a power outage (see Figure 7-8).

Another anti-condensation control method is based on a variable speed "shuttle" circulator that measures the boiler inlet temperature and responds by changing speed to hold that temperature as close to a setpoint as possible. The piping for this approach is shown in figure 7-9.

Figure 7-9. Piping for using a variable speed shuttle circulator for boiler anti-condensation control



The boiler circuit consists of a short piping loop containing a fixed speed circulator. The tank circuit is another short piping assembly containing the variable speed shuttle circulator, ΔP valve, and a normally open zone valve. The boiler circuit and tank circuit are coupled with a pair of closely spaced tees that hydraulically separate the boiler circulator from the variable speed shuttle circulator.

There are several techniques that allow biomass boilers to safely deal with power outages.

The boiler circulator runs whenever the boiler is called to operate. However, because of the closely spaced tees, the boiler circulator cannot induce flow in the tank circuit.

When the boiler inlet temperature is below the dewpoint setting for the variable speed circulator that circulator is either off or operating at a low speed. In either case, the forward opening resistance of the ΔP valve prevents flow in the tank circuit under this condition. Water leaving the boiler makes a U-turn at the closely spaced tees and flows back into the boiler. There is minimal heat loss from the boiler circuit, which allows the boiler to climb above the dewpoint temperature of the flue gases as quickly as possible.

Once the boiler inlet temperature climbs above the minimum inlet temperature setting, the shuttle circulator begins to speed up. As soon as the circulator reaches a speed sufficient to open the ΔP valve (typically set at 1 to 2 psi) flow occurs in the tank loop. This carries heat from the boiler to either the load (if operating) or the thermal storage tank or both. When the boiler inlet temperature is several degrees above the minimum setting, the shuttle circulator runs at full speed. If the boiler inlet temperature decreases, such as when the fire in a cordwood gasification boiler burns out, the shuttle circulator slows down as necessary to maintain a boiler inlet temperature high enough to prevent sustained flue gas condensation.

The normally open zone valve in Figure 7-9 opens during a power failure to allow forward thermosiphoning between the boiler and thermal storage tank. This is necessary due to the forward opening resistance of the ΔP valve. Be sure that all internal check valves are removed from the circulators.

There are some commercially available variable speed circulators with built-in temperature setpoint capabilities. Another possibility is to combine a variable speed circulator that is equipped with either a 0-10 volt or 4-20 mA analog input for speed control with a temperature controller that can output either of these control signals. This allows the concept shown in Figure 7-9 to be scaled for larger systems.

7.6 Boiler Over-Temperature Protection

When boilers operating on conventional fuels experience a power outage they immediately stop producing heat. This is not the case with biomass boilers, which usually have residual fuel (e.g., pellets or cordwood) burning in their combustion chamber when the power outage occurs.

There are several techniques that allow biomass boilers to safely deal with power outages. One is to provide on-site emergency backup power from an automatically started generator or a properly sized uninterruptible power supply (UPS). The latter device draws DC power from one or more batteries and converts it to AC power through an inverter. When a power outage occurs the UPS instantly switches to battery power.

If a UPS is used to protect a cordwood gasification boiler from overheating it should be sized to operate the boiler circulator for at least 30 minutes. Larger UPS units could be used to operate the boiler's blower and circulator. If the intent is to operate the cordwood gasification boiler as normal during a power outage, the UPS should be capable of operating the boiler and boiler circulator for a minimum of 4 hours to ensure that a full charge of wood can be consumed before the UPS battery is discharged to the point where it can no longer supply power.

A UPS can also be used to provide uninterrupted power to a pellet boiler during a momentary power outage. When a backup generator is present to power the pellet boiler during a prolonged outage, a UPS installed between the pellet boiler and generator can prevent the boiler from going into a prolonged burnout cycle, which might otherwise occur during the time required to start the backup generator and bring it online. Be sure that a UPS used in this manner is compatible with the power quality produced by the backup generator.

It's also possible to protect cordwood gasification boilers using a passive heat dump. This approach uses an array of fin-tube piping as the heat emitter. Multiple finned-tubes are assembled in a parallel, reverse-return piping array as seen in Figures 7-10 and 7-11.

Figure 7-10. Using a passive heat dump to protect against overheating during a power outage

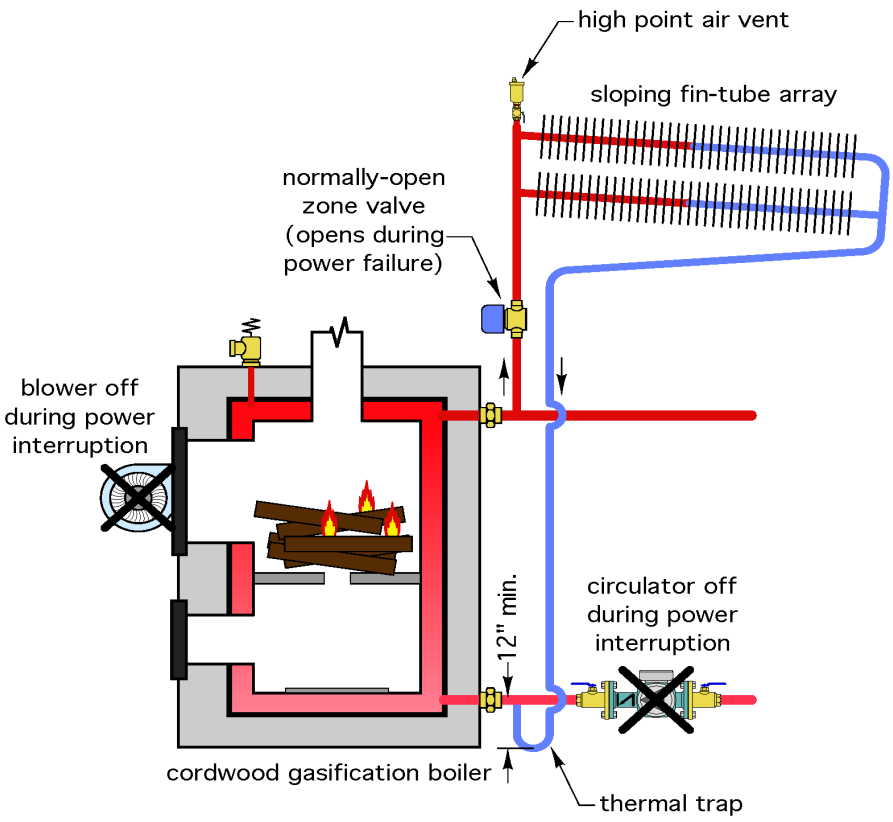


Figure 7-11. Finned-tube array above a cordwood gasification boiler as part of a passive heat dump

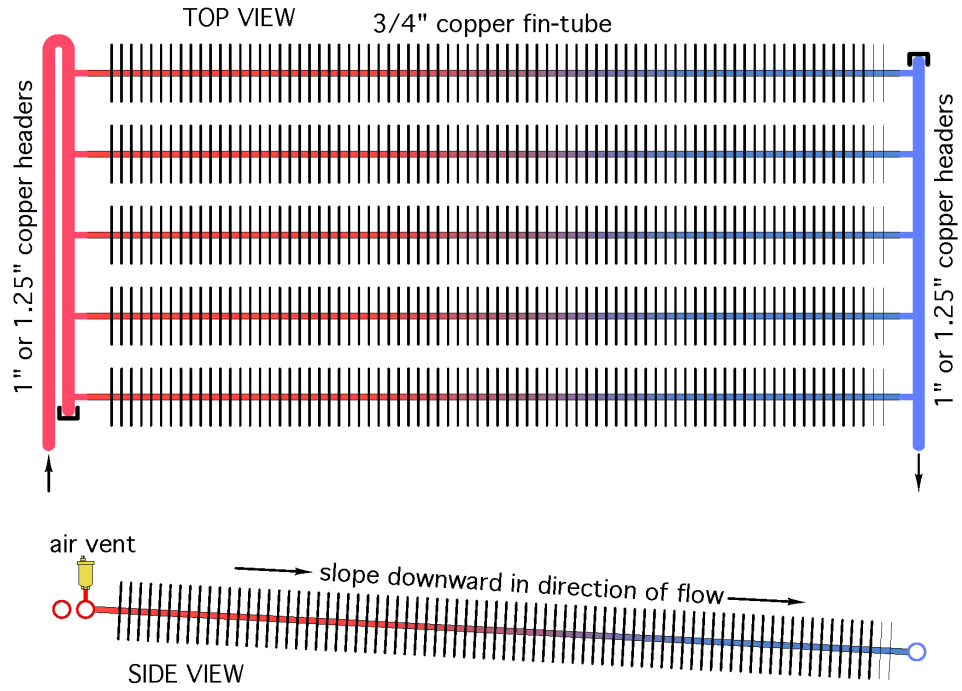


The finned-tube array is installed above the boiler and connected to the boiler's supply and return piping. A normally open zone valve (e.g., a valve open when not powered) is installed between the boiler supply pipe and the fin-tube array. This valve remains closed whenever electrical power is available to the system and thus blocks heat flow through the heat dump under normal conditions. When electrical power is lost the valve opens, allowing hot water from the boiler to thermosiphon though the fin-tube array and dissipate heat. An underslung thermal trap at least 12 inches deep is used on the piping connecting the fin-tube assembly to the boiler's inlet piping. Its purpose is to minimize heat transfer from the boiler return piping to the heat dump piping during normal operation. The fin-tube array should have a slight downward slope in the direction of flow to allow air removal at the high point through a valve or float-operated vent.

The normally open zone valve used for a passive heat dump should use a spring mechanism that ensures it will fully open on loss of power. The valve's operation should also be periodically tested by interrupting power and observing the valve's response. A manual test switch (spring loaded, normally closed contacts) should be installed to allow simple periodic testing of the valve.

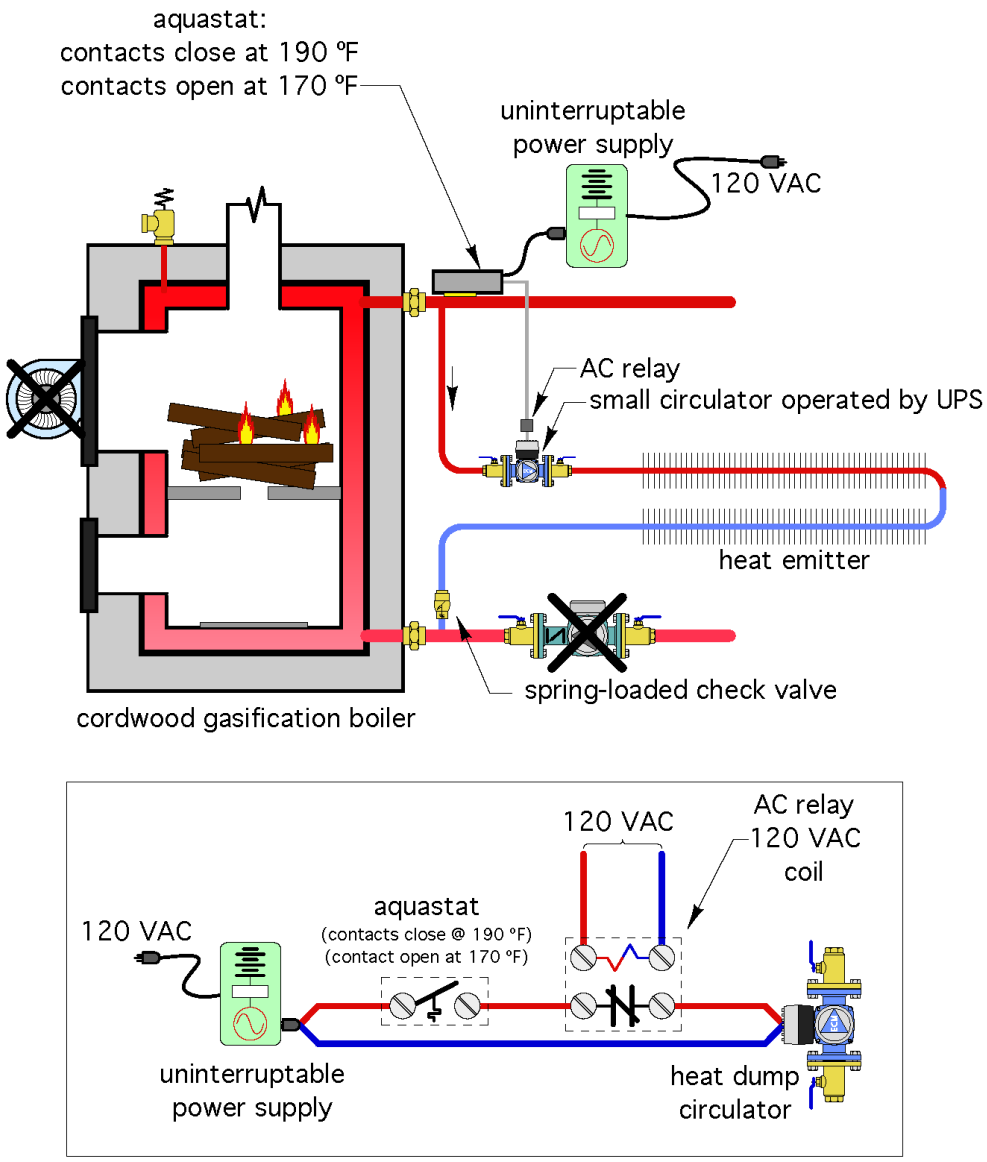
A suggested sizing guideline is to provide sufficient fin-tube length to dissipate 10% of the boiler's full-rated heat output based on a dissipation rate of 300 Btu/hr/ft of fin-tube. This assumes that the fin-tube is the same as used in typical residential baseboard convectors. The fin-tube should be piped in parallel segments with reverse-return piping, as shown in Figure 7-12.

Figure 7-12. Parallel segments of finned-tube with reverse return piping



It's also possible to create a *powered* heat dump in which flow is created by a small circulator powered by an uninterruptible power supply. This is different from the use of a UPS to keep the boiler and boiler circulator operating as normal. The concept is shown in Figure 7-13.

Figure 7-13. Powered heat dump using a small circulator operated by an uninterruptible power supply during a utility power outage



Note that an aquastat is installed on the piping near the boiler outlet. Its electrical contacts close whenever the boiler outlet temperature is at or above a value at which heat dissipation during a power outage should be in effect. These contacts open at a lower temperature where heat dissipation is not necessary. The aquastat limits heat dump operation to situations where the boiler is at an elevated temperature, and thus conserves battery power within the uninterruptible power supply.

Line voltage is passed from the closed contacts of the aquastat to the normal closed contacts of a relay with a 120 VAC coil. The relay contacts would remain open whenever utility-supplied electrical power is available and immediately close when it is not. This prevents the heat dump circulator from operating when utility power is available.

Small circulators with electronically commutated motors are available that operate with input power requirements of 10-40 watts and are well suited to this application.

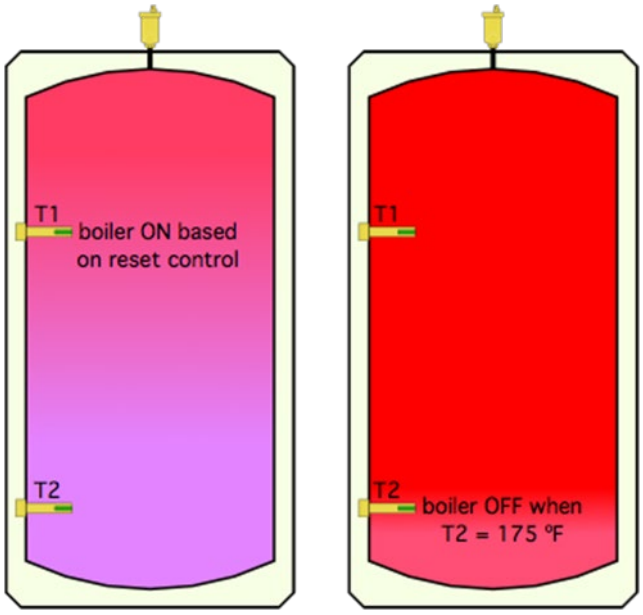
The uninterruptible power supply should be capable of operating the heat dump circulator for at least 30 minutes. The battery in the uninterruptible power supply should also be periodically tested to ensure it maintains adequate charge to operate the circulator for at least 30 minutes. When a circulator is used to operate the heat dump, the heat emitters do not necessarily have to be above the boiler.

7.7 Implementing Outdoor Reset Control for Pellet Boiler Control

The concept of using outdoor reset control was described previously. The discussion that follows provides details on how to implement that concept using specific hardware.

Figure 7-14 shows a thermal storage tank with two temperature sensors, one in the upper and the other in the lower portion of the tank.

Figure 7-14. A thermal storage tank with two temperature sensors when the pellet boiler is first turned on (left) and at end of charging cycle (right)

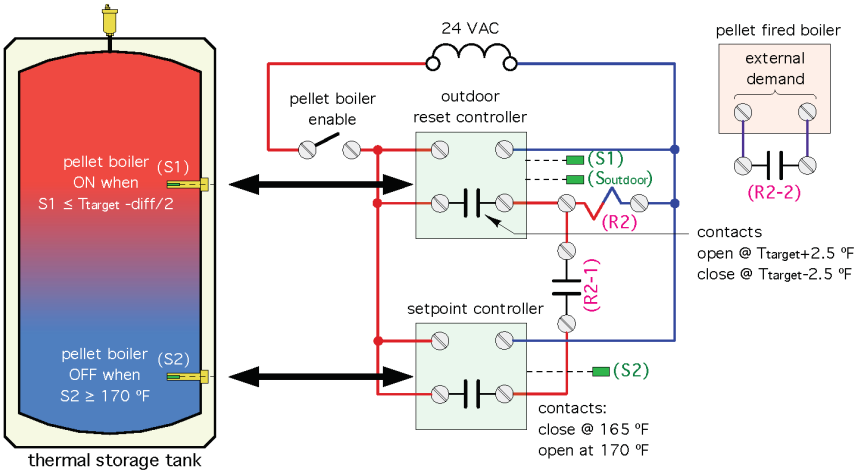


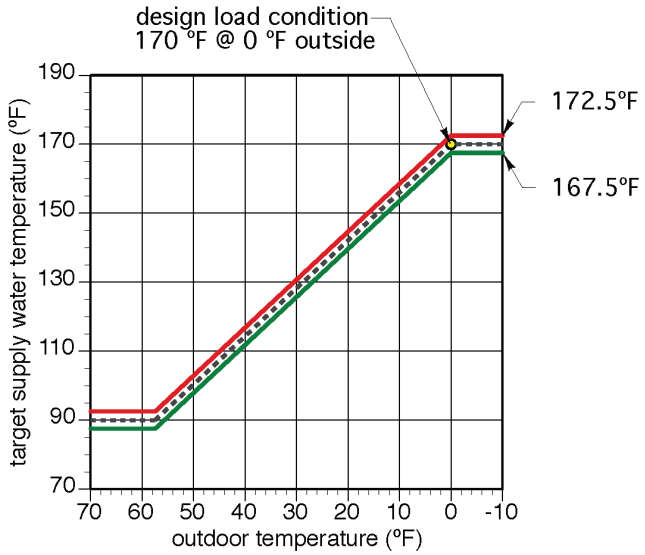
The upper sensor is used to turn the pellet boiler on when the temperature at that sensor drops to or below some “target” temperature that is continually calculated by the outdoor reset controller based on the outdoor air temperature.

The lower sensor is used to turn the boiler off when it reaches some user-set temperature limit, such as 175°F.

This combination of sensors and control strategy allows the upper portion of the thermal storage tank to reach the lowest temperature at which it can still maintain building comfort before the pellet boiler is turned on. It also allows the tank to be “fully charged” with heat before the boiler is turned off. This provides excellent temperature cycling and long boiler operating cycles. The electrical schematic in Figure 7-15 shows one way to implement this control strategy.

Figure 7-15. Electrical schematic for the two-sensor method of turning a pellet boiler on and off. Graph shows water temperature at upper tank sensor at which pellet boiler turns on.





The electrical circuit shown in Figure 7-15 has two controllers powered by 24 VAC, supplied from the secondary winding of a standard control transformer. The pellet-boiler enabled switch must be closed to provide 24 VAC power to these controllers. That switch is typically closed at the beginning of the heating season and opened at the end of the season. It should not be confused with a thermostat that closes whenever there is a heating demand in the building.

The differential setting determines the difference in temperature between when the electrical contacts in the controller are open and close.

When powered on by 24 VAC, the outdoor reset controller measures the current outdoor temperature and uses that temperature along with its settings to calculate the lowest water temperature that could supply the building's heating load. That temperature is called the "target" water temperature.

The outdoor reset controller closes its normally open electrical contacts when the temperature at the upper tank sensor S1 is at or below the target temperature, minus one half the controller's differential setting. The differential setting determines the difference in temperature between when the electrical contacts in the controller are open and close. On many (but not all) controllers, the differential is "centered" on the target temperature. For example, if the current target temperature was 143°F and the controller's differential setting was 10°F, the contacts would close at 143-(10/2) = 138°F and open at 143+(10/2)=148°F. If the target temperature changed to 125°F, the contacts would close when the sensor temperature was at or below 120°F, and open when the sensor temperature was at or above 130°F (assuming the differential setting was not changed).

The assumed differential setting for the graph in Figure 7-15 is 5°F. The green line indicates the water temperature at sensor S1 that would cause the electrical contacts in the outdoor reset controller to close. For example, when the outdoor temperature is 0°F, the calculated target supply water temperature is 170°F. When the temperature at the upper tank sensor (S1) drops to, or below 170-(5/2) = 167.5°F, the contacts in the outdoor reset controller close. These contacts open if the sensor temperature climbed to, or above, 170+(5/2) =172.5°F.

For the circuit shown in Figure 7-15, the closing of the contacts in the outdoor reset controller allows 24 VAC to power on the coil of relay R2. Normally open, contact R2-2 closes across the "external demand" terminals of the pellet boiler allowing it to start. Normally open, contact R2-1 also closes, enabling another path for 24 VAC across the closed contacts in the setpoint controller. The contacts in this setpoint controller would be closed because the temperature at the lower tank sensor is lower than 165°F.

As the boiler adds heat to the tank, the temperature at the upper tank sensor (S1) rises, and eventually causes the contacts in the outdoor reset controller to open. However, the temperature at the bottom of the tank is still well below 175°F, so the contacts in the setpoint controller remain closed, allowing 24 VAC to continuing passing through. The 24 VAC power continues through contact R2-1 to keep the coil of relay R2 energized. The pellet boiler continues to operate until the lower tank sensor (S2) reaches 175°F. When this temperature is reached the contacts in the setpoint controller open, breaking 24 VAC to relay coil R2 and opening contact R2-2 to turn off the pellet boiler.

The outdoor reset controller operation in Figure 7-15 is also set to provide a minimum target temperature of 90°F whenever the outdoor temperature is above approximately 57°F. It's also set to provide a maximum target supply water temperature of 170°F, even if the outdoor temperature drops below 0°F.

The settings that determine the relationship between target water temperature and outdoor temperature are user-adjustable. This allows controller response to be "fine-tuned" to the specific needs of each system.

7.8 Reducing Water Temperature to the Distribution System

The upper temperature limit of thermal storage tanks supplied by biomass boilers is significantly higher than the required water temperature of low-temperature heat emitters such as radiant panels. The high-temperature water needs to be mixed with lower temperature water returning from the low temperature heat emitters to provide an appropriate supply water temperature. This is easily done using one of the mixing assemblies commonly employed in other types of hydronic heating systems.

This manual discusses two common types of mixing assemblies: the three-way motorized mixing valves and variable speed injection mixing. Full details on these as well as other mixing assemblies can be found in the references cited in Appendix C.

7.9 Mixing with Three-Way Motorized Valves

One of the most common mixing assemblies used in hydronic heating and cooling systems is based on a three-way motorized mixing valve, an example of which is shown in Figure 7-16.

Figure 7-16. Example of a three-way motorized mixing valve with motorized actuator attached

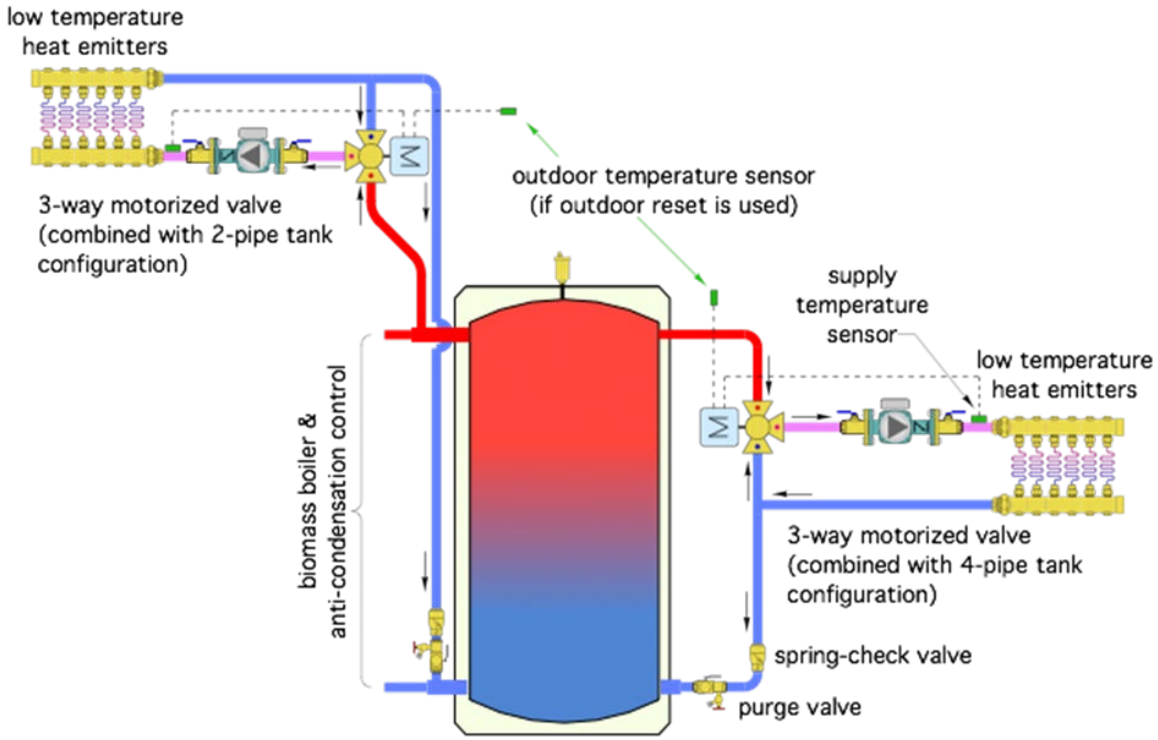
Courtesy of Paxton Corporation.



This assembly consists of a three-port, rotary mixing valve body coupled to an electrically-operated gear motor actuator. Three-way value bodies, along with associated actuators are available in pipe sizes from three-quarter-inch to six-inch.

Figure 7-17 shows how three-way motorized mixing valves can be installed in systems with either a two-pipe or four-pipe thermal storage tank configuration. The piping assembly to the left of the tank is for a two-pipe tank configuration, while the piping assembly on the right is for a four-pipe tank assembly.

Figure 7-17. How to install a three-way motorized mixing valve for either a two-pipe or four-pipe tank configuration



Notice that the supply temperature sensor for the controller operating the mixing valve's actuator is installed downstream of the load circulator. This ensures that the sensor detects the fully mixed water temperature on route to the heat emitters.

Three-way motorized mixing valves can create an outlet temperature anywhere between the temperatures of the entering hot and "cool" streams. The motorized actuator rotates the valve's shaft very slowly. Most actuators used in this type of application require 90–120 seconds to rotate the valve's shaft by 90°F.

The mixed outlet temperature is determined by the proportions of hot water and cool return water passing through the valve. The controller operating the valve's actuator can operate to maintain a fixed mixed water temperature or a mixed temperature that is based on outdoor reset control.

Designers should select a valve body with a Cv value that's approximately equal to the flow rate (measured in gallons per minute) required in the distribution system when operating at design load conditions. This will limit the pressure drop through the valve to about 1 psi.

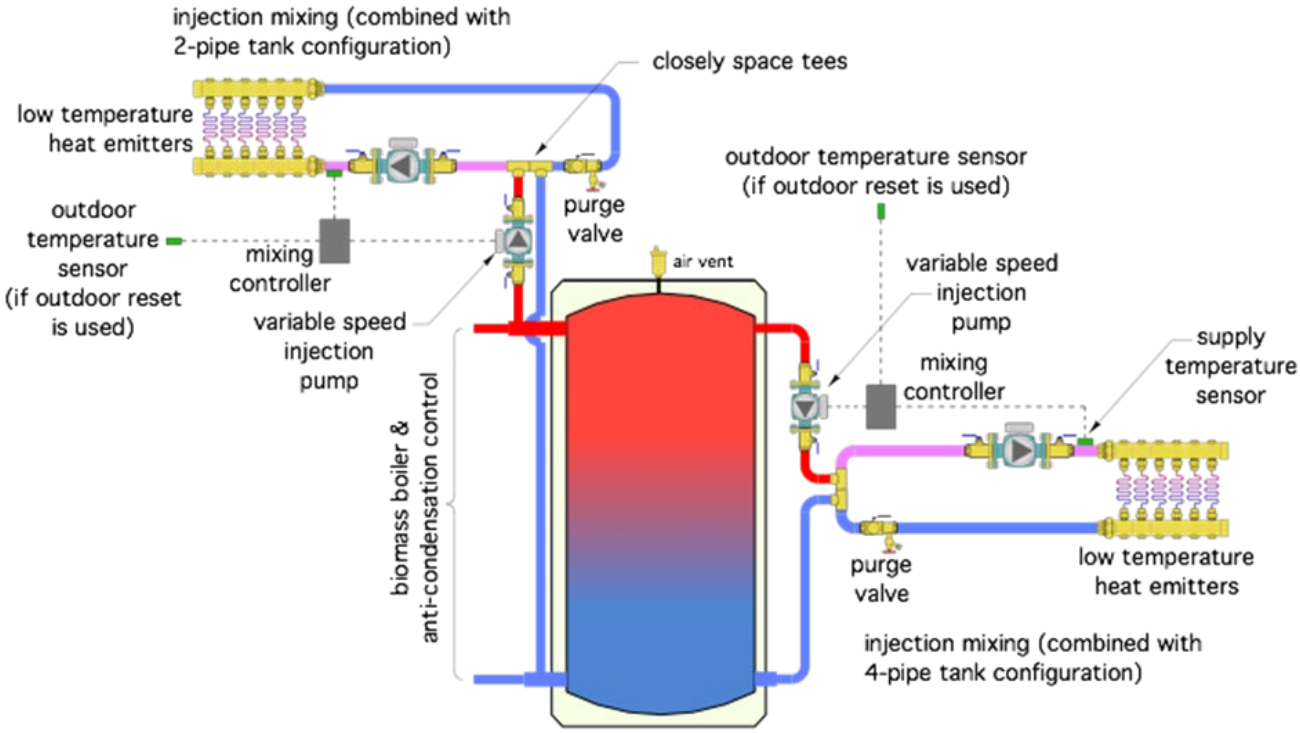
Three-way motorized mixing valves can also be used to supply multiple independently-controlled zones. There can also be multiple three-way motorized mixing valves in the same system when multiple supply water temperatures are needed at the same time in different portions of the system.

Systems using three-way motorized mixing valves can also be configured for constant circulation in the distribution system. When no heat input to the system is needed the controller/actuator operating the valve fully closes the valve's hot port. All flow returning from the distribution system passes through the valve and is routed back to the supply side without any added heat. Continuous flow is especially beneficial in combination with large heated floor slabs in buildings with overhead doors or other areas of high-localized heat loss. It allows heat from the interior areas of the slab to be redistributed to the high-heat loss areas and thus maintains more uniform comfort within the building

7.10 Variable Speed Injection Mixing

Another well-established mixing method uses a variable speed circulator to "inject" (e.g., regulate) higher temperature water into a circulating distribution system. Figure 7-18 shows how a variable speed injection pump can be used for both two-pipe and four-pipe buffer tank configurations.

Figure 7-18. How to install a variable speed injection circulator for either a two-pipe and four-pipe tank configuration



The variable speed pump can be a standard wet-rotor circulator with a permanent split capacitor (PSC) motor or a circulator with an electronically commutated motor (ECM).

When a standard (PSC) circulator is used, the injection mixing controller regulates the frequency and voltage of the AC power supplied to the circulator. Such controllers are readily available and can regulate motor speed from full speed down to very low RPM. They are relatively inexpensive and can operate circulators with PSC motors up to one-sixth horsepower. Speed control can be based on maintaining a fixed supply water temperature to the distribution system or based on outdoor reset control. When an ECM type circulator is used, its speed is usually controlled by a 0-10 VDC or a pulse width modulation (PWM) input from another controller.

The variable speed injection pump should be sized to move water from thermal storage to the load so that design load can be supplied using the *lowest* water temperature anticipated in the upper portion of the thermal storage tank.

If an outdoor reset control is used to determine the pellet boiler “on” temperature at the upper tank sensor, the injection pump must be capable of moving flow into the distribution system at the same flow rate that the system would be operating at under design load conditions.

If an outdoor reset control is used to determine the pellet boiler “on” temperature at the upper tank sensor, the injection pump must be capable of moving flow into the distribution system at the same flow rate that the system would be operating at under design load conditions. When the water in the upper portion of the thermal storage tank is higher than the required supply temperature to the distribution system, the injection pump reduces speed.

Variable speed injection mixing can be scaled up to large systems using injection circulators operated by variable frequency drives (VFD). However, some VFDs cannot slow the injection circulator motor below approximately 25% of full speed. In such cases, the injection circulator may have to cycle on and off under low-load conditions to prevent excessive heat input to the distribution system. Another possibility is use of two parallel-piped injection circulators, one larger than the other. The smaller injection circulator handles low-load conditions, and the larger one assumes control as the loads increase.

As was the case with three-way motorized mixing valves, distribution systems supplied by a variable-speed injection circulator can be configured for constant circulation. The injection circulator turns off when no heat input is needed in the system.

7.11 Integrating Biomass Boilers with Existing/Auxiliary Boilers

Many biomass boilers are retrofitted into systems that having existing boilers. In a new biomass boiler system, an auxiliary boiler is often included as part of the overall system. The presence of an existing or auxiliary boiler (hereafter referred to as an existing/auxiliary boiler) enhances the overall system in several ways including the ability to (1) maintain building comfort if the biomass boiler is not operating (either intentionally or if it is down for service), (2) supplement the heat output of the biomass boiler under peak loading conditions, (3) take advantage of energy sources that may be offered at favorable rates under specific conditions, such as off-peak electrical rates where and when they are available.

The following are important considerations when integrating a biomass and conventional boiler into a system:

- Respect and enhance the desired operating characteristics of the biomass boiler.
- Respect the operating conditions of the existing/auxiliary boiler.
- When the cost of heat provided from pellets or cordwood is less expensive than heat produced by other fuels, the biomass boiler will have preferential operation over the existing/auxiliary boiler.
- Correct any operational issues with the existing boiler, such as reducing or eliminating short cycling.
- Allow either boiler to be the sole heat source if necessary. This infers designs that allow either boiler to be turned off and isolated from the system, if necessary for repair.
- Heat from the biomass boiler/thermal storage subsystem should be injected upstream of the location where the existing/auxiliary boiler injects heat to the distribution system.

7.12 Never Connect Boilers in Series

Although it may seem simple or apparent, a biomass boiler should never be connected in series with an existing boiler. A series arrangement forces water to flow through both boilers regardless of which is operating. Routing heated water through an unfired boiler allows that boiler to dissipate heat from its jacket as well as through induced convective air currents through its venting system. This is a needless waste of energy.

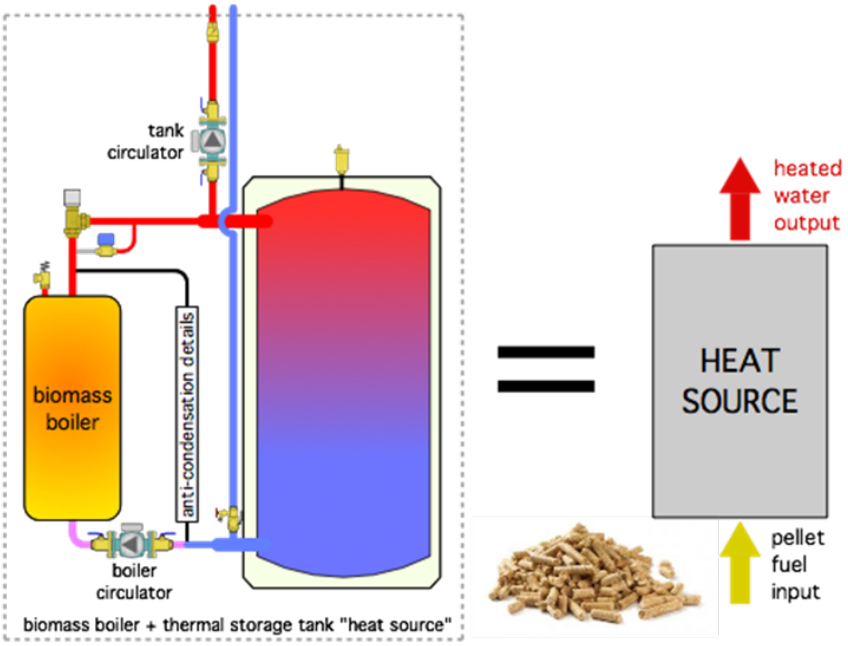
A biomass boiler should never be connected in series with an existing boiler.

Boilers connected in series also preclude the ability to isolate and remove either boiler, if necessary for service or replacement, without shutting down the system. Boilers connected in series also increase the flow resistance of the system resulting in increases pumping power to achieve a given flow rate.

7.13 Biomass Boiler + Storage as Heat Source

The biomass boiler, thermal storage tank, and the piping that connects them should be thought of, collectively, as a single heat-source entity, as depicted in Figure 7-19.

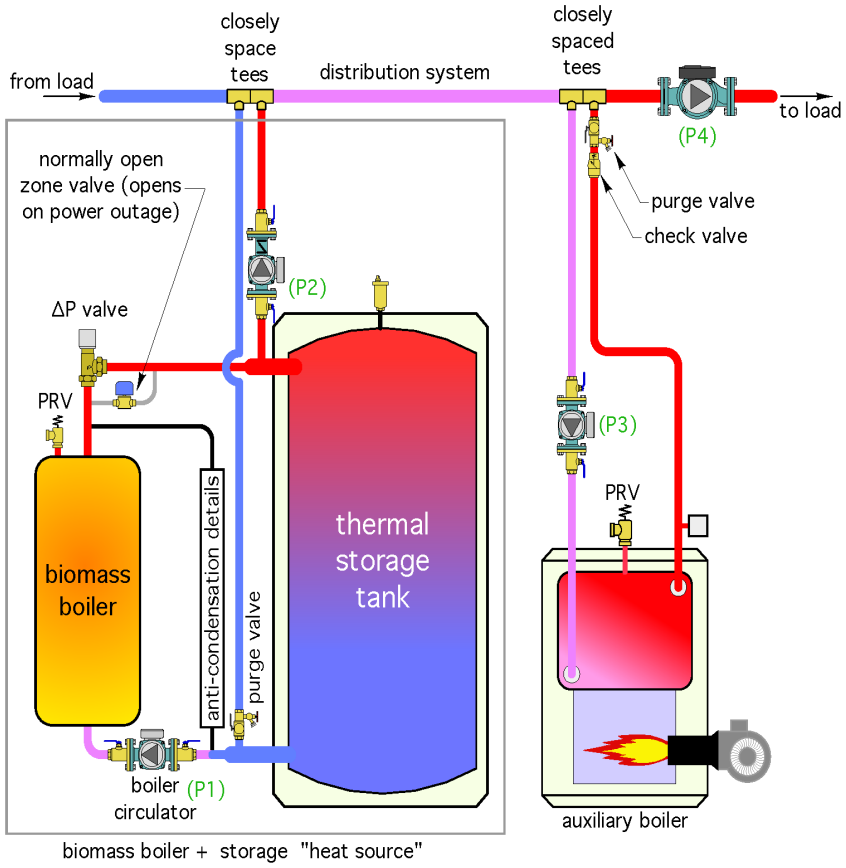
Figure 7-19. Concept of treating the biomass boiler and the thermal storage tank, combined. as the "biomass boiler + storage heat source"



With a two-pipe or three-pipe tank configuration, heat flowing to the remainder of system is, at times, produced by the boiler, at other times it comes from storage, and sometimes from both at the same time. To emphasize the concept of the biomass boiler and thermal storage as a single heat-source entity, this combination will be referred to as biomass boiler + storage heat source.

In general, the biomass boiler + storage heat source should be piped in combination with an existing/auxiliary boiler as shown in Figure 7-20.

Figure 7-20. Illustration of the biomass boiler + storage heat source piped to a distribution system in combination with an existing/auxiliary boiler

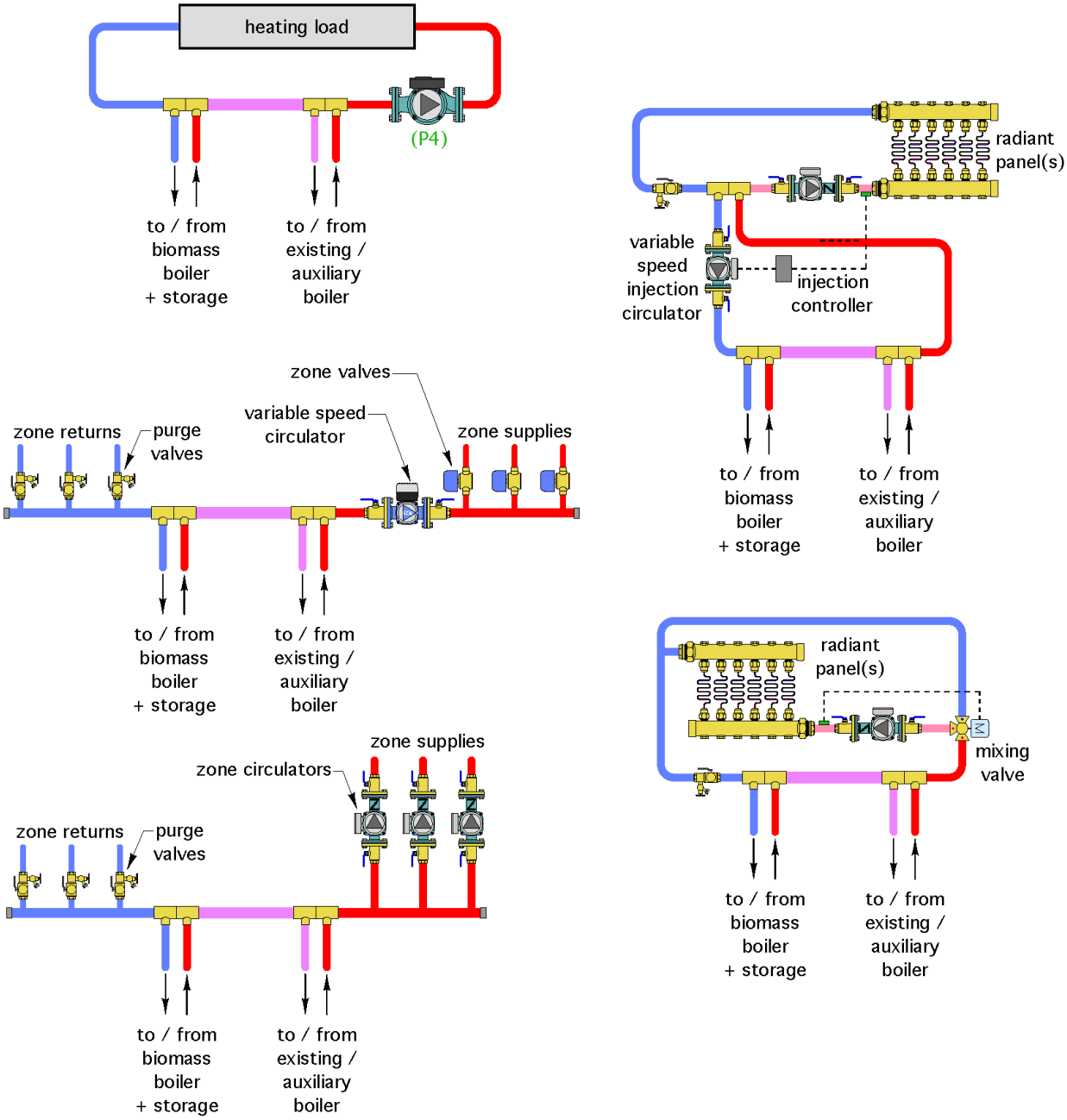


With the piping shown in Figure 7-20, heat can be supplied from the biomass boiler + storage heat source, or the existing/auxiliary boiler. Under certain conditions it's also possible to supply heat from both at the same time.

The closely spaced tees that connect each heat source to the distribution system provide hydraulic separation between the load circulator (P4), the existing/auxiliary boiler circulator (P3), and the tank circulator (P2). The piping of the thermal storage tank provides hydraulic separation between the biomass boiler circulator (P1) and the tank circulator (P2).

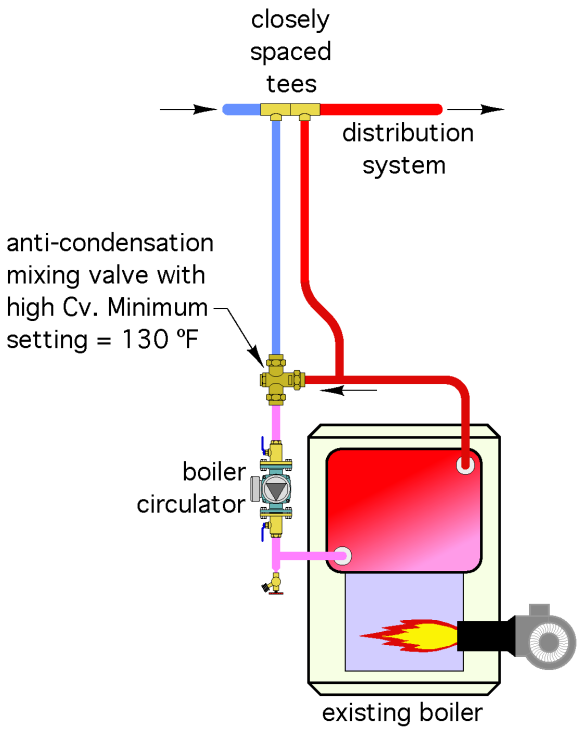
The heating distribution system in Figure 7-20 is shown with a single circulator (P4). However, it can be configured several different ways, to include multiple zones, as well as mixing devices that regulate the supply water temperature to lower temperature heat emitters such as radiant panels. Figure 7-21 shows some examples of how the distribution system can be configured.

Figure 7-21. Possible configurations for distribution systems based on connecting heat sources as shown in figure 7-20



The piping configuration shown in Figure 7-20 assumes that the distribution system operates at water temperatures high enough to prevent sustained flue-gas condensation in the existing/auxiliary boiler. However, if the distribution system has been modified by adding heat emitters that allow it to operate at lower supply water temperatures (e.g., temperatures that could cause sustained flue-gas condensation in the existing/auxiliary boiler), the boiler piping should be modified to include an anti-condensation thermostatic mixing valve for the existing/auxiliary boiler, as shown in Figure 7-22.

Figure 7-22. Auxiliary/existing boiler piping that includes an anti-condensation thermostatic mixing valve



The anti-condensation mixing valve allows the existing/auxiliary boiler to operate at temperatures above the dewpoint of its flue gases, while still adding heat to the low-temperature distribution system. If the existing/auxiliary boiler is a modulating/condensing (mod/con) boiler, it is not necessary or desirable to use an anti-condensation mixing valve.

7.14 Managing Heat Flow from Multiple Heat Sources

All systems that combine a biomass boiler + storage with an existing/auxiliary boiler need controls that determine when each heat source adds heat to the distribution system. Those controls need to meet three objectives: (1) favor heat input from the biomass boiler + storage heat source over that from the existing/auxiliary boiler whenever possible; (2) avoid loss of comfort due to inadequate supply water temperature to the distribution system; and (3) avoid conditions that inadvertently send heat produced by the existing/auxiliary boiler to the thermal storage tank.

Experience has shown that there are several possible ways to potentially control the heat sources with these goals in mind. For example, a standard multistage boiler controller might be used to operate the biomass boiler + storage as the fixed first stage of heat input, and then activate the existing/auxiliary boiler as second stage heat input if the first stage is not producing the necessary supply water temperature. Although this is common practice in systems with multiple and identical boilers, it can, under some circumstances, fail to address the third objective.

For example, the biomass boiler + storage may go off-line due to a fault condition in the boiler. A standard multistage boiler controller does not comprehend this abnormal condition. It only understands that the first stage of heat input is not creating the necessary supply water temperature in the distribution system. The boiler controller reacts by turning on the existing/auxiliary boiler as the second stage, while maintaining operation of the circulator between the thermal storage tank and distribution system (which is the device operated as the first stage). This could eventually cause the heat generated by the existing/auxiliary boiler to inadvertently flow into the thermal storage tank. While this doesn't create a safety issue or damage any equipment, it does create an undesirable condition in which there is substantially higher heat loss from the thermal storage tank into its surrounding space. That heat loss can needlessly overheat that space. This situation also limits the heat absorption ability of the thermal storage tank when the biomass boiler comes back on line. If the circulator between the biomass boiler and thermal storage tank (e.g., P1 in Figure 7-23) was also operating, heat from the tank would be carried to the unfired biomass boiler where it creates jacket heat loss and convective air currents up the chimney (remember that biomass boilers do not have automatic flue dampers).

It's necessary to determine the conditions under which the biomass boiler + storage heat source can contribute heat to the system, and only allow the circulator between the tank and distribution system to operate when these conditions exist.

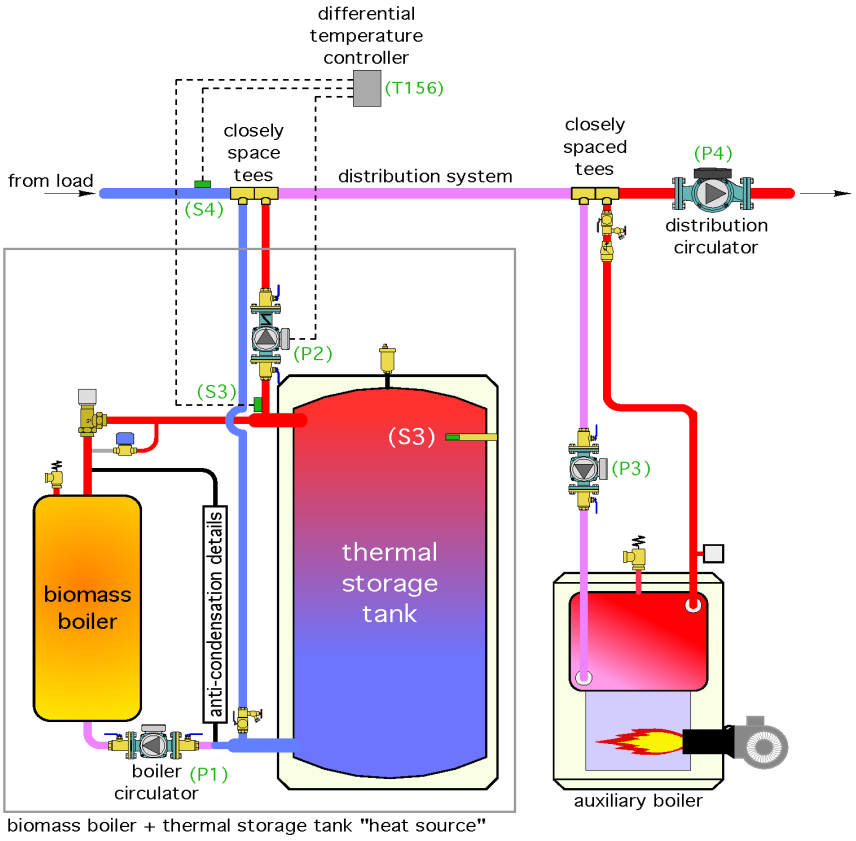
From a thermodynamic perspective this condition needlessly converts high-grade energy (e.g., the fuel used by the existing/auxiliary boiler) into low-grade energy (heat). The latter is much harder to regulate or contain, especially over several hours or days. To avoid this circumstance, it's necessary to determine the conditions under which the biomass boiler + storage heat source can contribute heat to the system, and only allow the circulator between the tank and distribution system (e.g., P2 in Figure 7-23) to operate when these conditions exist.

Fortunately, this is easy to accomplish using a standard differential temperature controller. This relatively inexpensive controller is used in many solar thermal systems. It compares the temperature in the solar thermal collector to the temperature of the thermal storage tank. When the temperature of the collectors is some set differential above the temperature of the storage tank, this controller allows circulation between them. When this differential is minimal (e.g., the collector temperature is only perhaps 5°F higher than the temperature of the storage tank) or when the collector temperature is lower than that of the storage tank, the circulator between the tank and collectors is turned off.

This same concept can be applied in biomass boiler systems. The temperature at the upper header of the thermal storage tank is compared to the temperature of the water returning from the distribution system. As long as the temperature at the upper header is a few degrees Fahrenheit above the return water temperature, the circulator between the tank and distribution system is allowed to operate. However, if the return temperature from the distribution system approaches that in the tank's upper header, or climbs above it, the tank circulator is not allowed to operate.

Figure 7-23 shows how a differential temperature controller (T156) and its associated temperature sensors (S3) and (S4) would be placed in the system.

Figure 7-23. Placement of a differential temperature controller and its associated temperature sensors



Sensor S3 measures the temperature at the upper tank header very close to the tank. This location allows S3 to perceive the presence of hot water from either the biomass boiler, if it's operating, or the upper portion of the tank, if the biomass boiler is off. Sensor S4 measures the temperature of water returning from the distribution system.

Whenever a heating load is active, the differential temperature controller is powered on and could operate with the following control logic:

IF (S3) ≥ (S4) + 5°F THEN (P2) is allowed to operate

IF (S3) ≤ (S4) + 3°F THEN (P2) is not allowed to operate

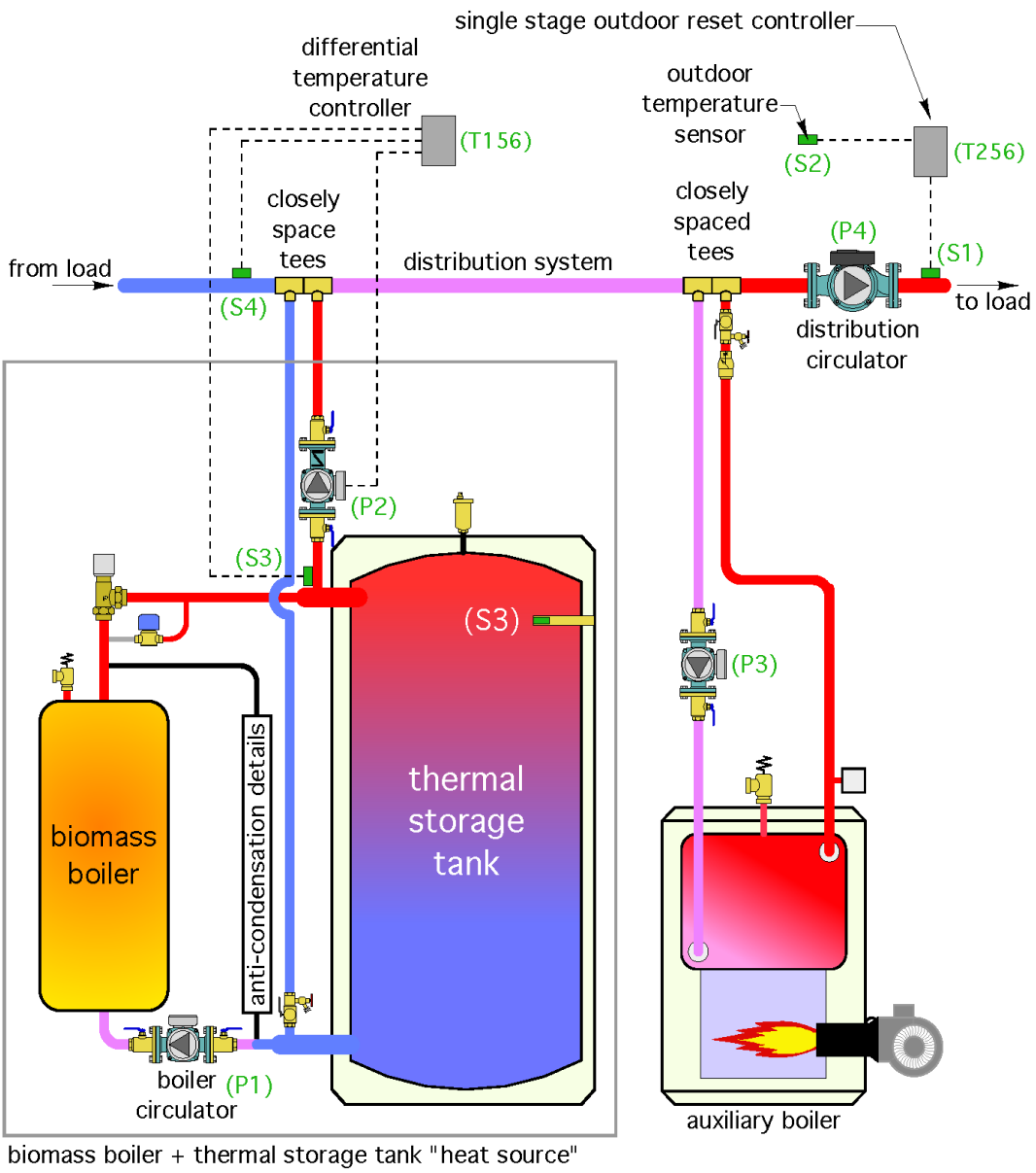
This control logic meets the previously stated objectives one and three. Objective two can be met using a standard outdoor reset controller to compare the water temperature supplied to the distribution system to a calculated target temperature. The latter represents the minimum supply water temperature at which the distribution system can maintain building comfort.

For example, on a day when the outdoor temperature is 0°F, a given distribution system may require a supply water temperature of 160°F to maintain building comfort. However, when the outside temperature is 35°F the required supply water temperature may only be 115°F. Under the latter conditions it's possible to extract significantly more energy from thermal storage before resorting to operating the existing/auxiliary boiler.

The outdoor reset controller allows the supply water temperature to be higher than the minimum required to maintain comfort. However, if the supply water temperature drops below the value necessary to maintain comfort, the outdoor reset controller will turn on the existing/auxiliary boiler and its associated circulator. Figure 7-24 shows the system from Figure 7-23 with an outdoor reset controller (T256) and its associated temperature sensors S1 for supply temperature and S2 for outdoor temperature.

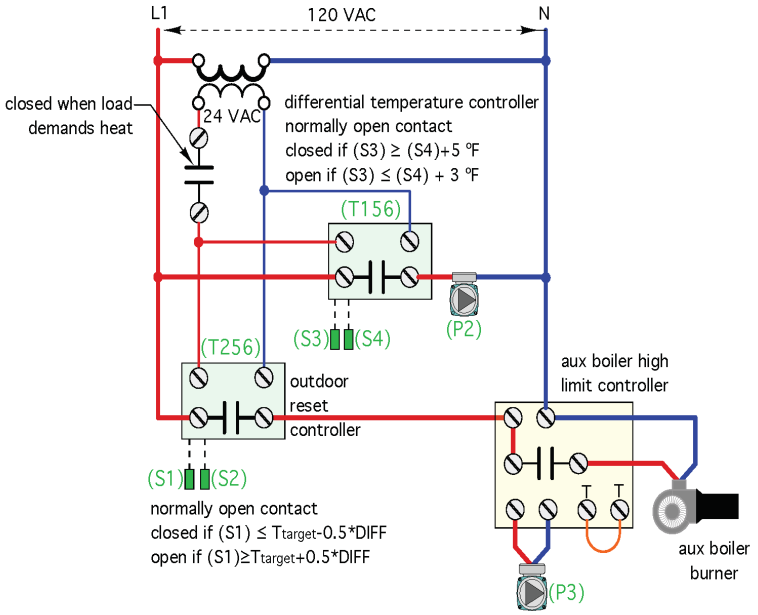
If the supply water temperature drops below the value necessary to maintain comfort, the outdoor reset controller will turn on the existing/ auxiliary boiler and its associated circulator.

Figure 7-24. Differential temperature controller (T156) combined with an outdoor reset controller (T256) and their associated temperature sensors



The combination of the differential temperature controller (T156) and outdoor reset controller (T256) addresses all three previous stated objectives for controlling heat input to the distribution system from both heat sources. Figure 7-25 shows how these devices can be combined electrically, along with circuitry that signals when a heating demand is present.

Figure 7-25. Electrical schematic for combining a differential temperature controller (T156) and outdoor reset controller (T256) to manage heat input to the distribution system



This circuitry assumes that the differential temperature controller (T156) and outdoor reset controller (T256) are powered by 24 VAC. That power only reaches both controllers when there is a heating demand in the system, which is evidenced by a closed relay contact. The latter is typically supplied from a multizone relay center or a thermostat if the building has only one zone.

When a heating demand occurs the differential temperature controller (T156) is powered on and within seconds determines if the biomass boiler + storage heat source is at or above the temperature where it can contribute heat to the circulating distribution system. If it is, the relay contact in the differential temperature controller (T156) closes, passing 120 VAC to the tank circulator (P2). If it isn't, the circulator (P2) remains off.

When a heat demand occurs, the outdoor reset controller is also powered on. It measures the supply water temperature to the distribution system and determines if it is below the necessary value to maintain building comfort. If it is too low, the contacts in the outdoor reset controller (T256) close, which passes 120 VAC power to the high-limit controller on the existing/auxiliary boiler. That controller turns on circulator (P3) and fires the burner to produce heat. Circulator (P2) remains on as long as the return water temperature measured by sensor (S4) doesn't rise to within 3°F of the temperature at the upper tank header, measured by sensor (S3). Assuming that the temperature at (S3) is still well above that at (S4), the biomass boiler + tank continues to contribute heat to the system along with the auxiliary boiler.

It's possible to reduce short cycling of an existing boiler when thermal storage is added to the system as part of the biomass boiler retrofit

If the return water temperature at (S4) rises to within 3°F of the temperature at (S3), or climbs above the temperature at (S3), circulator (P2) is turned off. The existing/auxiliary boiler continues to add heat to the system until the supply water temperature climbs a few degrees Fahrenheit above the target temperature. When this condition is reached, the contacts in the outdoor reset controller open, turning off the existing/auxiliary boiler and circulator (P3). When there is no further heat demand, both controllers and circulators (P2) and (P3) are turned off.

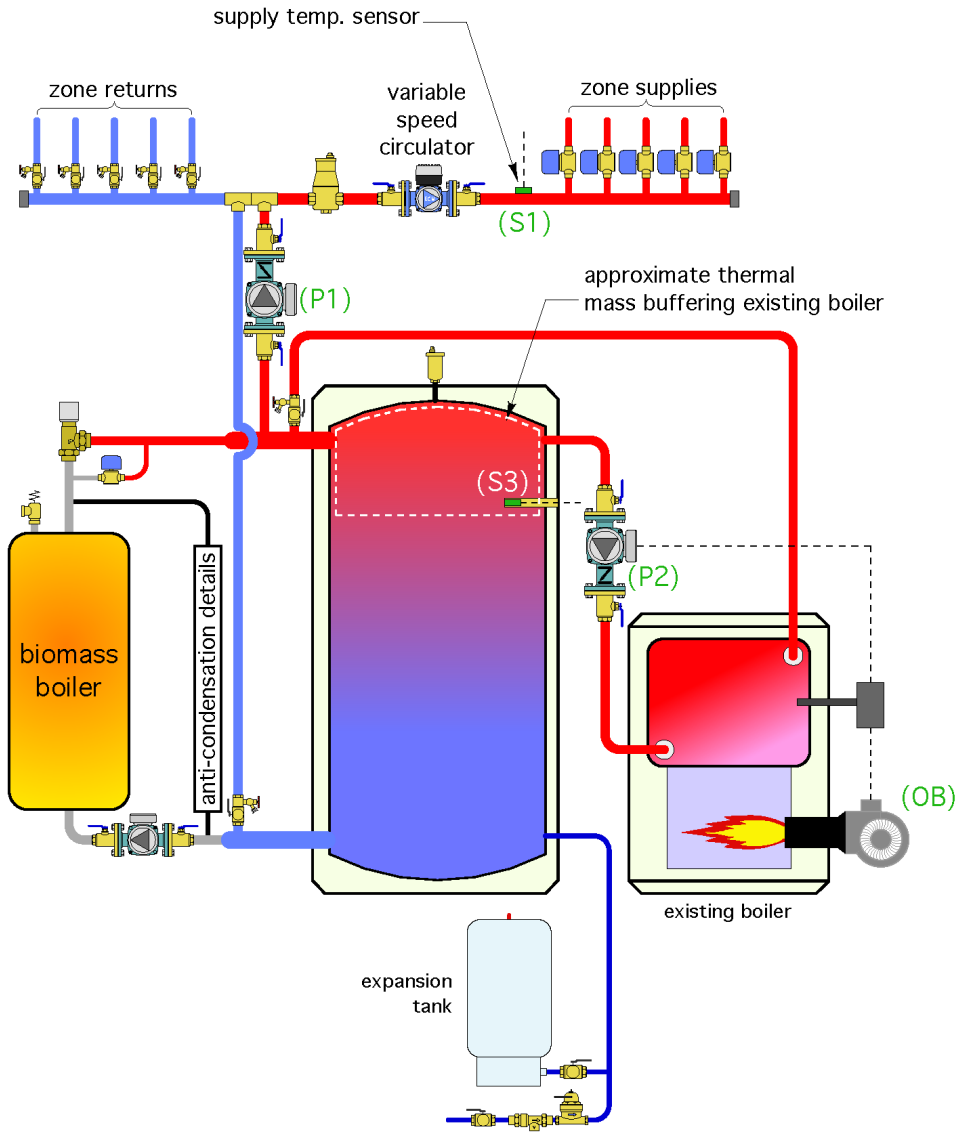
Note: The temperature setting on the high-limit controller of the existing/auxiliary boiler should be set relatively high to prevent its control action from interfering with that of the outdoor reset controller.

7.15 Buffering the Existing/Auxiliary Boiler

In some situations, a biomass boiler and thermal storage will be added to a system with an existing oversized boiler and a highly zoned distribution system. These preexisting conditions frequently cause the existing boiler to short cycle.

It's possible to reduce short cycling of an existing boiler when thermal storage is added to the system as part of the biomass boiler retrofit. This is done by allowing a small portion of the thermal storage to act as buffering mass for the existing boiler under specific conditions. Figure 7-26 shows how the system can be configured.

Figure 7-26. Configuration to reduce short cycling of an existing oversized boiler by connecting it to the upper portion of the thermal storage tank



The existing boiler is piped across the upper portion of the thermal storage tank. This allows the upper portion of the tank to buffer the operation of the existing boiler. When the load is space heating, the existing boiler is not meant to continuously maintain the upper portion of the thermal storage tank at a minimum temperature.

In systems that supply just space heating, the existing boiler should operate only when there is a load, and the current status of the thermal storage tank cannot provide the necessary supply water temperature to the load.

Possible control criteria would be if a heating load is present and the temperature at sensor (S3) in the upper portion of the thermal storage tank (see Figure 7-26) is a few degrees below the minimum required supply water temperature for the heating load.

An exception is when the thermal storage tank also supplies domestic hot water on a 24/7 basis using an internal coil heat exchanger or external heat exchanger. When this is the case, the upper portion of the thermal storage tank can be maintained by the existing boiler at a minimum temperature suitable for domestic water heating. These options will be described in the following section.

An exception is when the thermal storage tank also supplies domestic hot water on a 24/7 basis using an internal coil heat exchanger or external heat exchanger.

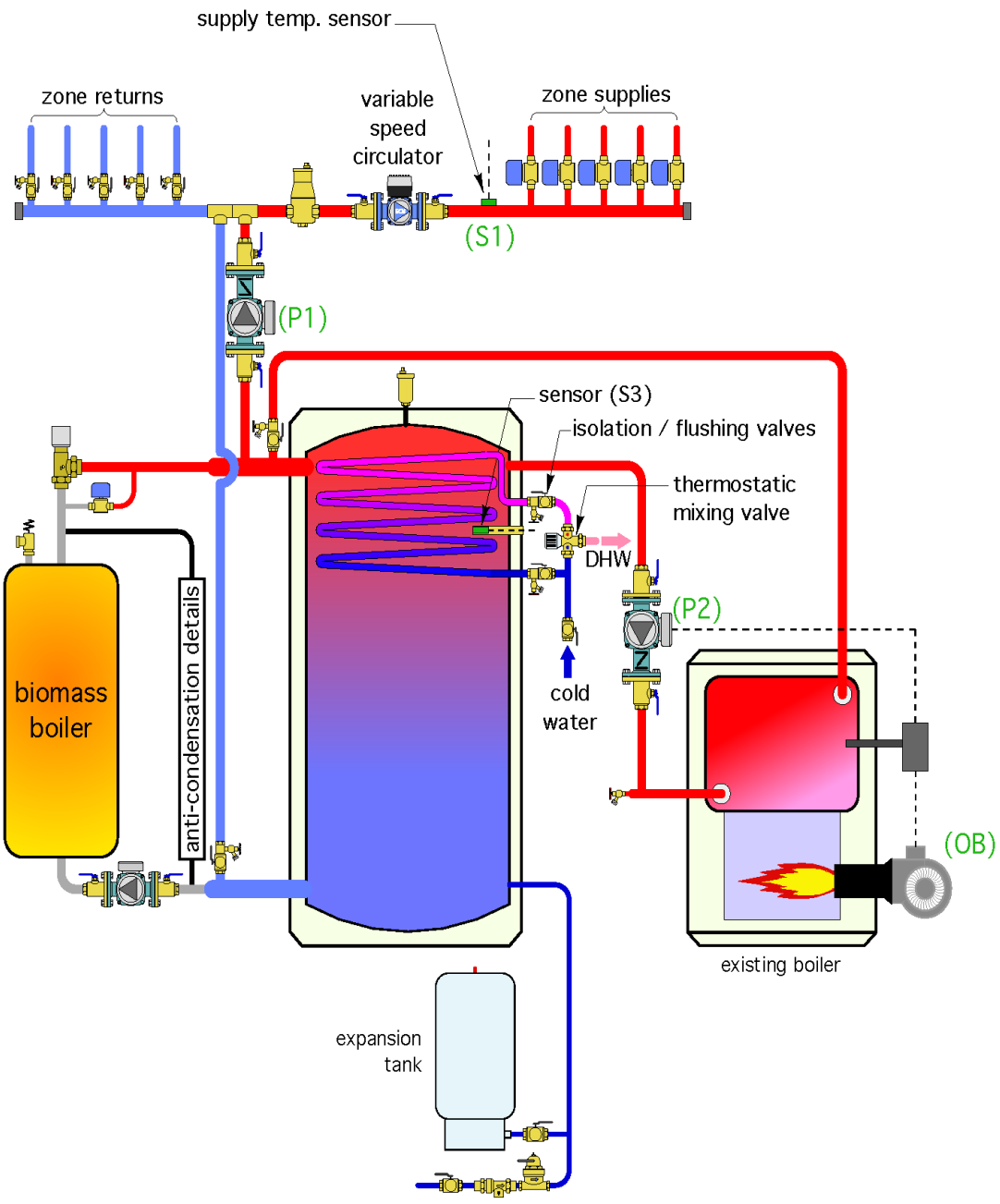
7.16 Providing Domestic Water Heating with Space Heating

Many buildings have both space heating and domestic water heating loads. When the domestic hot water (DHW) load is small, such as hand washing in a shop environment, or supplying a small kitchenette in a break room, it's best handled by a separate electrically-powered, point-of-use water heater. If the domestic water heating load is substantial, such as supplying multiple showers in an athletic facility, a commercial laundry, or for frequent vehicle washing, that load can be partially or fully supplied by the same system that supplies space heating.

There are several approaches depending on the design objective. For example, in a typical residential application, domestic hot water is used throughout the year, whereas the building heating load may only be present over perhaps 65% of the year. The common design concept in such a situation is to use heat produced by pellets (rather than conventional fuels) during times when the pellet boiler would also be enabled for space heating and turn off the pellet boiler during months when no space heating is needed. When the pellet boiler is turned off, domestic water could be heated by the existing/auxiliary boiler or by another dedicated device such as a tankless water heater.

Figure 7-27 shows a possible system configuration where domestic water is fully heated within a stainless-steel coil heat exchanger permanently located within the upper portion of the thermal storage tank.

Figure 7-27. Heating domestic water within a coil heat exchanger located inside the thermal storage tank



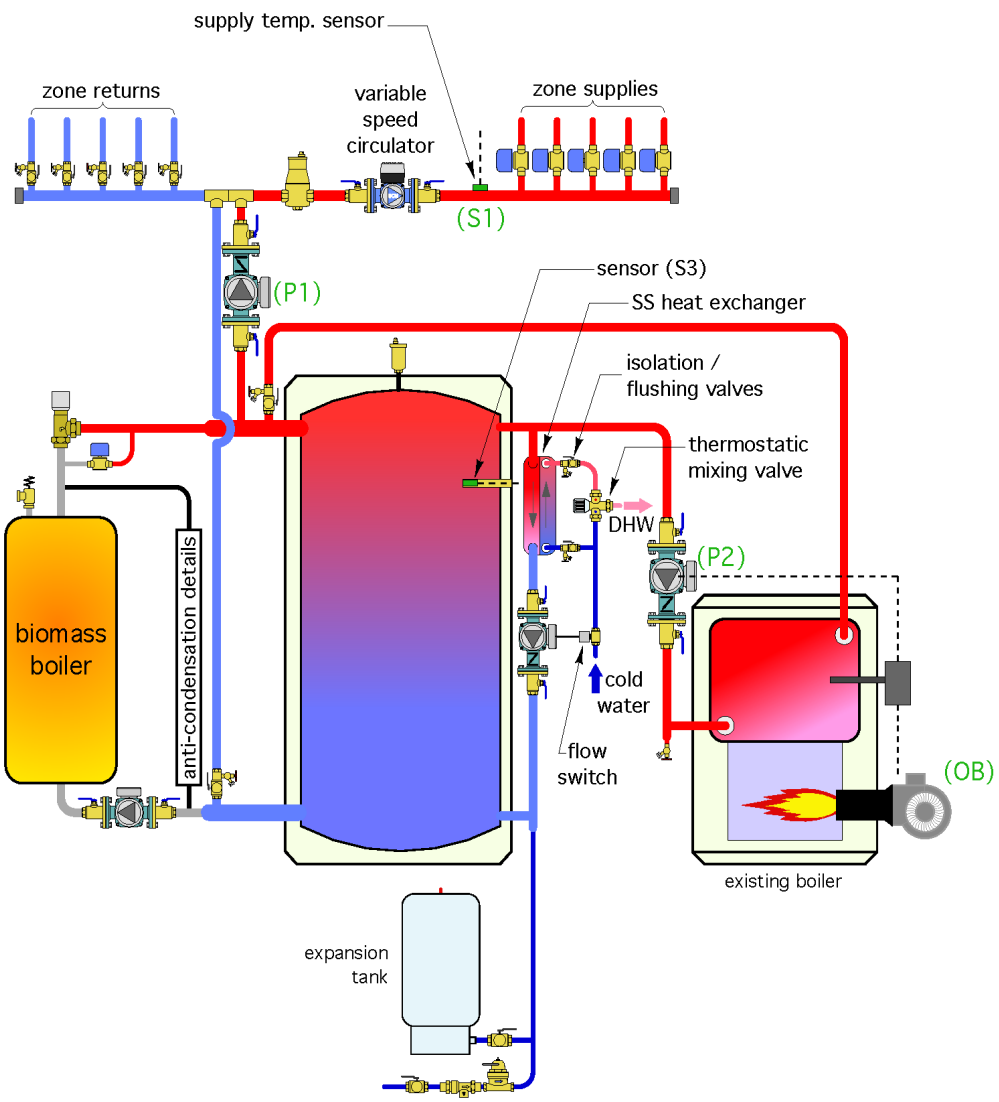
Cold domestic water enters the bottom of the coil heat exchanger and makes a single pass through the stainless-steel exchanger. The water temperature in the coil heat exchanger depends on the water temperature in the upper portion of the tank. At times this temperature could be very high, such as 180°F. Because of this, an American Society of Sanitary Engineering (ASSE) 1017 rated anti-scald mixing valve MUST be used between the heat exchanger coil outlet and DHW delivery to the building. The outlet temperature from this anti-scald valve should never be more than 120°F.

The outlet temperature from this anti-scald valve should never be more than 120°F.

If the pellet boiler cannot maintain a sufficient temperature in the upper portion of the tank, the existing/auxiliary boiler fires based on the temperature at sensor (S3). It is suggested that the minimum temperature at sensor (S3) be at least 10°F higher than the desired DHW delivery temperature.

The inlet and outlet connections of the coil heat exchanger are equipped with combination isolation/flushing valves. These valves allow the coil to be isolated and flushed with a descaling fluid if necessary. Figure 7-28 shows another method of using heat from thermal storage to produce domestic hot water.

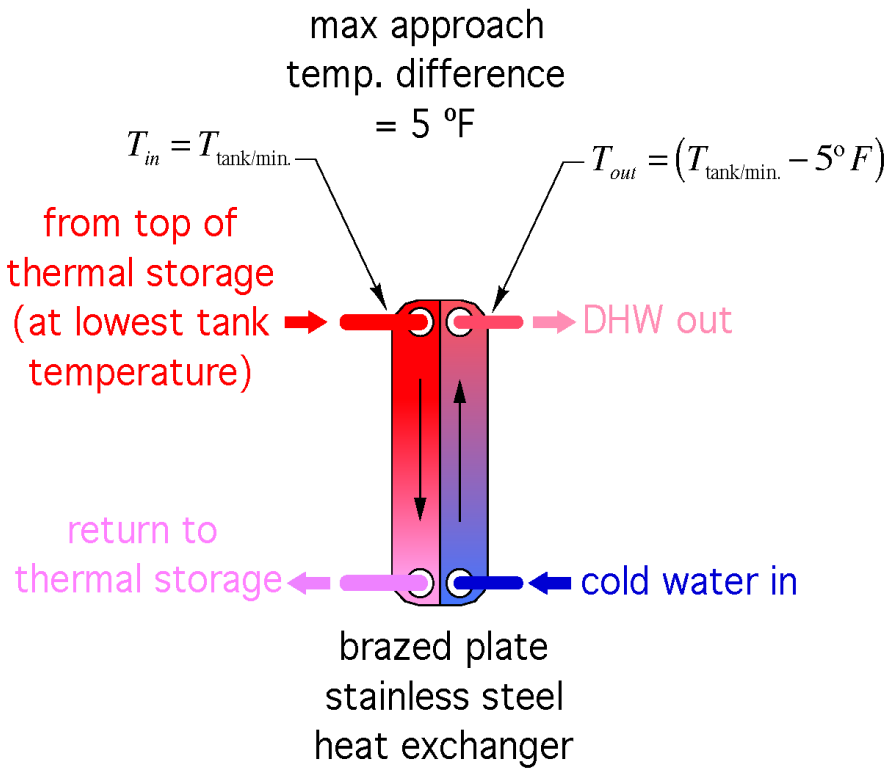
Figure 7-28. Using heat from thermal storage to produce domestic hot water through an external brazed plate heat exchanger



This system uses a brazed plate stainless-steel heat exchanger mounted outside the thermal storage tank in combination with a small circulator and domestic hot water flow switch. The flow switch is mounted on the *cold*-water supply to the domestic water heating sub-system. When this flow switch detects a preset minimum flow rate, it closes electrical contacts that turn on the small circulator, typically through a relay circuit. The circulator routes hot water from the upper portion of the thermal storage tank through the primary side of the heat exchanger. Cold domestic water moves in counterflow through the secondary side of the heat exchanger where it is fully heated. The heated water then passes through an ASSE 1017 rated anti-scald mixing valve to ensure a delivery temperature no higher than 120°F. When domestic hot water flow decreases to some minimum value, the flow switch turns off the heat exchanger circulator.

The brazed plate heat exchanger should be generously sized. Many heat exchanger vendors provide online software than can be used for sizing. A maximum approach temperature difference of 5°F is suggested under design DHW flow requirements and at the minimum water temperature in the upper portion of the thermal storage tank, as shown in Figure 7-29.

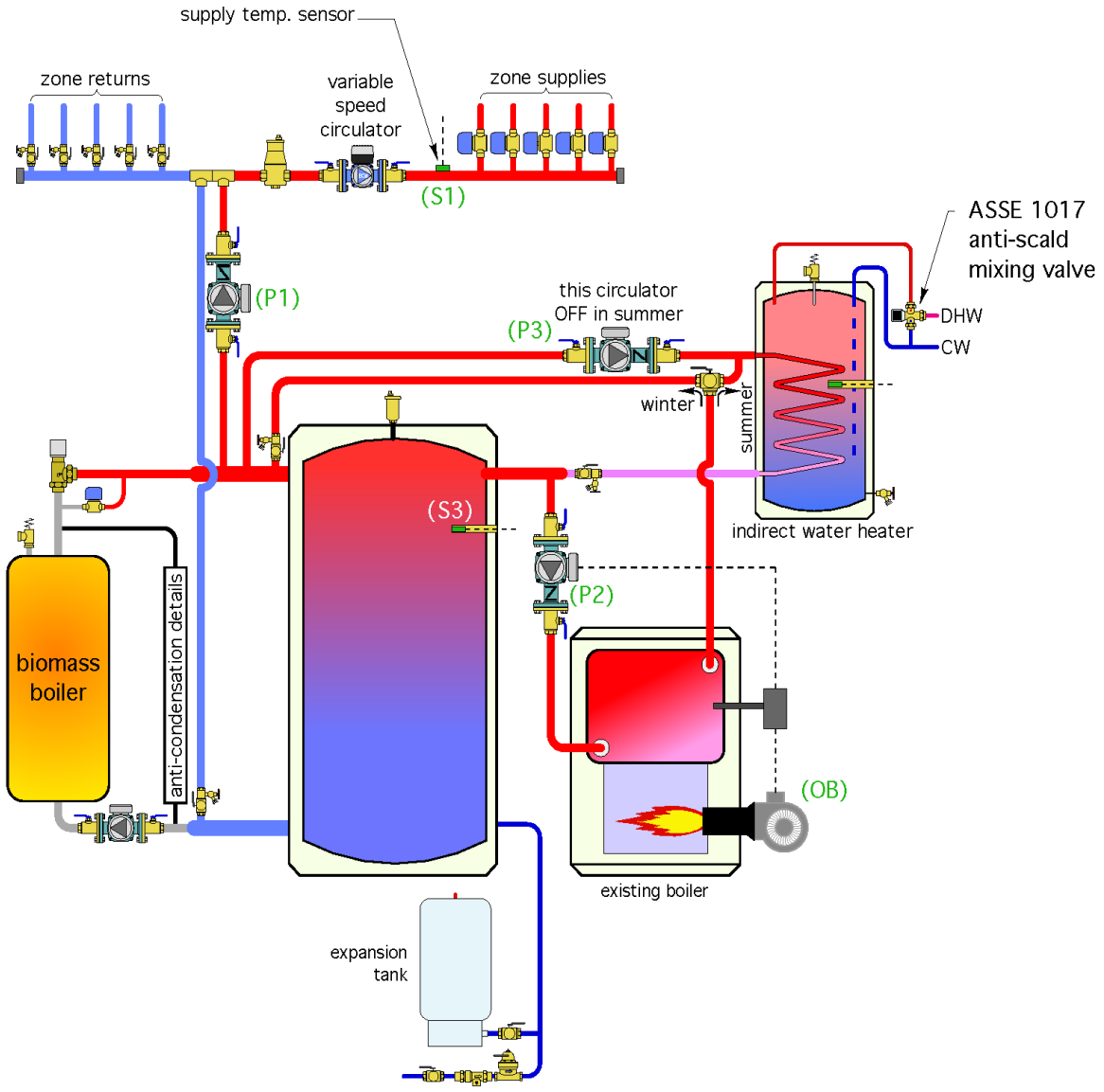
Figure 7-29. Suggested maximum approach temperature difference when size a brazed plate heat exchanger for producing domestic hot water using heat from thermal storage tank



If the pellet boiler cannot maintain a sufficient temperature in the upper portion of the tank, the existing/auxiliary boiler operates based on the temperature at sensor (S3) in the upper portion of the thermal storage tank. The minimum temperature at sensor (S3) should be at least 5°F higher than the desired DHW delivery temperature.

The inlet and outlet connections of the brazed plate heat exchanger are equipped with combination isolation/flushing valves. These valves allow the heat exchanger to be isolated and flushed with a descaling fluid if necessary. Domestic water heating can also be provided using an indirect water heater connected as a shown in Figure 7-30.

Figure 7-30. Integrating an indirect domestic water heater into a biomass heating system



This system allows the existing/auxiliary boiler to provide supplemental heat for space heating and domestic water heating during the heating season. It also allows the existing/auxiliary boiler to supply heat directly to the indirect water heater if the pellet boiler is turned off during warm weather. Doing so reduces standby heat loss from the thermal storage tank during non-space heating months.

During the heating season, flow from the existing/auxiliary boiler is routed through the upper portion of the thermal storage tank, as previously described.

To switch from heating season to summer mode the three-way ball valve is manually turned 90°F to allow all flow exiting the existing/auxiliary boiler to pass into the coil heat exchanger of the indirect water heater. This flow is driven by circulator (P2). Flow returning from the indirect water heater goes back to the existing/auxiliary boiler. Circulator (P3) in Figure 7-30 must be turned off during summer mode. It's also possible to use a three-way motorized ball valve rather than the manually operated three-way ball valve, along with appropriate wiring so that summer/winter operation can be controlled by a switch.

Ideally, the water-to-air heat exchanger coil should be selected to provide design load heat output using a water temperature no higher than 120°F. Doing so allows a wide temperature cycling range within the thermal storage tank and helps ensure long on-cycles for the biomass boiler.

Note that flow from thermal storage to the coil of the indirect water heater only passes through the upper portion of the thermal storage tank. This is done for several reasons. First it provides the hottest water to the coil heat exchanger. Second, it prevents relatively hot water returning from the coil heat exchanger from breaking up temperature stratification, which would occur if this return flow were introduced into the lower portion of the thermal storage tank. Third, it recognizes that indirect water heaters have significant thermal mass, and as such, do not need significant buffering from thermal storage. This design relies on temperature stratification within the thermal storage tank to limit the amount of that tank's thermal mass which participates in the domestic water heating mode.

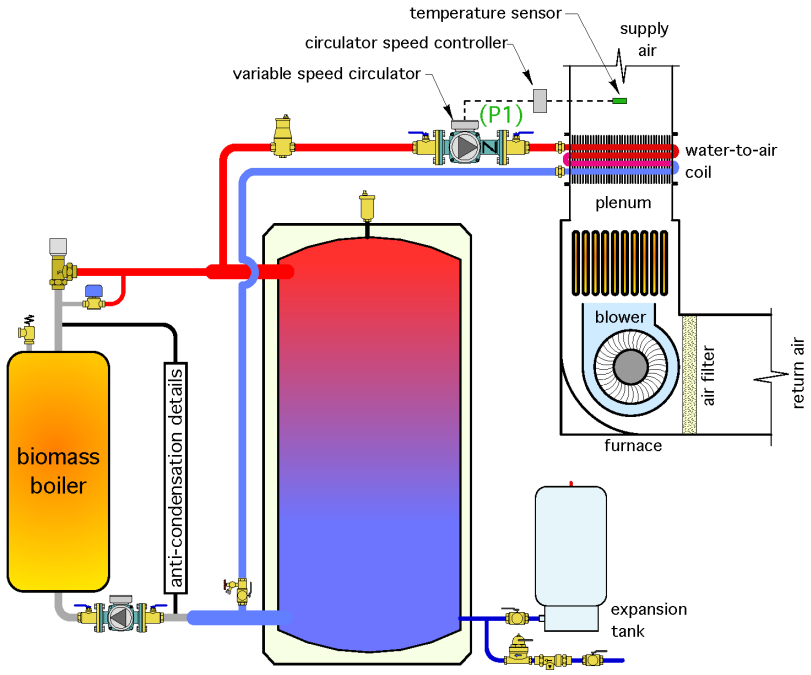
During the heating season, the existing/auxiliary boiler only operates when a load (e.g., space heating or domestic water heating) is in demand and only if the temperature at sensor (S3) drops below some minimum value. That minimum temperature must be high enough to allow adequate domestic water heating by the indirect water heater. A suggested value is at least 10°F above the desired domestic hot water delivery temperature.

One disadvantage to this approach is higher standby heat loss because of two thermal storage tanks being maintained at elevated temperatures during the heating season. Another shortcoming is that, for installations without an existing indirect water heater, the hardware cost is likely to be higher than that associated with the method shown in Figure 7-28.

7.17 Biomass Boiler Combined with Forced Air Distribution System

Many houses and light commercial buildings are heated by furnaces operating on conventional fuels. It's possible to add a biomass boiler and thermal storage to these systems, using the existing ducting system to deliver the heat. This is done by adding a water-to-air heat exchanger, commonly called a "hot water coil," to the discharge plenum of the furnace, as shown in Figure 7-31.

Figure 7-31. Use of a hot water coil to deliver heat through the existing ducting system in buildings with forced air distribution



Ideally, the water-to-air heat exchanger coil should be selected to provide design load heat output using a water temperature no higher than 120°F. Doing so allows a wide temperature cycling range within the thermal storage tank and helps ensure long on-cycles for the biomass boiler. This suggested temperature limit of 120°F for the coil will likely require it to have multiple tube passes, such as shown in Figure 7-32.

Figure 7-32. Water-to-air heat exchanger coil with multiple tube passes

Courtesy fo Allan Antcliffe, P.Eng.



The coil must also be evaluated for its air-side static pressure drop in relationship to the furnace's blower and ducting system. The coil's air-side static pressure drop must be low enough that the existing furnace blower can provide adequate air flow to the building with that air flow passing through the new coil. Furnace specifications typically list the static pressure capability of the blower along with associated air flow rates.

In situations where there is an existing direct expansion (DX) cooling coil mounted on the furnace plenum, it's likely that the furnace blower will not have sufficient static pressure to handle the new hot water coil in addition to the cooling coil. In these situations, it's better to use a separate air handler and damper system, which will be described shortly.

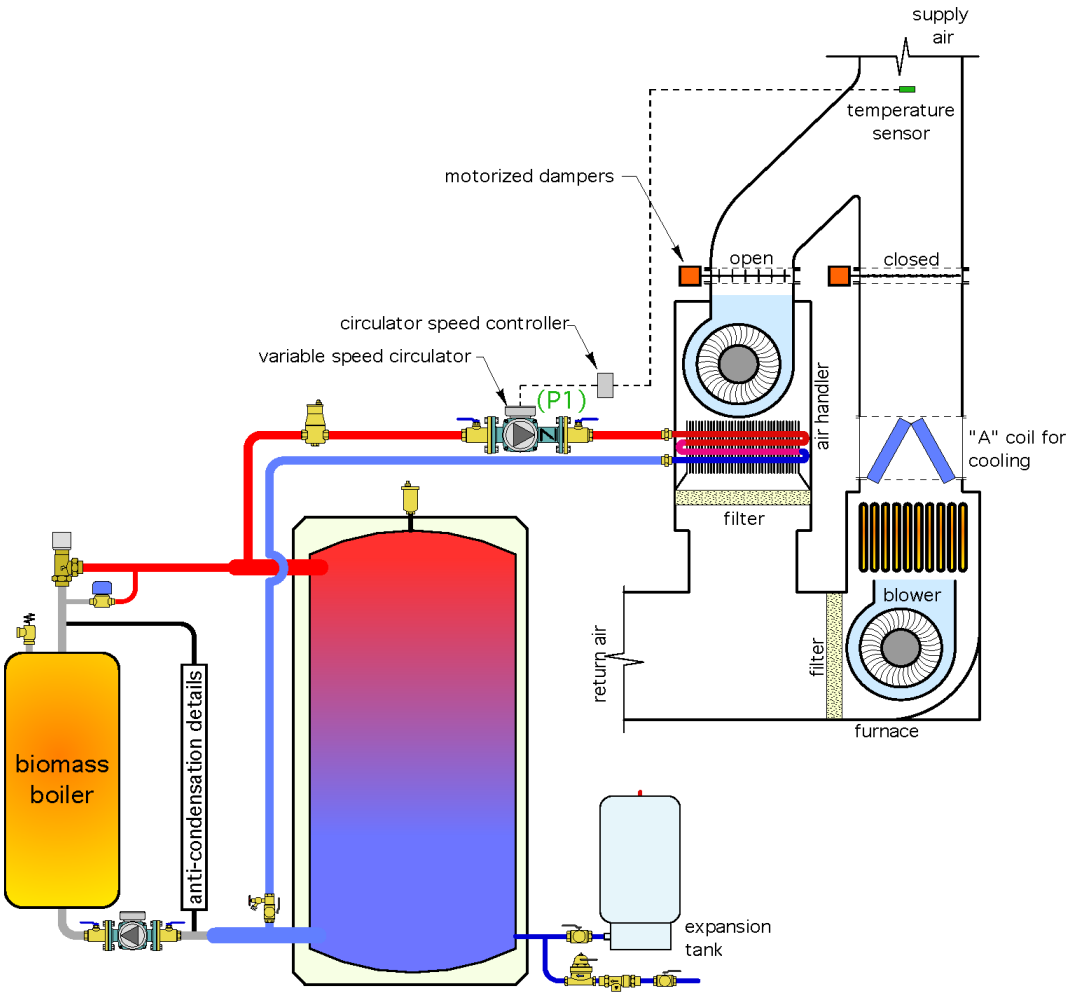
It's also important to regulate the heat transfer rate of the coil so that there is limited variation in the air temperature delivered to the ducting system. For the system in Figure 7-31 this regulation is accomplished using a variable speed circulator to control the hot water flow rate through the coil. The controller that regulates the circulator speed monitors the air temperature downstream of the coil. If this temperature begins to climb above the setpoint temperature, the circulator reduces the water flow rate through the coil and vice versa. The water temperature to the coil can also be regulated using a three-way motorized mixing valve. In either case, the variation in water flow rate through the coil should be based on an "equal percentage" characteristic, in which the flow rate increases slowly at low-flow rates, and higher at higher flow rates. This allows the heat output from the coil to vary in approximate proportion to the coil's flow rate.

When the water temperature at the upper header of the thermal storage tank is at least some user-set differential above the required air delivery temperature, a control system turns on the furnace's blower, the variable speed circulator controller, and the variable speed circulator. The controller regulates the speed of circulator (P1) as needed to maintain the required air delivery temperature.

If the water temperature in the tank is below the minimum value when a call for heating occurs, circulator (P1) and the circulator speed controller remain off. The furnace blower and burner provide all heat to the forced air delivery system. The control system needs to integrate with the thermostat wiring for fan operation during times when heat is supplied from the biomass boiler + thermal storage. It's also important to use a check valve, or circulator with an internal check valve in the coil circuit. This prevents heat produced by the furnace's burner from reverse thermosiphoning through the coil circuit. Do not mount the water-to-air coil on the return side of the furnace. Doing so will void the warranty of most current generation furnaces.

If adequate static pressure is not available from the furnace blower to accommodate the water-to-air coil it will be necessary to use a separate air handler and damper system. An example of such a system is shown in Figure 7-33.

Figure 7-33. Separate air handler and damper system to accommodate the water-to-air coil when static pressure from furnace blower is not sufficient



In this system, an air handler with water-to-air heat exchanger coil delivers heat from the biomass boiler + storage. Normally closed motorized dampers are installed in the supply plenum of the air handler and the furnace. The damper above the air handler opens when the air handler is operating and closes at all other times. The motorized damper above the furnace remains open except when the air handler is operating. The flow rate of hot water through the air handler coil is again controlled by the variable speed circulator (P1).

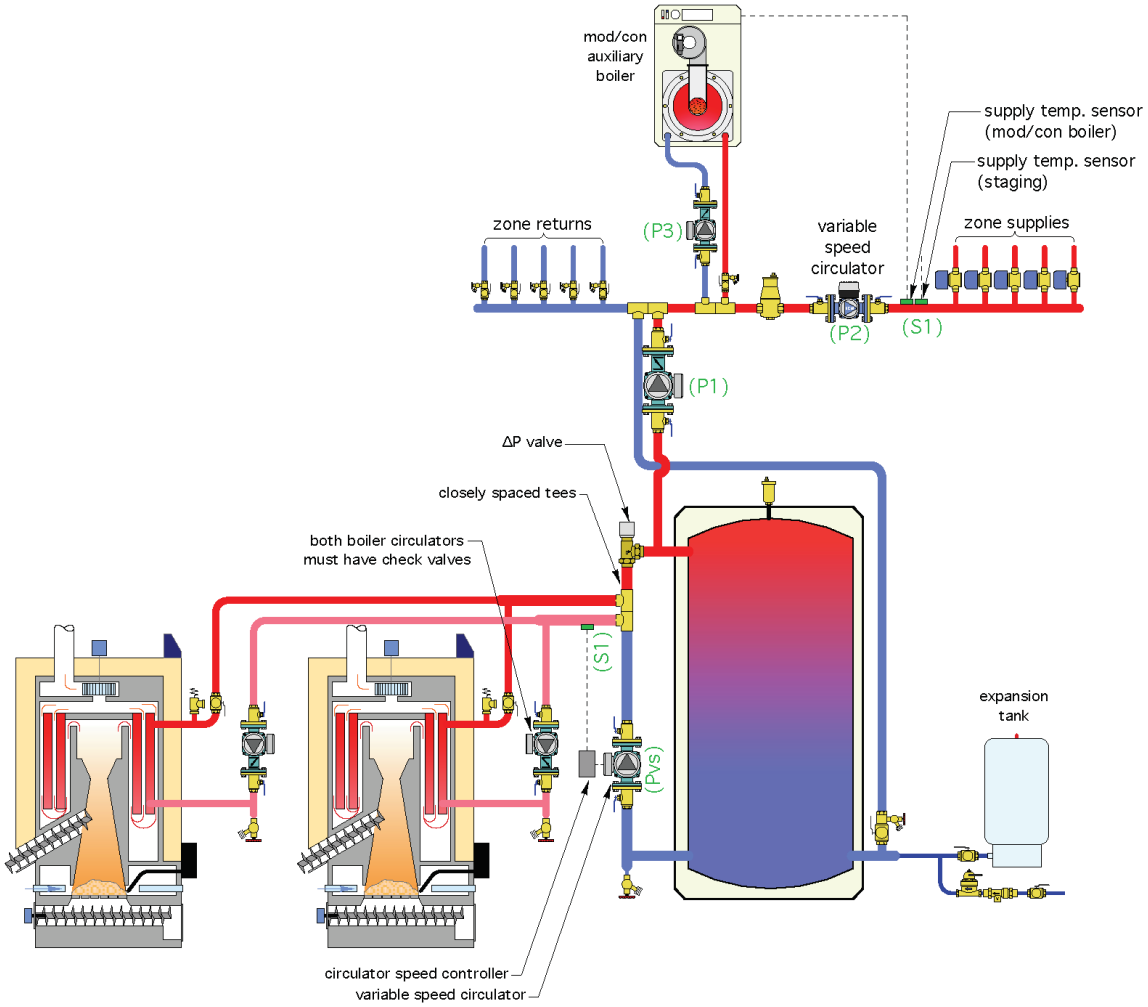
The controls for this system could be based on a two-stage room thermostat. The first stage would operate the air handler, its associated motorized damper, and circulator (P1). The second stage would operate the furnace and its associated motorized damper. The controls must be configured to turn off the air handler, its motorized damper, and circulator (P1) whenever the second stage (e.g., the furnace) is called into operation. If this is not done, heat from the furnace will be inadvertently moved into the thermal storage tank.

7.18 Multiple Pellet Boiler System Configuration

When design loads are high, such as above 300,000 Btu/hr or more, it's possible to use two or more biomass boilers in a staged configuration rather than a single large boiler. This approach has several advantages including (1) smaller boilers controlled in stages provide better load matching compared to a single large boiler. This increases the on-cycle duration of the boilers relative to that of a single large boiler and thus improves thermal efficiency and reduces emissions; (2) because of improved load matching it may be possible to reduce the size of the thermal storage tank relative to the tank volume that would be required for a single large boiler; and (3) using two or more boilers provides redundancy that allows one boiler to supply heat to the load if the other boiler is down for maintenance.

Figure 7-34 shows a system with two pellet boilers serving as the primary heat source and a single oil-fired boiler serving as the auxiliary heat source.

Figure 7-34. Two pellet boilers serving as the primary heat source and a single mod/con boiler serving as the auxiliary heat source



Each pellet boiler has its own circulator with internal check valve, which operates when its associated boiler is firing, and remains off at other times. This prevents extraneous heat loss that would occur if heated water was circulated through an unfired boiler. The ΔP valve prevents forward or reverse thermosiphoning from the thermal storage tank through external piping. In larger systems the ΔP valve could be replaced by a motorized ball valve that opens whenever one or both pellet boilers are operating.

The boilers are fired independently of any demand from the distribution system. They are fired based on the temperature at four locations within the thermal storage

Each pellet boiler circulator also has a spring-loaded check valve to prevent reverse flow when only one boiler is operating.

Anti-condensation protection for the pellet boilers is provided by a variable speed shuttle circulator (Pvs). Its speed is regulated based on the water temperature returning to either pellet boiler. At return temperatures below 130°F, the shuttle circulator is off. It reaches full speed when the return temperature to the pellet boilers is 5–10°F higher than the starting temperature.

The boilers are fired independently of any demand from the distribution system. They are fired based on the temperature at four locations within the thermal storage tank. Boiler number one is fired when the temperature at sensor S2 drops below some minimum setpoint, determined by the type of heat emitters used. It continues to operate until the temperature at sensor S4 reaches a relatively high setpoint. Boiler number two will fire if the temperature at sensor S1 drops a few degrees below the minimum temperature required at design load and will remain on until the temperature at sensor S3 reaches a relatively high setpoint. Thus, this system uses a “double version” of the temperature stacking control concept described earlier in this section for a single pellet boiler application.

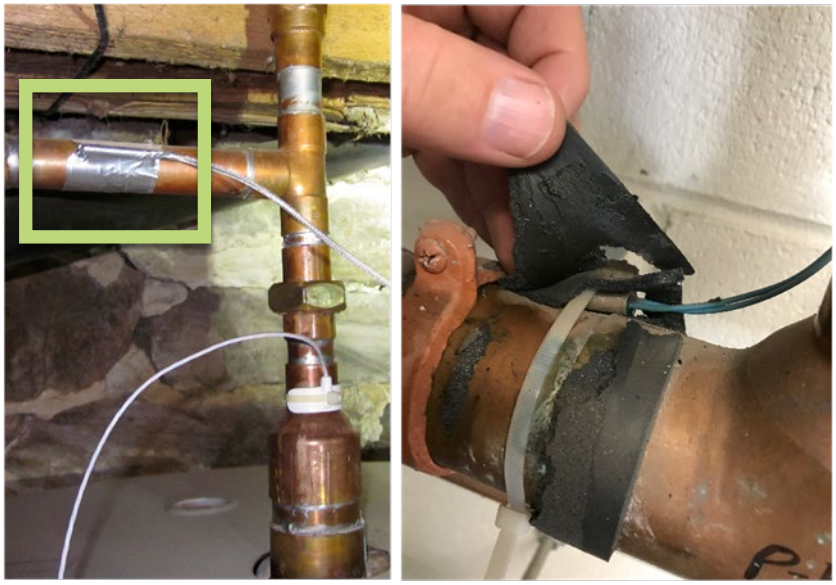
Heat from the pellet boilers or storage is transferred into the distribution system by circulator P1. That circulator can be operated as on/off or as a variable speed shuttle circulator. System number 8 in section 8 provides more information on how the controls for this system could be configured.

7.19 Temperature Sensor Details

Most of the controllers discussed in this manual rely on temperature sensors. Control actions are based on the temperature information these sensor report to their associated controller(s). Accurate temperature sensing is critical for accurate control. The accuracy of most sensors used with modern controllers is a fraction of 1°F. However, the ability of the temperature controller to react to specific user-desired settings is very dependent on how the sensor is mounted.

Field observations have shown that unexpected control action can be partially (and sometimes totally) traced to poorly mounted temperature sensors.

Figure 7-35. Temperature sensors that have been improperly mounted



The temperature sensor seen inside the green box of Figure 7-35 is taped to the copper tubing. The intended purpose was to measure water temperature in the upper portion of a thermal storage tank—the top of which is seen just below the piping. Instead, this sensor is measuring a temperature somewhere between that of the tube surface and the surrounding air. The pellet boiler in this system was fired based on the temperature of this sensor. Boiler operation was not as expected.

The sensor seen in the right-side photo is poorly insulated from surrounding air temperature, and as such cannot accurately report the surface temperature of the copper tube it is strapped to. Most sensors used with modern HVAC controllers are negative temperature coefficient thermistors. They have a very repeatable electrical resistance at a given temperature. The term "negative temperature coefficient" means that sensor resistance decreases as the temperature increases.

The solid-state thermistor bead in a typical thermistor sensor is very small. This bead is typically mounted by its manufacturer in a small metal housing with two lead wires extending from it. These lead wires are usually not long enough to reach from the sensor's installed location to the controller. Therefore, a cable must be used to complete the circuit between the sensor and controller. The sensor and cable together form the sensor circuit, and the resistance of the sensor circuit is what the controller feels. Adding significant resistance to this circuit makes the controller think that the temperature at the sensor is lower than the actual temperature.

The sensor and cable together form the sensor circuit, and the resistance of the sensor circuit is what the controller feels.

Designers should verify the minimum wire size (e.g., the largest AWG number) that the controller manufacturer allows for connecting the sensor to the controller as well as verify the maximum sensor cable length. In most applications, insulated 18 AWG copper conductors within a cable are sufficient to extend the sensor leads to the controller.

The sensor cable should never be routed in the same conduit or electrical raceway as line voltage wiring. Strong electromagnetic fields in the vicinity of sensor cables can induce voltage into the sensor circuits that affect how the controller reacts. If the sensor cable must pass adjacent to equipment that creates strong magnetic fields, control manufacturers often recommend use of “twisted pair” or shielded cable. The latter wraps the individually insulated conductors within an aluminum foil shield which itself is surrounded by the outer cable jacket. One end of this foil shield needs to be connected to a grounded electrical device, and the other end should be electrically isolated and not fastened to anything.

The bond between the sensor lead wires and the sensor cable can, under some circumstances, add significant resistance to the circuit. One situation where this has created problems is where sensor lead wires are connected to cables using standard wire nuts and then exposed to moisture. This leads to corrosion at the bond between the sensor leads and the cable wires. Over time this increases the resistance of the sensor circuit, which makes the controller interpret the sensor temperature as lower than the actual temperature.

If it’s necessary to make the electrical junction in an area that could be exposed to moisture, the joint should be made with the gel-fired compression connectors typically used for exterior telephone wiring connections. Another possibility is to solder the lead wires from the sensor to their respective cable wires, and then seal the joint tightly with a heat shrinkable sleeve.

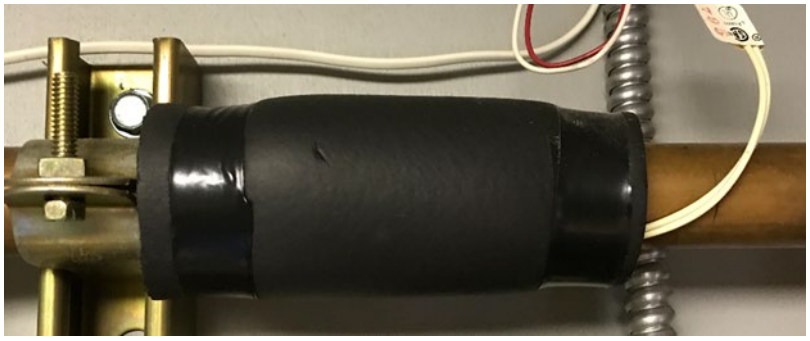
7.20 Sensor Mounting

Sensors that are improperly mounted can report temperatures that are significantly different from the temperatures they are intended to measure. The ideal mounting scenario places the tip of the sensor housing directly in the fluid being measured. Direct immersion sensors with threaded enclosures are available for some controllers but are less common for basic temperature controllers used in HVAC systems compared to sensors with simple cylindrical housings. Direct immersion sensors are more commonly used for heat metering equipment where high accuracy is required.

Direct immersion sensors must be threaded into connections that form pressure tight seals. The sensor dimensions must also be small relative to the pipe diameter so that the sensor’s presence does not create significant flow resistance. One drawback of direct immersion sensors is that a sensor failure and subsequent replacement involves opening the piping circuit which requires some fluid drainage and replacement.

Sensors with simple cylindrical housings can be mounted on the surface of copper piping. They can also be positioned into a well that threads into an FPT tapping in the system piping or other components. Sensors mounted to piping surfaces should be placed with any flat or slightly concave portion of their housing directly against a clean copper pipe surface. The housing is then strapped in place using *two* nylon-pull ties. The pull ties should be rated to withstand the maximum possible temperature of which the sensor could be exposed. Low-quality pull ties will weaken over time when exposed to high temperatures and could eventually break. Once the sensor is strapped to the pipe it should be covered with an insulated sleeve that extends at least 3 inches out from each end of the sensor housing. The ends of the insulation sleeve should be wrapped with high-quality electrical tape to seal the insulation sleeve to the pipe, ensuring that no air can pass between the pipe surface and the sleeve. The lead wires from the sensor should also be fastened to some nearby surface to provide a strain relief in case the sensor cable is accidentally pulled. Figure 7-36 shows an insulation sleeve installed over a small thermistor sensor that has been strapped to the outside of a copper pipe.

Figure 7-36. Insulation sleeve installed over a small thermistor sensor



When the temperature of water in a thermal storage tank is to be measured, the sensor should be mounted in a well that's threaded into an appropriate tapping on the tank.

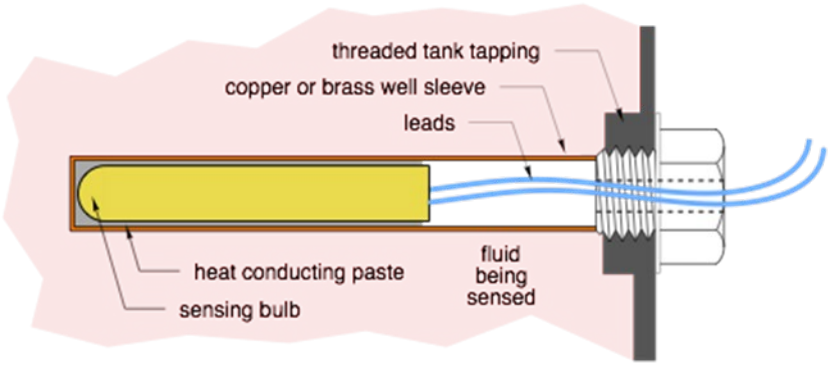
Figure 7-37 shows a Honeywell 121371B copper sensor well and a three-eighths inch diameter thermistor sensor that fits properly inside that well. These wells are available in either half or three-quarter inch MPT threads. Many thermal storage tanks have half or three-quarter inch FPT threaded tappings to accept these wells. When this type of well needs to go into tanks with 1.5 or 2 inch FPT tappings, use a brass or stainless-steel bushing for the size transition.

Figure 7-37. Homeywell 121371B copper sensor well



Before inserting the sensor, a small amount of thermal paste should be injected into the end of the well using a plastic syringe. The sensor body should also get coated with thermal paste. The objective is to completely fill the gap between the sensor body and inside surface of the well with thermal paste, as shown in Figure 7-38.

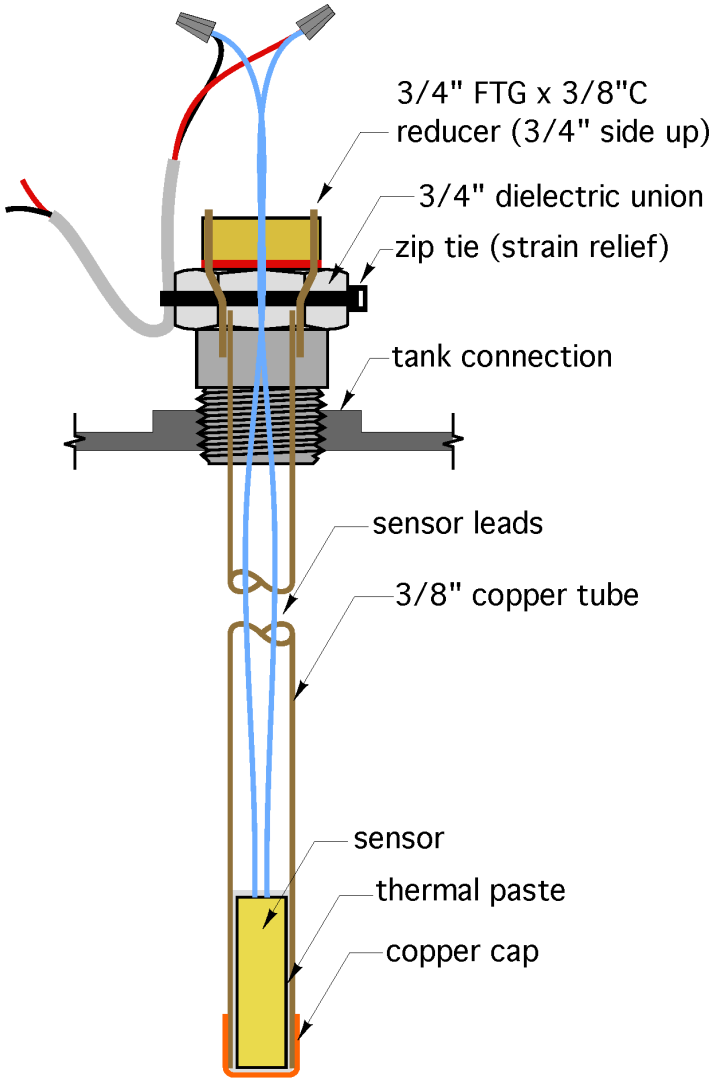
Figure 7-38. Illustration of the proper placement of a sensor in a well



Thermal paste reduces thermal resistance between the inside of the well and the sensor, and temperature measurement accuracy improves. Thermal paste also reduces the time lag between changes in temperature of water surrounding the well and when those changes are detected by the sensor.

For situations where a commercial sensor well is not adequate, it's possible to make a sensor well using copper tubing closed at the end with a soldered cap, as shown in Figure 7-39.

Figure 7-39. Illustration of a custom-made sensor well



The length of the well can be whatever is required. This is helpful when a sensor needs to be located at a specific height in the tank, and the well needs to be mounted from the top of the tank. Be sure there's adequate head room to insert the well. If not, mount the well in the tank before the tank is positioned.

The three-eighths inch type M copper tube called out in Figure 7-39 has an inside diameter of 0.450 inches. A three-eighths inch diameter sensor housing fits into this tubing, leaving about one-thirty-second inch gap between the sensor house and inside of the tube. This gap should be filled with thermal paste. The three-eighths inch tube can be sealed to a three-quarter inch MPT adapter, using a brass slip bushing.

It's also important to provide strain relief for the wires connecting the sensor leads to the cable—a temperature-rated zip tie holding the sensor cable to the exterior portion of the well or other nearby solid surface is generally acceptable.

Also, be sure to label and tag every sensor in the system. Label the sensors on the piping and electrical schematics as you design the system and attach tags to the sensors as they are installed.

7.21 Boiler-to-Storage Flow Rate

One condition 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 break up temperature stratification and reduce the temperature difference between the top and bottom of the thermal storage tank. A suggested maximum flow rate is one that yields a nominal 20°F temperature rise across the biomass boiler when it is operating at full capacity.

One condition that has been observed on several biomass boiler systems is excessively high-flow rate between the boiler and thermal storage.

Even higher temperature rises of 25–30°F across the biomass boiler are preferred if allowed by the boiler manufacturer. The higher the temperature rise across the boiler, the lower the required flow rate between the boiler and thermal storage tank. Lower flow rates entering the thermal storage tank reduce mixing and help preserve temperature stratification. They also reduce the size and power requirement of the boiler circulator.

The relationship among boiler capacity, temperature rise, and flow rate can be determined using formula 7-1.

Formula 7-1:

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

Where:

f = boiler flow rate (gpm)
Q = rated boiler output (Btu/hr)
ΔT = temperature rise across boiler (°F)
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°F temperature rise (e.g., difference between inlet and outlet temperature) in a system using water would require a flow rate of:

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

This is a low-flow rate that could be accommodated using one-inch piping and a relatively small circulator.

7.22 Storage to Load Flow Rate

It's also important not to breakup temperature stratification within a thermal storage tank due to excessively high-flow rate between the tank and the load. A suggested minimum temperature drop for the distribution system under design load conditions is 20°F. Slightly higher temperature drops of 25–30°F are advantageous but require careful planning and selection of heat emitters. Radiant floor panel circuits in residential applications should generally be limited to temperature drops of 15–20°F. Radiant floor circuits used in commercial or industrial buildings can have temperature drops of 20–25°F under design load conditions.

8 System Design Templates

The first seven sections of this manual provided an overview of cordwood gasification boilers and pellet boilers and discussed important system-design details. This section combines information from previous sections into several system-design "templates" for residential and commercial applications.

Each template includes a summary description of the system, a piping schematic, an electrical control schematic, a description of operation, and possible controller settings that are appropriate given the design and anticipated operating conditions.

These templates are presented as starting points for subsequent system design. Although well documented, the templates do not represent complete installation documentation for any specific system. Designers remain responsible for selecting particular hardware and controller settings that could facilitate the concepts represented by any of these templates. It is also the designer's responsibility to verify that any systems developed from these templates fully conform to any applicable building, energy, or mechanical codes in the jurisdiction where the system will be installed.

These templates are presented as starting points for subsequent system design. Although well documented, the templates do not represent complete installation documentation for any specific system.

8.1 System 1

This space heating-only system is based on a common situation where an existing hydronic system with an oil-fired boiler supplies multiple zones of fin-tube baseboard. The flow in each zone is controlled by a small zone circulator. A pellet boiler is retrofitted to the system.

The pellet boiler is fired based on upper and lower temperature sensors in the thermal storage tank and operates independently of any call for space heating from the zone thermostats. The pellet boiler is turned on based on the outdoor reset control at the upper temperature sensor and turned off when the lower temperature sensor reaches a setpoint of 175°F. This yields a wide temperature swing in the thermal storage tank which leads to longer pellet boiler on-cycles, higher efficiency, and lower emissions. The warmer the outdoor temperature, the greater the temperature cycling range of the thermal storage tank. The pellet boiler is protected against sustained flue-gas condensation by a thermostatic loading unit.

Whenever a zone load is active, an outdoor reset controller monitors the supply temperature to the distribution system. If it detects that the supply water temperature is 10°F or more below its calculated target value, it turns on the oil-fired boiler and associated circulator. This relatively wide differential minimizes the possibility for short cycling the oil-fired boiler, given that it is not buffered by the thermal storage tank.

A three-way thermostatic mixing valve has been added to the oil-fired boiler piping to protect the boiler against sustained flue-gas condensation when the distribution system is operating at low temperatures. This detail allows for a substantial temperature reset of the distribution system, which allows wider temperature swings of the thermal storage tank under partial-load conditions.

The circulator carrying heat from thermal storage to the distribution system (P2) can only operate when the temperature at the upper header of the thermal storage tank is at least 5°F above the temperature on the return side of the distribution system. This prevents heat produced by the oil-fired boiler from being inadvertently moved into thermal storage. The thermal storage tank is piped in a two-pipe configuration. A motorized ball valve with a spring-return actuator closes to prevent flow through the pellet boiler whenever the circulator (P1) is off.

Because there is no mixing device in the distribution system there will be times when high-temperature water (up to 190°F) is delivered to the baseboards. There will also be times when the water temperature supplied to the baseboards is lower, but always warm enough to meet the current space heating load. This is acceptable given that fin-tube baseboard has low-thermal mass. The room thermostats will compensate for the different rates of heat output from the baseboard by varying the “on-time” of the zone circulators.

This system includes a normally open zone valve that opens during a power outage to provide an unblocked piping path between the pellet boiler and thermal storage tank. A thermosiphon will develop through this piping path to dissipate residual heat from the pellet boiler into the storage tank. Some boiler suppliers do not require this “heat dump” provision, so it will be treated as optional.

Figure 8-1a. Piping schematic for system 1

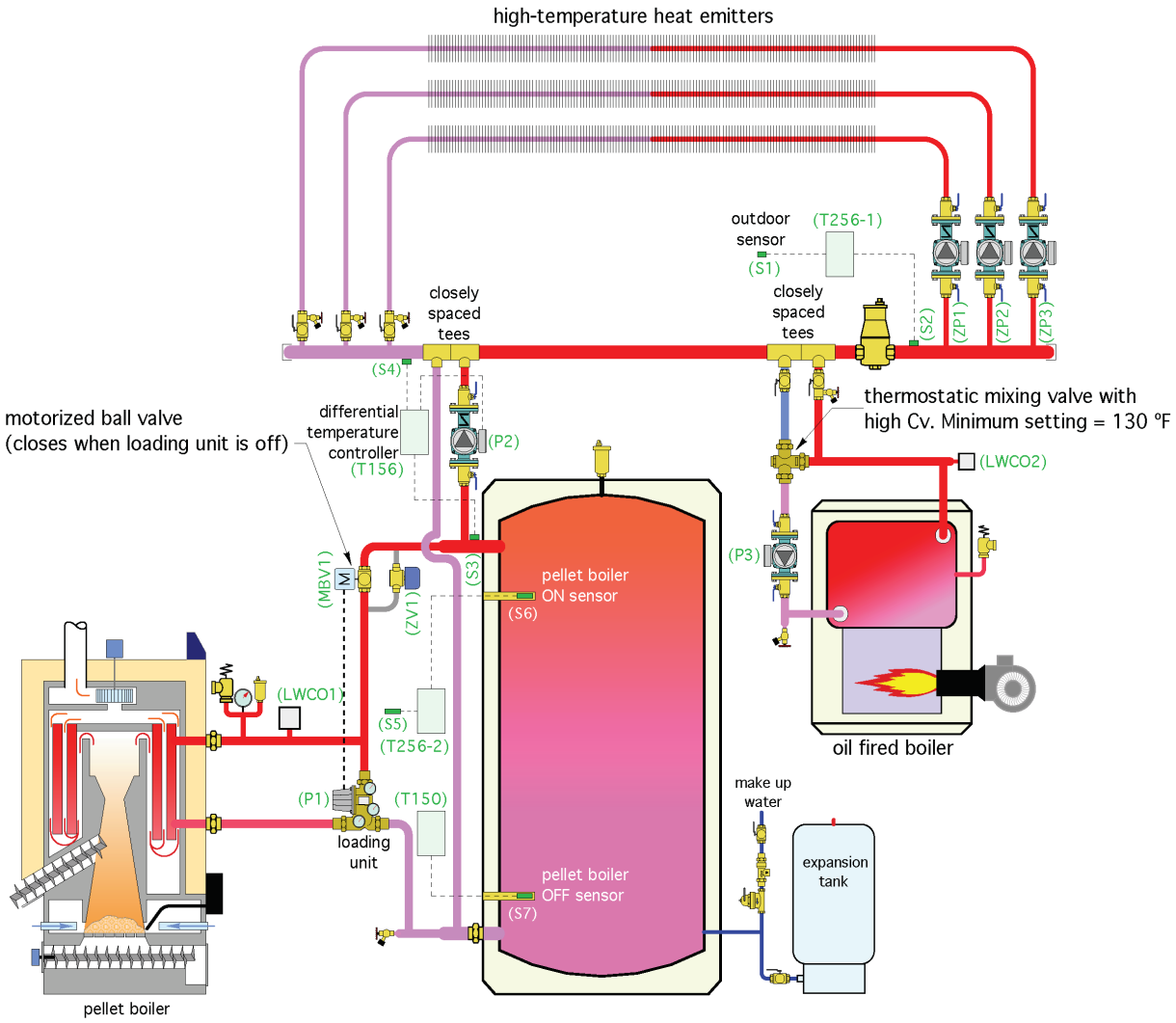
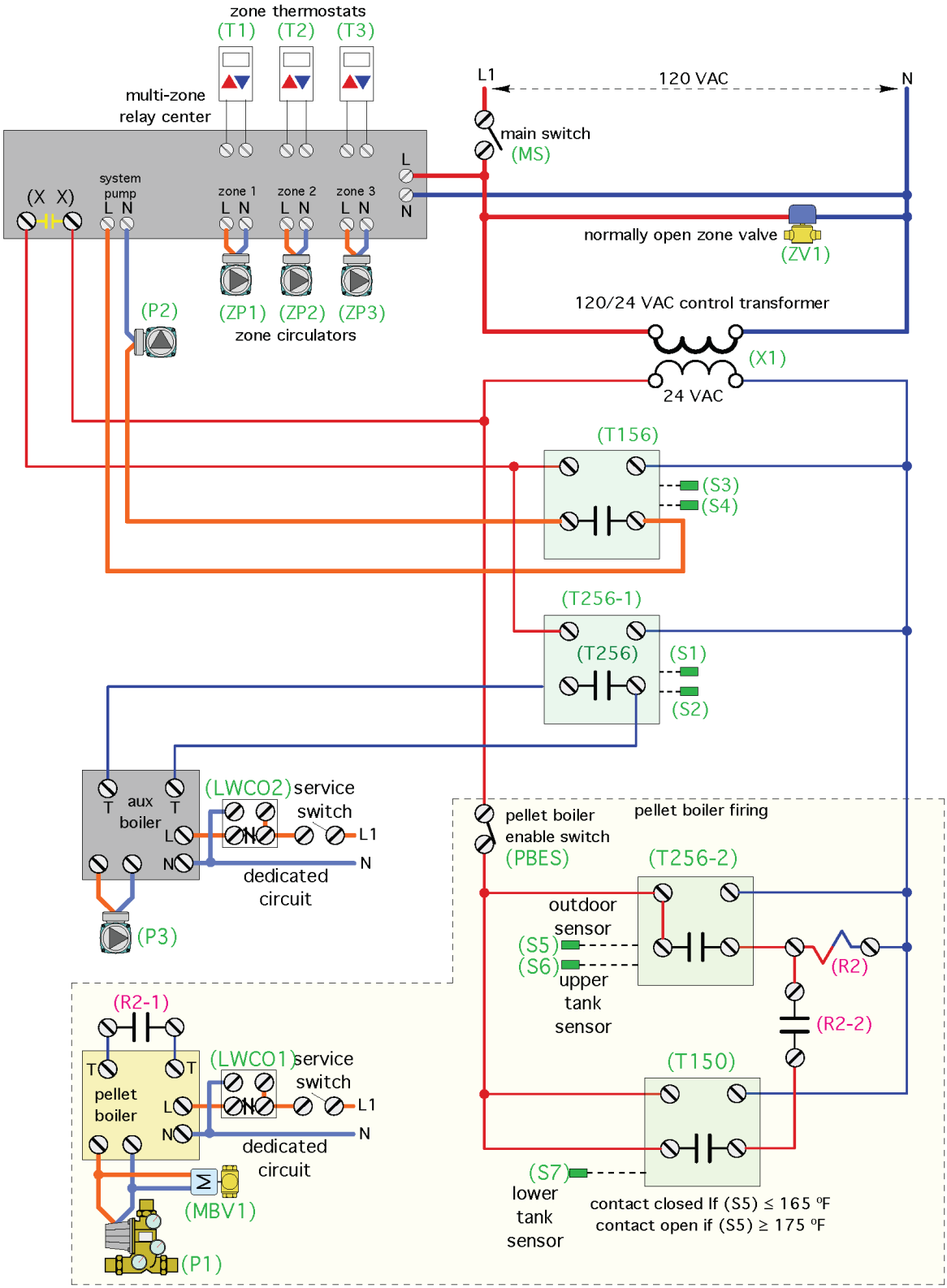


Figure 8-1b. Electrical schematic for system 1



8.1.1 Description of Operation for System 1

Power supply: Power for the pellet boiler is 120 VAC and 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.

Power for the auxiliary boiler is 120 VAC and 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, 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 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°F 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 startup 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 the 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°F 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°F. At that point, the contacts in setpoint controller (T150) open, breaking 24 VAC 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 and thus avoid sustained flue gas condensation.

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 dissipates residual heat from the pellet boiler into thermal storage.

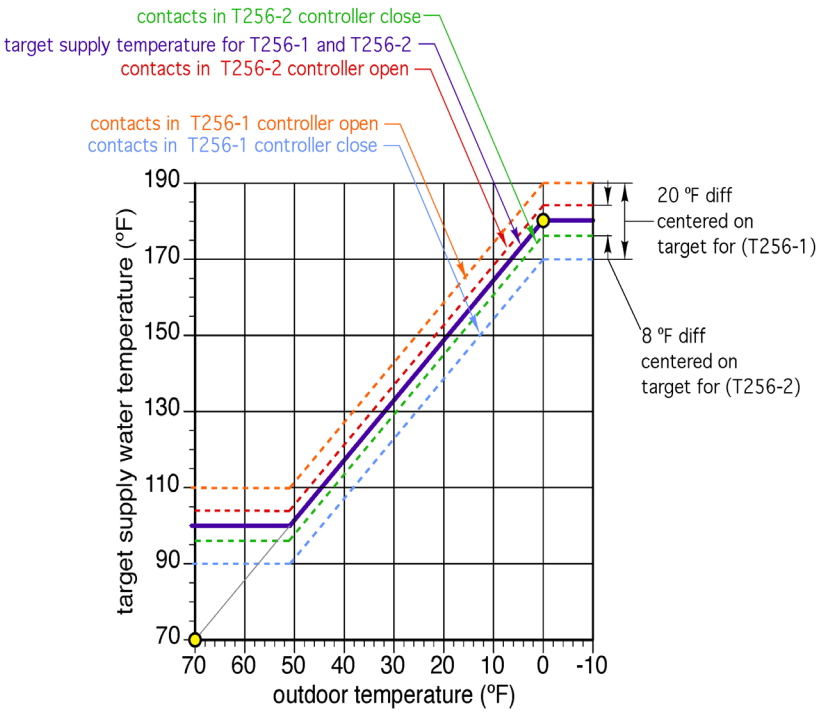
If the pellet boiler switch (PBES) is opened, such as at the end of the space heating season, the pellet boiler, its associated controllers, and its circulator (P1) will not operate.

Distribution system: On a call for heating from any zone thermostat (T1, T2, T3), the associated zone circulator (ZP1, ZP2, ZP3) is turned on. The “system pump” terminals in the multizone relay center, also are energized with, 0120 VAC. The isolated relay contact (X X) in the multizone relay center closes, passing 24 VAC 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°F above the return water temperature, the contacts in the (T156) controller close. This allows 120 VAC 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°F or more below the target supply water temperature the contacts in the (T256-1) controller close across the terminals (T T) 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°F 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°F 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 (S2) will eventually drop to 10°F below the target temperature, at which time the oil-fired boiler and circulator (P3) will turn on. Note: The high limit controller on the oil-fired boiler should be set relatively high (200 ºF suggested) so that it will not interfere with operation of the (T256-1) outdoor reset controller.

Suggested controller settings: Figure 8-1c shows how the two outdoor reset controllers (T256-1) and (T256-2) would be configured based on the description of operation.

Figure 8-1c. Suggested settings for (T256-1) and (T256-2) outdoor reset controllers in system 1



8.1.2 Suggested Settings for System 1

- 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 temperature 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 = 10°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)

8.2 System 2

This system is appropriate for situations where the distribution system has extensive zoning, requiring zone valves, and where domestic water will be produced, using heat from the pellet boiler when it's available during the heating season. When the pellet boiler is turned off during warmer weather, domestic water is heated by the existing/auxiliary boiler, using an on-demand subsystem.

This system is also suited to circumstances where the existing boiler short cycles due to zoning and/or oversizing. It could also be applied in new installations.

There are several similarities with system 1 including the methods used for pellet boiler operation, anti-condensation protection, and differential temperature control for determining when thermal storage can contribute heat to the space heating loads. This system does *not* include a “heat dump” provision. That provision, if desired, can be easily implemented by adding a normally open zone valve as shown in system 1 (Figure 8-1a).

The pellet boiler is turned on by the temperature at the upper tank sensor based on outdoor reset control. It continues to fire until the temperature sensor in the lower portion of the tank reaches a relatively high temperature. This control logic is completely independent of the heating zones' status or demand for domestic hot water and executes whenever the pellet boiler enable switch is closed.

This system uses a thermal storage tank with a two-pipe configuration. A ΔP valve, set for 1.0 psi prevents flow through the pellet boiler when its associated circulator is off. This valve also prevents reverse thermosiphoning from the thermal storage tank through the boiler and associated piping

The boiler is protected against sustained flue-gas condensation by a loading unit with a set temperature of 130°F. The bypass port of the loading unit is fully closed when the water temperature in the loading unit reaches 148°F.

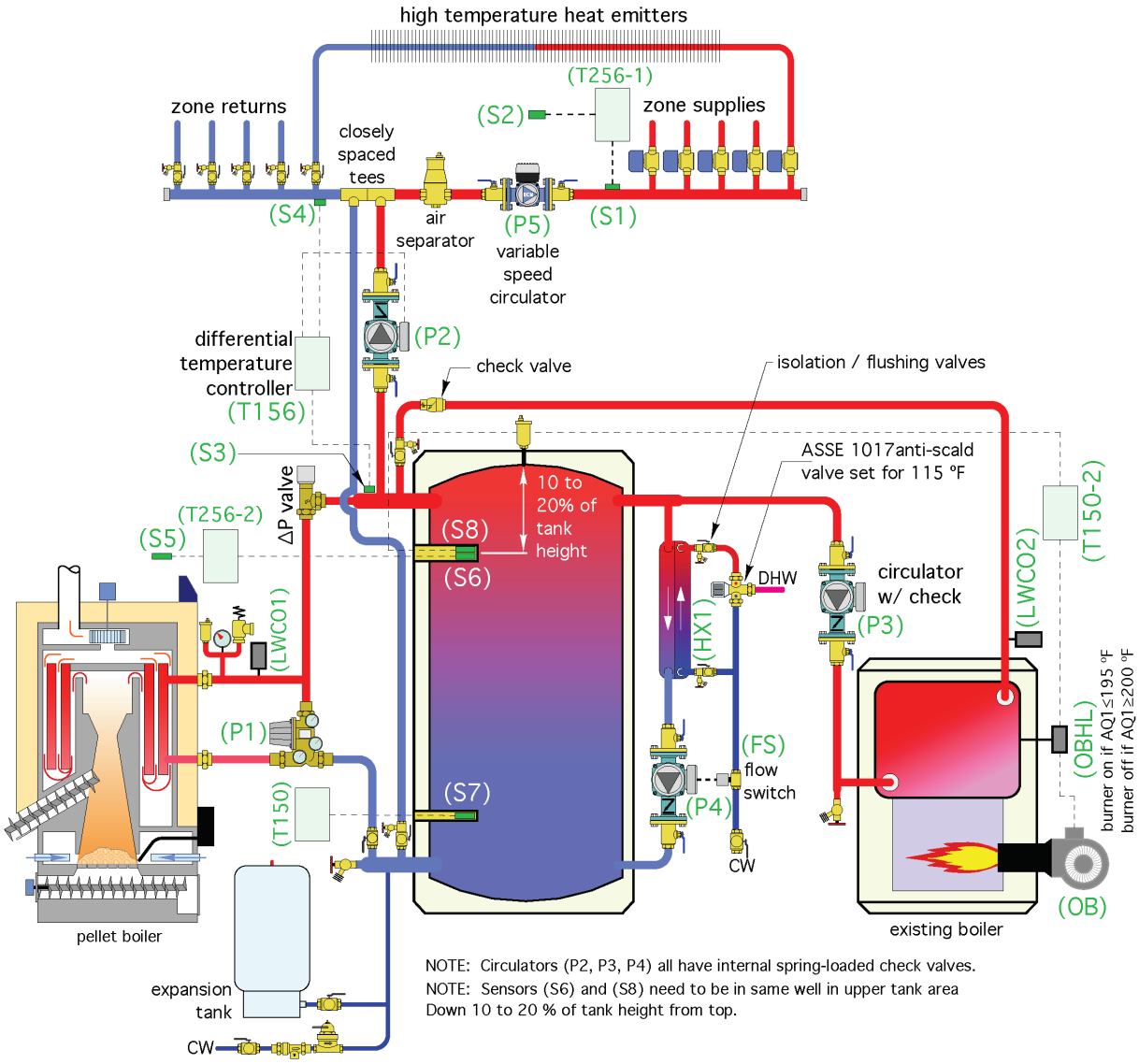
The existing/auxiliary boiler is piped so that it heats the upper portion of the thermal storage tank. The thermal mass of the upper 10-20% of the tank helps buffer the existing (oversized) boiler against short cycling. If the pellet boiler cannot maintain a temperature of at least 120°F at the top of the tank, the auxiliary boiler fires to do so. The heated water reserve at the top of the tank can be immediately used for either space heating or domestic water heating.

When there is a space heating demand from any zone thermostat the associated zone valve opens, and circulator (P5) is turned on. Circulator (P5) automatically changes speed to maintain a constant differential pressure regardless of which heating zones are active. When there is a demand for heat from one or more of the zone thermostats, and the temperature at the upper tank header is at least 5°F above the temperature on the return side of the distribution system, circulator (P2) is turned on, and hot water is delivered to a set of closely spaced tees in the system. These tees provide hydraulic separation between circulator (P2) and the variable speed pressure-regulated circulator (P5).

Domestic water is heated “on-demand” by transferring heat from the hot water reserve at the top of the thermal storage tank to cold domestic water through a stainless-steel heat exchanger. This occurs when a flow switch detects a demand for domestic hot water of 0.6 gallons per minute or more. An anti-scald mixing valve prevents hot water at temperature over 115°F from entering the domestic hot water distribution piping.

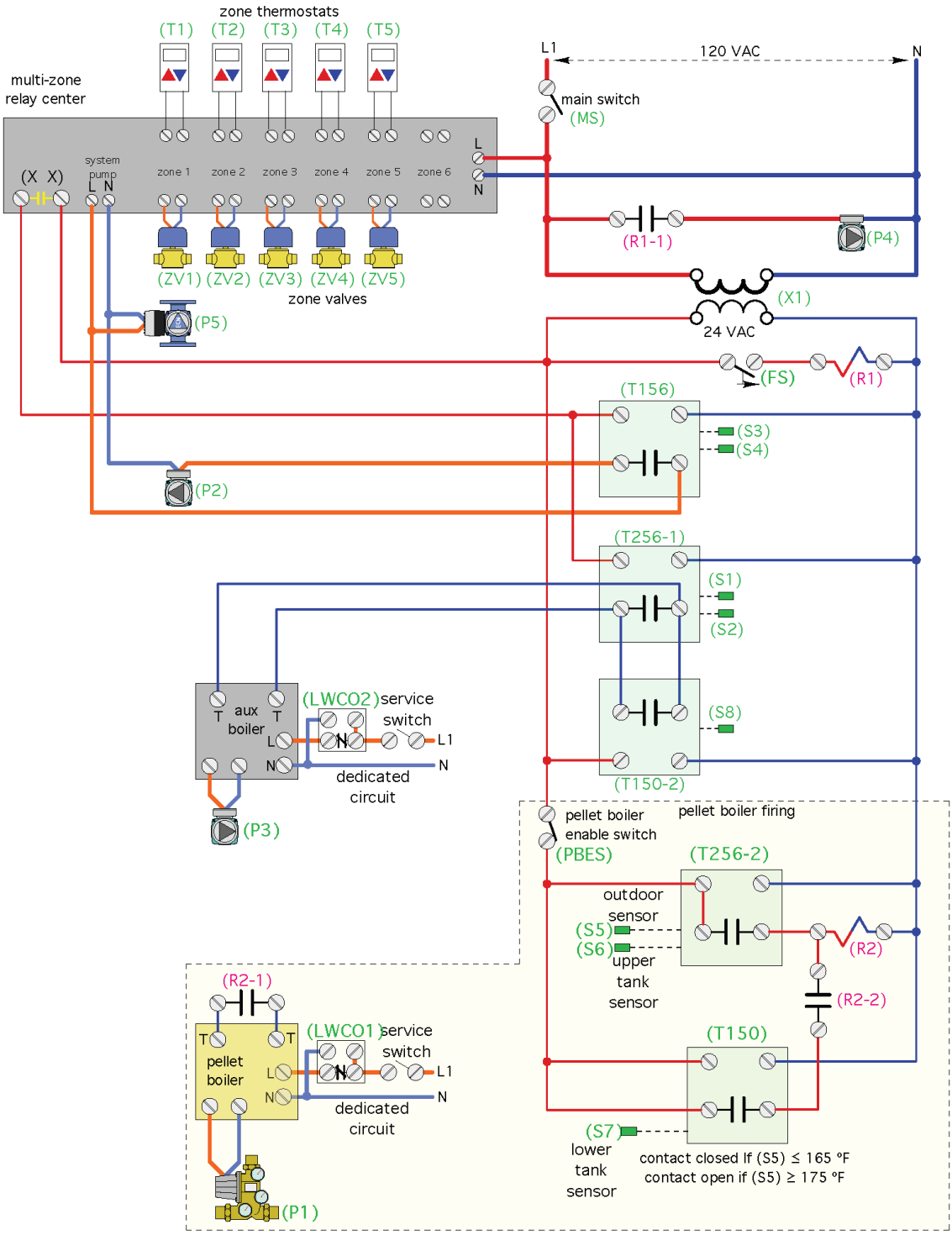
The pellet boiler can be turned off during warmer weather by the pellet boiler enable switch (PBES). With the pellet boiler disabled, the temperature setpoint controller (T150-2) operates the oil-fired boiler and circulator (P3) to maintain temperatures at the top of tank between 120°F and 140°F so that domestic water can be heated on demand. Heat migration from the tank is reduced by the use of a ΔP valve, a spring-loaded check valve in circulator (P2), and a spring-check valve in the auxiliary boiler piping.

Figure 8-2a. Piping schematic system 2



NOTE: Sensors (S6) and (S8) need to sense temperature at the same location in the tank and must be mounted in the same well, which should be located 10–20% of tank height down from top.

Figure 8-2b. Electrical schematic system 2



8.2.1 Description of Operation for System 2

Power supply: Power for the pellet boiler is 120 VAC and 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.

Power for the existing/auxiliary boiler and circulator (P3) is 120 VAC and 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, P5), 24 VAC transformer and controllers (T156, T256-1, T150-2, T256-2, T150)is supplied through another 120 VAC dedicated circuit powering transformer (X1). The main switch (MS) for this circuit must be closed for these devices to operate.

Pellet boiler operation: The pellet boiler enables switch (PBES) 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 season. When the (PBES) is closed, 24 VAC is supplied to outdoor reset controller (T256-2) and temperature setpoint controller (T150). 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 8-2. When the temperature at the upper tank sensor (S6) drops to 2°F 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 routine. Relay contact (R2-2) also closes. 24 VAC pass 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 2°F 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°F. At that point, the contacts in setpoint controller (T150) open, breaking 24 VAC 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 boiler's water temperature to quickly climb above the dewpoint of the exhaust gases. If the pellet boiler switch (PBES) is opened, such as at the end of the space heating season, the pellet boiler and its associated controllers (T256-2) and (T150) as well as its circulator (P1) will not operate.

Space heating distribution system operation: On a call for heating from any zone thermostat (T1, T2, T3, T4, T5), the associated zone valve and variable speed circulator (P5) is turned on the by the multizone relay center (MZRC). 24 VAC from transformer (X1) pass through the (X X) terminals of the multizone relay center (MZRC) and turns on differential temperature controller (T156) and outdoor reset controller (T256-1). The (T156) measures the temperature at the return side of the distribution system at sensor (S4) and compares it to the temperature of the upper tank header at sensor (S3). If the temperature at (S3) is at least 5°F higher than the temperature at (S4), the contacts in the (T156) controller close, passing 120 VAC to circulator (P2), which moves water 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). However, the (T256-1) is set for a wider differential (20°F) compared to the differential of the (T256-2) controller (4°F). If the water temperature at sensor (S2) on the supply side of the distribution system is 10°F or more below the target supply water temperature the contacts in the (T256-1) controller close across the terminals (T T) of the auxiliary boiler enabling it and circulator (P3) to operate. Heat from the oil-fired boiler is then injected into the distribution system. Circulator (P2) continues to run unless the temperature on the return side of the distribution system at sensor (S4) climbs to within 3°F of the temperature of the upper tank header at sensor (S3). 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°F 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 (S2) will eventually drop 10°F below the target temperature, at which time the oil-fired boiler and circulator (P3) will turn on.

Domestic water heating: The temperature of the upper portion of the thermal storage tank is continuously measured by controller (T150-2). The contacts in this controller close if the upper tank temperature drops to or below 120°F. Those contacts complete a circuit across the terminals (T T) of the existing/auxiliary boiler high-limit controller, turning on that boiler and its circulator (P3) to add heat to the upper portion of the tank. The auxiliary boiler continues to add heat to the upper portion of the thermal storage tank until the temperature at sensor (S8) reaches 140°F, at which point the contacts in the (T150-2) controller open, turning off the auxiliary boiler and circulator (P3). NOTE: If the pellet boiler is operating normally, and at the suggested settings shown in Figure 8-2c, the water temperature in the upper portion of the tank should stay above 120°F most of the time based on heat input from the pellet boiler.

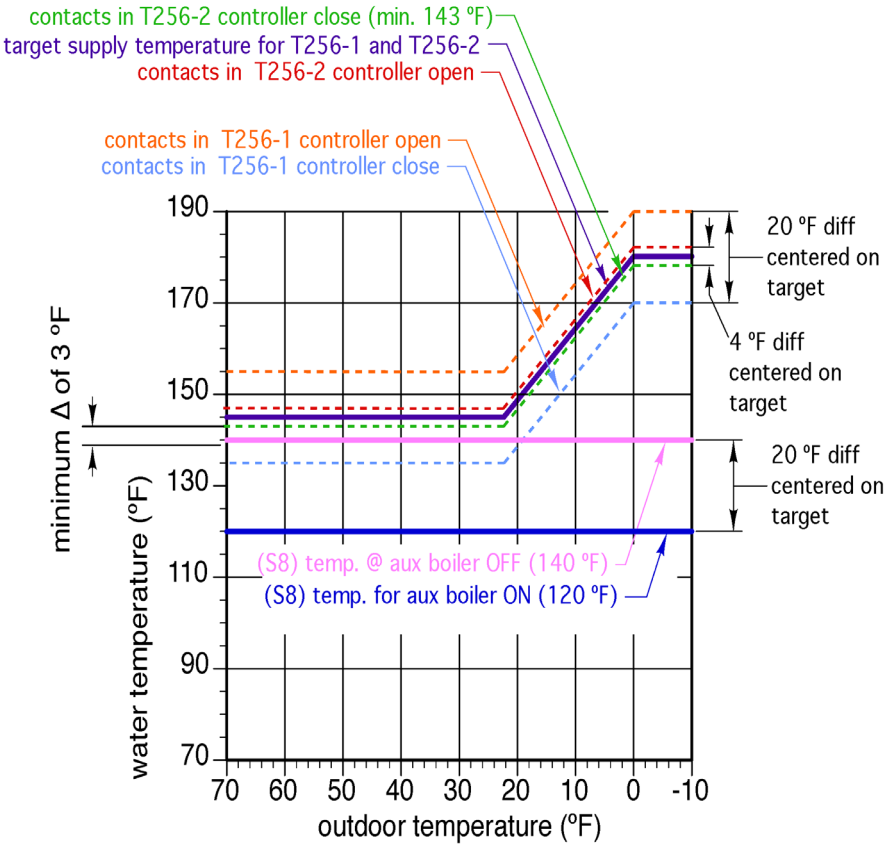
Whenever there is a demand of domestic hot water of 0.6 gallons per minute or higher, the flow switch (FS) closes, passing 24 VAC to the coil of relay (R1). Relay contact (R1-1) closes to turn on circulator (P4), which immediately routes hot water from the top of the thermal storage tank through the 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 heated to or above the desired domestic hot water delivery

temperature of 115°F. The hot water leaving (HX1) passes through an ASSE 1017 listed anti-scald mixing valve to ensure that the maximum hot water delivery temperature to the plumbing system is 115 °F. When the domestic hot water flow rate drops to 0.4 gpm or less, the flow switch (FS) opens, turning off relay coil (R1) and circulator (P4).

8.2.2 Suggested Controller Settings for System 2

Figure 8-2c shows how the two outdoor reset controllers (T256-1) and (T256-2) would be configured based on the description of operation.

Figure 8-2c. 8-2c. Configuration of the temperature controllers (T256-1, T256-2, T150-2) in system 2



NOTE: The temperature at which the (T150-2) controller opens its contacts must be at least 3 °F lower than the lowest temperature at which the (T256-2) controller closes it contacts. In Figure 8-2c the (T150-2) controller opens its contacts at 140 °F. The lowest temperature at which the (T256-2) controller closes its contacts is 143 °F.

- T256-2 outdoor reset controller—monitors upper tank sensor (S6)
    - Outdoor design temperature = 0°F
    - Supply water temperature at outdoor design = 180°F
    - Maximum supply water temperature = 180°F
    - Minimum supply water temperature = 145°F
    - Outdoor temperature at no-load condition = 70°F
    - Supply water temperature at no-load condition = 70°F
        - Differential = 4°F (centered on target temperature)
- T256-1 outdoor reset controller—monitors supply temperature sensor for distribution system (S2)
    - 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)
- T150 setpoint controller (monitors lower tank temperature sensor (S7)
    - Setpoint = 170°F
        - Differential = 10°F (centered on target temperature)
- T150-2 controller (monitors temperature in upper portion of tank)
    - Setpoint = 130°F
        - Differential = 20°F
- 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)

8.3 System 3

This system is appropriate in situations where a pellet boiler will be added to a system that supplies multiple zones of low-temperature radiant panel heating (≤ 120°F supply water at design load), and where a modulating/condensing boiler is used as the auxiliary boiler. This template could also be used for a new construction application with the same constraints.

This system takes full advantage of the temperatures to be maintained in the upper portion of the buffer tank by the pellet boiler or auxiliary boiler. The control system is relatively simple, while supplying full-outdoor reset control of the supply water temperature to the distribution system and ensuring that domestic hot water is available on demand.

The pellet boiler is turned on whenever the temperature at the upper tank sensor (S3) is less than or equal to 128°F. The pellet boiler continues to run until the temperature at the lower tank sensor (S4) is 175°F. This control logic is completely independent of the status of the heating zones or demand for domestic hot water and is in effect whenever the pellet boiler enable switch is closed.

This system is appropriate in situations of low-temperature radiant panel heating (≤ 120°F supply water at design load), and where a modulating/condensing boiler is used as the auxiliary boiler.

The system uses a thermal storage tank with a two-pipe configuration. A ΔP valve set for 1.0 psi is used to prevent forward flow migration through the pellet boiler when it is off. The ΔP valve also prevents reverse thermosiphoning from the thermal storage tank through the boiler and associated piping.

The pellet boiler is protected against sustained flue-gas condensation by a loading unit with a fixed thermostatic element setting of 115°F. The loading unit's bypass port is fully closed when the water temperature leaving the loading unit reaches 133°F.

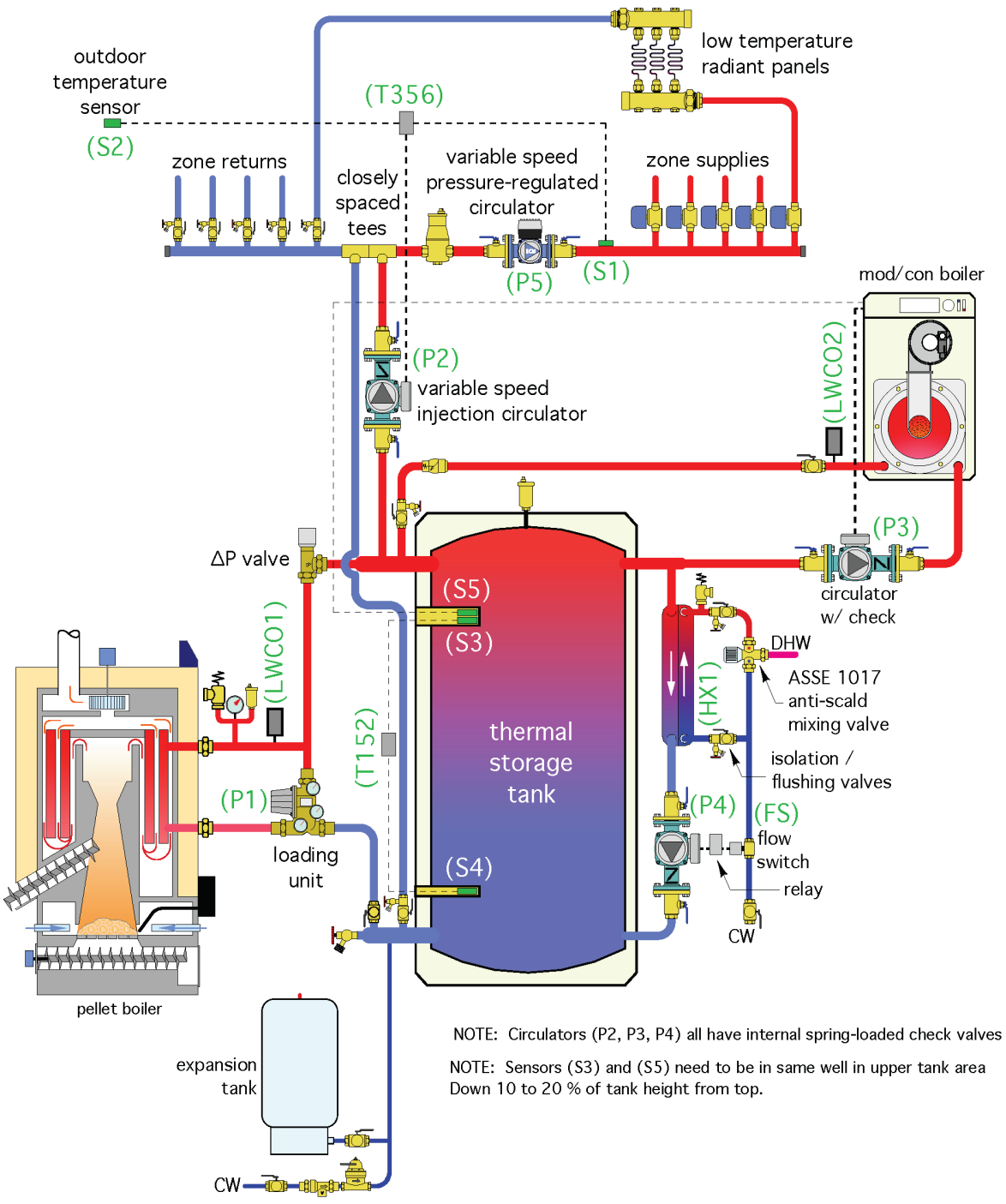
The modulating/condensing auxiliary boiler is piped so that it only heats the upper portion of the thermal storage tank. The thermal mass of the upper 10–20% of the tank buffers the modulating/condensing boiler against short cycling. If the pellet boiler cannot maintain a temperature of at least 125°F at sensor (S5) near the top of the tank, the auxiliary boiler fires to do so. The heated water reserve at the top of the tank can be immediately used for either space heating or domestic water heating.

When there is a space heating demand from any of the zones, heated water is drawn from the upper left tank header by circulator (P2), which operates as a variable speed injection circulator. The rate of heat transfer to the distribution system, and thus the supply water temperature at sensor (S1) is regulated, based on outdoor reset control by the speed of circulator (P2). The closely spaced tees above circulator (P2) provide hydraulic separation between it and the variable speed distribution circulator (P5). Circulator (P5) automatically changes speed to maintain a constant differential pressure across the distribution system regardless of which heating zones are active. This helps ensure stable flow rates in all zones.

A flow switch (FS) closes whenever the demand for domestic hot water exceeds 0.6 gallons per minute. This switch closure turns on circulator (P4) via a relay. Hot water from the top of the thermal storage tank immediately flows through the primary side of the stainless-steel heat exchanger (HX1) as cold domestic water flows through the other side and is fully heated. An anti-scald mixture limits the hot water temperature to the building's plumbing system to 115°F.

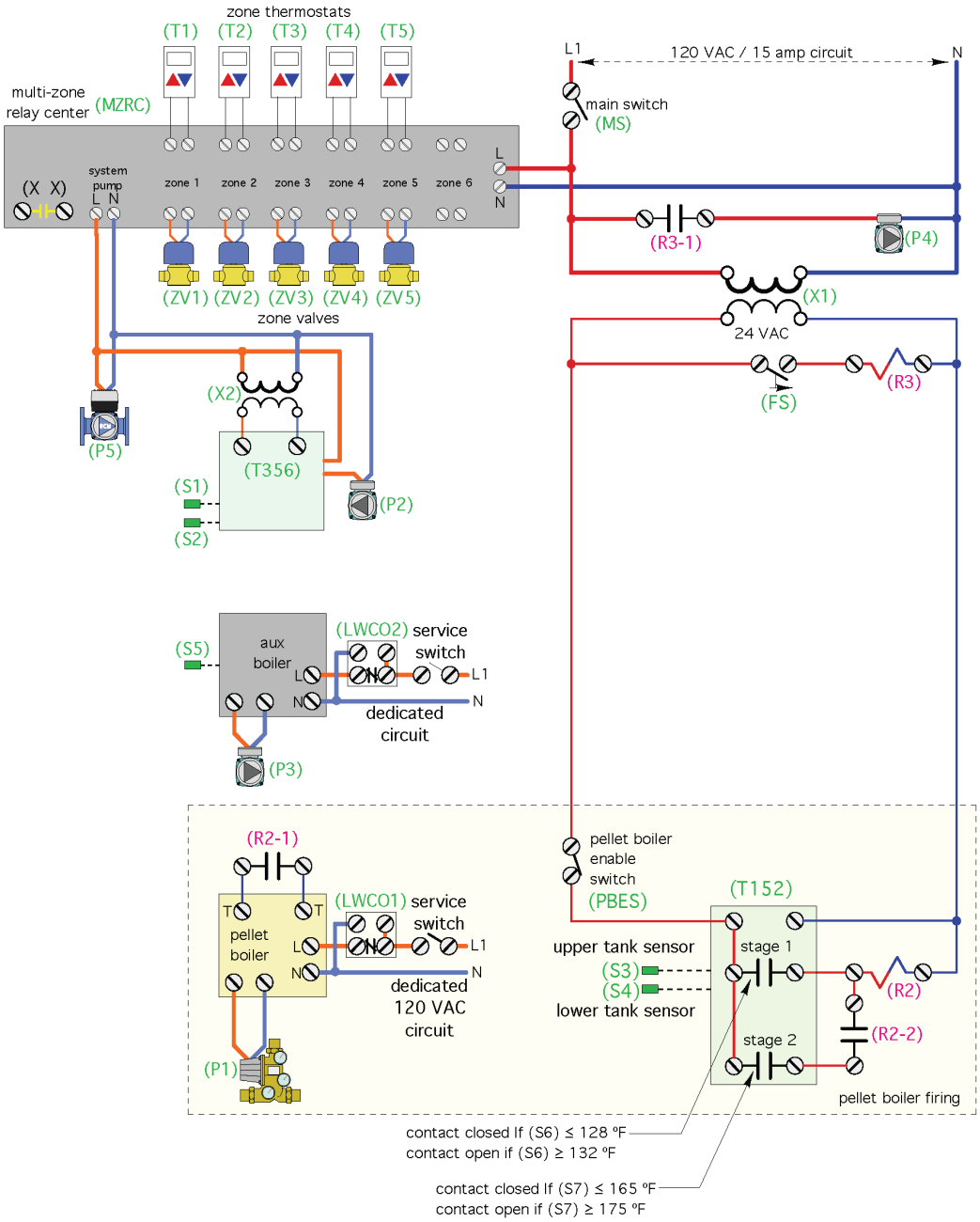
If the pellet boiler is turned off in warm weather (by opening the pellet boiler enable switch) the temperature at the top of the thermal storage tank is maintained between 125°F and 135°F by the modulating/condensing boiler. Heat migration from the tank is minimize by the ΔP valve, a spring-loaded check valve in circulator (P2) and a spring-check valve in the auxiliary boiler piping.

Figure 8-3a. Piping schematic for system 3



Note: Sensor (S5) should be mounted in the same well as sensor (S3). That well should be 10–20% of the tank height down from top.

Figure 8-3b. Electrical schematic for system 3



8.3.1 Description of Operation

Power supply: Power for the pellet boiler is 120 VAC and 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.

Power for the auxiliary boiler is 120 VAC and 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, P5), the 24 VAC transformer (X1), the multi-zone relay center (MZRC), temperature controller (T152), and relay coils (R2) and (R3) 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°F, the stage 1 contacts in the (T152) controller close. This passes 24 VAC from the 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 two 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°F, the stage one contacts in the outdoor reset controller (T152) open. However, 24 VAC continues to pass through the closed stage two contacts in controller (T152) and closed contacts (R2-2) until the lower tank sensor (S4) reaches 175°F. At that point, the stage 2 contact in controller (T152) opens, breaking 24 VAC to relay coil (R2), which removes the external demand from the pellet boiler, allowing it to enter its normal shut down procedure.

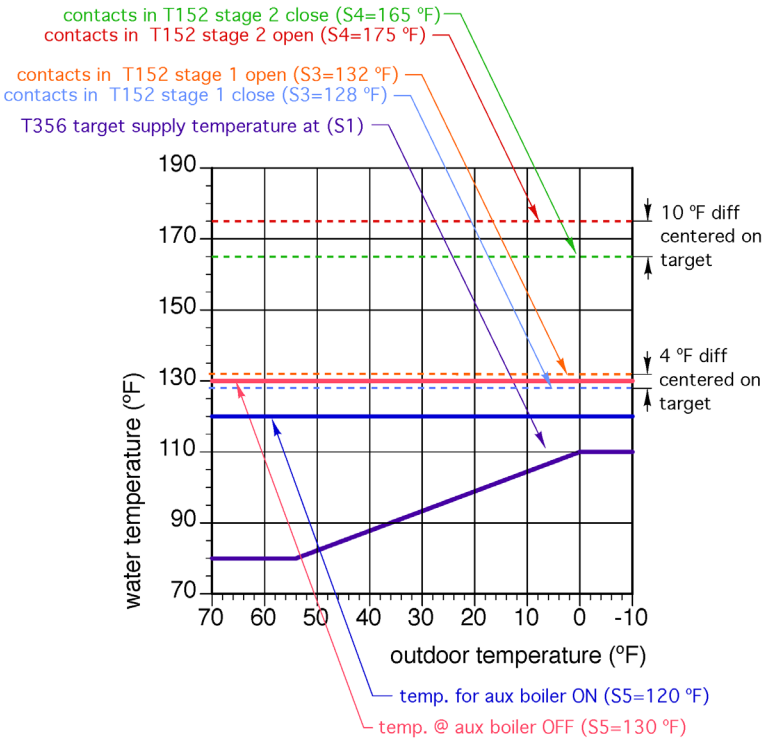
Auxiliary boiler operation: The internal controller within the auxiliary boiler monitors the temperature at sensor (S5) in the upper portion of the thermal storage tank. If that temperature drops to or below 120°F, the auxiliary boiler turns on, along with its associated circulator (P3). Heated water is directed from the auxiliary boiler to the upper left header of the thermal storage tank. From there it 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°F, the auxiliary boiler and circulator (P3) are turned off.

Space heating distribution system operation: On 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 by the multizone relay center (MZRC). Circulator (P5) is turned on and operates in a preset constant differential pressure mode, as 120 VAC is 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 off 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°F 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, the flow switch (FS) closes, passing 24 VAC 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°F. The hot water leaving (HX1) passes through an ASSE 1017 listed anti-scald mixing valve to ensure that the maximum hot water delivery temperature to the plumbing system is 115°F. 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).

Suggested initial controller settings: The suggested settings of the controllers in this system are shown in Figure 8-3c and the listing that follows.

Figure 8-3c. Suggested controller settings for system 3



- Stage one contacts in T152 controller—Monitor's upper tank temperature; contacts close at 128°F and open at 132°F
- Stage two contacts in T152 controller—Monitor's lower tank temperature; contacts close at 165°F, open at 175°F
- Injection mixing controller T356 settings:

- No-load condition—70°F supply water temperature when outdoor temperature is 70°F
- Design load condition—110°F supply water temperature when outdoor temperature is 0°F or lower
- Minimum supply water temperature = 80°F
- Maximum supply water temperature = 110°F

- 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°F or lower
  - Boiler off when temperature at sensor S5 is 130°F or higher
- Pellet boiler settings:
  - High-limit temperature = 200°F
  - Other settings as per boiler manufacturer's recommendations
- Antiscald mixing valve setting:
  - 115°F domestic hot water leaving temperature

This system uses a cordwood gasification boiler as its primary heat source. An existing oil-fired boiler is configured for supplemental heating, or to handle all heating if the cordwood gasification boiler is not operating.

8.4 System 4

This system uses a cordwood gasification boiler as its primary heat source. An existing oil-fired boiler is configured for supplemental heating, or to handle all heating if the cordwood gasification boiler is not operating.

Thermal storage is provided by two closely-coupled ASME certified, 360-gallon, pressure-rated tanks insulated to R-24 (°F•hr•ft2/Btu). These tanks are piped in a hybrid two-pipe configuration, which provides approximately equal flow rates through both tanks and reduces entering flow velocity to help preserve stratification when the load is operating simultaneously with the cordwood gasification boiler. This piping also allows the tanks to provide hydraulic separation between circulators (P1) and (P2).

The cordwood gasification boiler is protected against sustained flue-gas condensation by a loading unit with an internal temperature setting of 130°F. The bypass port at the top of the loading unit is fully closed when the water temperature entering the boiler reaches 148°F.

A ΔP valve set for 1.0 psi prevents flow returning from the distribution system from passing through the cordwood gasification boiler when circulator (P1) is off. The ΔP valve also prevents reverse thermosiphoning through the boiler.

A normally open zone valve (NOZV) opens during a power outage to provide a “detour” around the ΔP valve to allow forward thermosiphoning between the cordwood gasification boiler and thermal storage tanks. It is critically important that the boiler and thermal storage tanks are mounted on the same level as shown on the schematic to allow thermosiphon flow to develop.

An optional uninterruptible power supply (UPS) is shown on the piping and electrical schematics. If present, the UPS should be sized to maintain circulator (P1) on for at least 60 minutes during a power outage. The flow it creates enhances heat transfer between the boiler and thermal storage during a power outage.

The distribution system consists of three (or more) zones of fin-tube baseboard that requires 180°F supply water temperature at design load conditions. An outdoor reset controller allows the distribution system to operate down to the lowest possible temperature that can maintain building comfort before turning on the oil-fired boiler. Flow through space heating zones is provided by a variable speed, pressure-regulated circulator that automatically changes speed to maintain constant differential pressure. A differential temperature controller prevents inadvertent heat transfer from the return side of the distribution system into thermal storage.

Domestic water heating is provided though a stainless-steel brazed plate heat exchanger heated by water from the upper portion of the thermal storage tanks. Tank water passes through the primary side of the heat exchanger, propelled by circulator (P4), which is turned on by a flow switch whenever the domestic hot water flow rate is 0.6 gallon per minute or higher. Domestic water passes in counterflow through the secondary side of the heat exchanger. The heat exchanger has been sized to operate with an approach temperature difference of 5°F under full-design, domestic hot water flow rate. Supplemental domestic water heating, if needed, is supplied by an electrical tankless water heater. The water delivered to the building’s hot water plumbing is limited to 115°F by an ASSE 1017, anti-scald mixing valve. The isolation/flushing valves provided allow the brazed plate heat exchanger as well as the electric tankless water heater to be isolated and flushed, if necessary, to remove scaling.

Figure 8-4a. Piping schematic for system 4

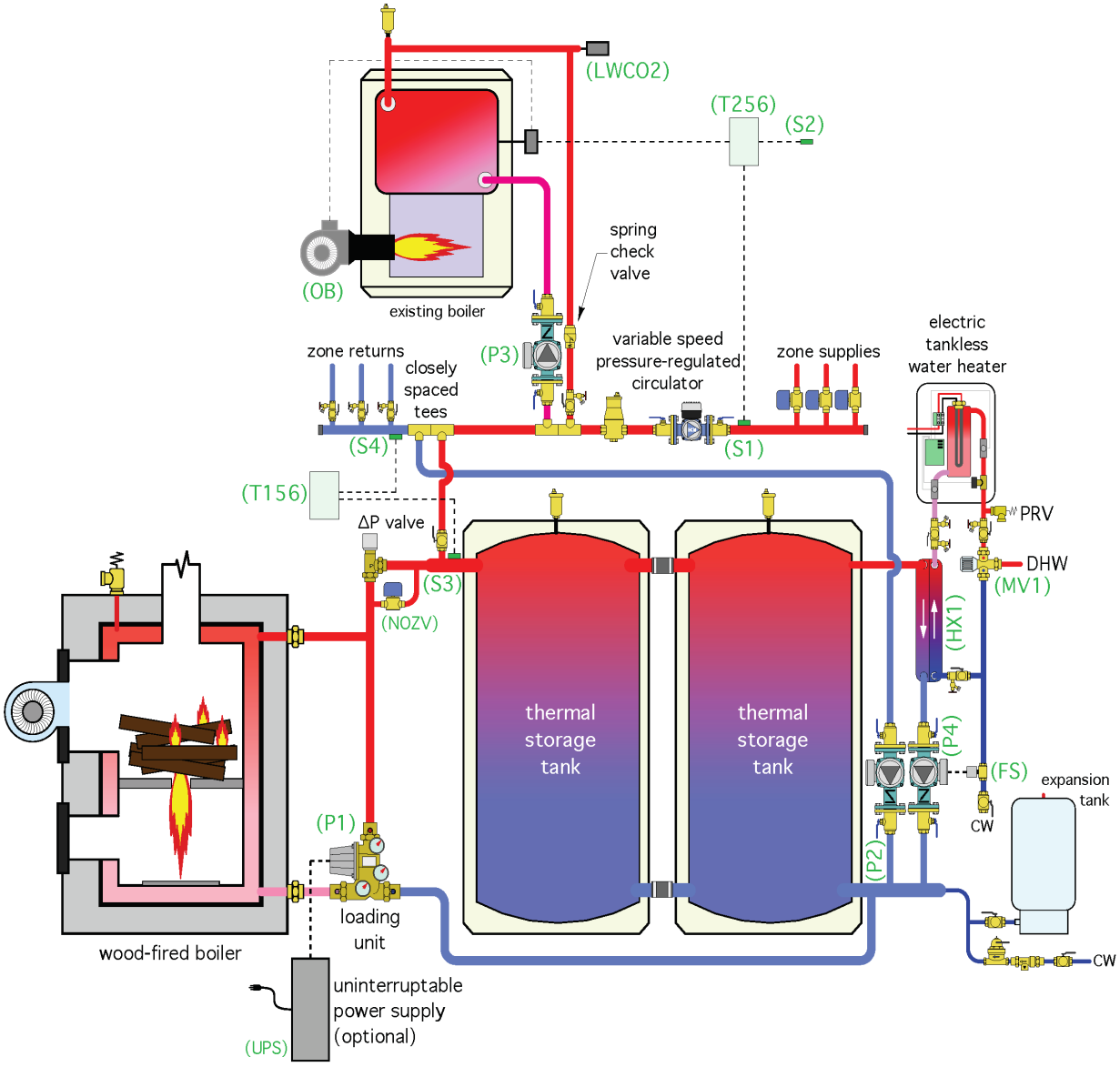
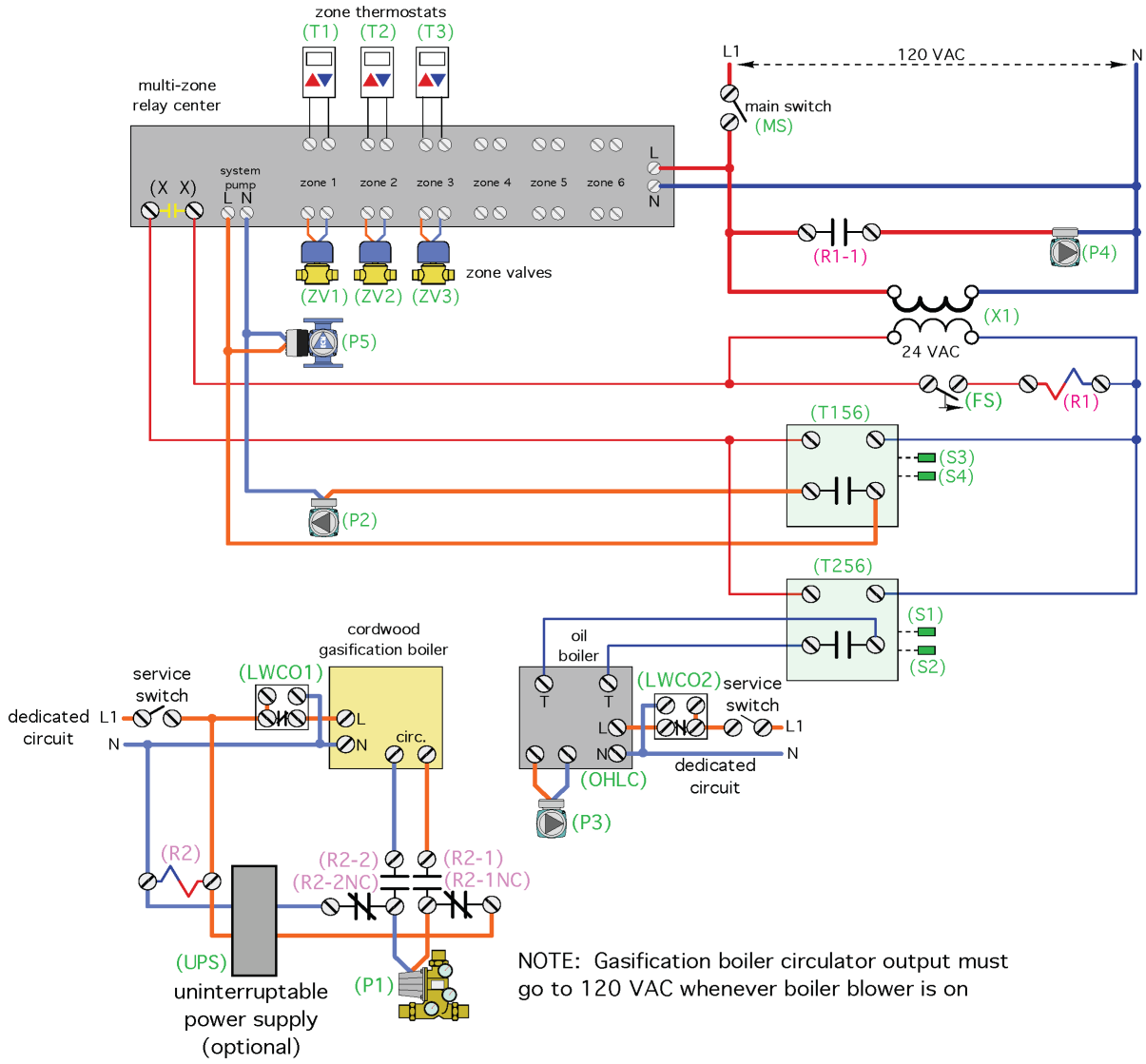


Figure 8-4b. Electrical schematic for system 4



8.4.1 Description of Operation

Power supply: Power for the cordwood gasification boiler is 120 VAC and 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.

Power for the oil-fired boiler is 120 VAC and 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, P5), the 24 VAC transformer (X1), the multizone 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 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 the loading unit is fully closed and the bypass port fully open while the boiler is warming above the dewpoint of its exhaust gases. This prevents heat from the boiler reaching the load or thermal storage. As the water temperature leaving the loading unit rises above 130°F, 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°F or higher the cold port is fully open 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. When utility power is lost 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 circulator (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 terminals (T T) in the high-limit controller, circulator (P3) is turned on and the burner is enabled to fire. Assuming the circuit across the (T T) terminals remains closed, the burner fires until the boiler's water temperature reaches 195ºF, 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 175ºF. NOTE: The 195ºF and 175ºF temperatures associated with the boiler high-limit controller are in effect safety settings. The operating controller for the boiler is the (T256). The (T256) will only allow the burner to operate up to a target temperature measured at the supply water temperature sensor (S1). and under design load conditions the water temperature leaving the oil-fired boiler is limited to 190ºF as shown in figure 8-4c.

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

The (X X) contacts of the (MZRC) close, passing 24 VAC power from the transformer (X1) to differential temperature controller (T156). This controller compares the temperature at the return side of the distribution system at sensor (S)4 to the temperature of the upper tank header at sensor (S3). If the temperature at (S3) is at least 5ºF 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 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 24 VAC 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 10ºF 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.

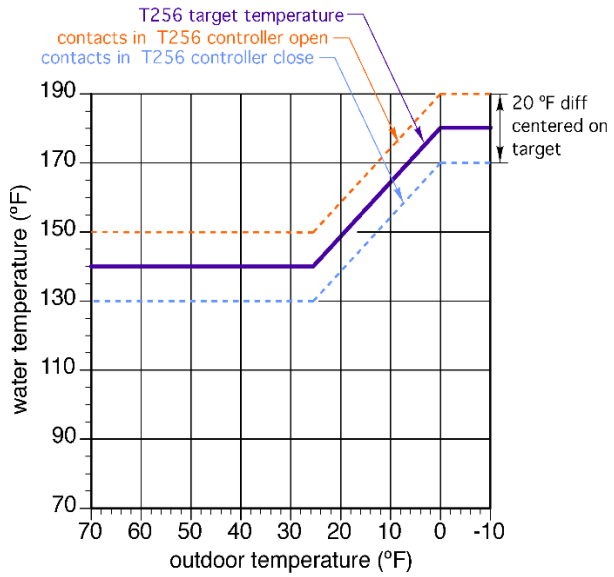
Domestic water heating: Whenever there is a demand of domestic hot water of 0.6 gallons per minute or the higher flow switch (FS) closes, the 24 VAC pass to the coil of relay (R1). Relay contact (R1-1) closes to turn on circulator (P4), which immediately routes hot water from the top of the thermal storage 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 5ºF of the temperature at the top of the thermal storage tanks.

The heated water leaving the 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 115ºF (assuming it enters the heater at a lower temperature). If the water entering the heater is above 115ºF, the elements will not turn on. Hot water leaving the heater passes through an ASSE 1017 listed thermostatic mixing valve (MV1), which is set to limit hot water delivery temperature to 115ºF.

8.4.2 Suggested controller settings

Figure 8-4c shows how the outdoor reset controller (T256) is set.

Figure 8-4c. Outdoor reset controller settings for (T256) controller in system 4



The minimum target water temperature has been limited to 140°F to prevent the oil-fired boiler from operating with sustained flue-gas condensation. If the oil-fire boiler was equipped with an anti-condensation mixing valve, the minimum water temperature could be lowered to 90°F.

- T256 outdoor reset controller—monitors supply temperature 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)

8.5 System 5

This system uses a cordwood gasification boiler as its primary heat source for space heating and domestic hot water. An existing oil-fired boiler is configured for supplemental space heating, or to handle all heating if the cordwood gasification boiler is not operating. Supplemental domestic water heating is provided by an electric tankless water heater.

This system uses a cordwood gasification boiler as its primary heat source for space heating and domestic hot water. An existing oil-fired boiler is configured for supplemental space heating, or to handle all heating if the cordwood gasification boiler is not operating.

Thermal storage is provided by an unpressurized tank that has a liner rated for 175°F continuous duty. The tank is insulated to R-24 (°F•hr•ft2/Btu). The cordwood gasification boiler is interfaced to the thermal storage tank via an external brazed plate stainless-steel heat exchanger. Two additional brazed plate heat exchangers interface the tank water to the closed/pressurized space heating distribution system, and to the domestic water heating subsystem. All flows passing into or out of the tank water are directed horizontally using tees at the end of the inlet and outlet piping. All piping passing through the tank shell penetrates at least 2 inches above the high-water level of the tank (e.g., the water level when the tank water is at its maximum temperature). An air space above the water in the tank provides expansion space for the water in the tank.

The cordwood gasification boiler is protected against sustained flue-gas condensation by a loading unit with an internal temperature setting of 130°F. The bypass port at the top of the loading unit is fully closed when the water temperature entering the boiler reaches 148°F.

Thermosiphon flow through the heat exchanger circuits on the tank are prevented by spring-loaded check valves within circulators (P1B, P4, P2A). Purging valves are provided to ensure rapid filling and purging of the piping from the tank water through the external heat exchangers. A normally open zone valve (NOZV) opens during a power outage to allow forward thermosiphoning between the cordwood gasification boiler and thermal storage tanks.

The distribution system consists of three (or more) zones of fin-tube baseboard that require 180°F supply water temperature at design load conditions. An outdoor reset controller allows the distribution system to operate down to the lowest possible temperature that can maintain building comfort before turning on the oil-fired boiler. Flow through space heating zones is provided by a variable speed pressure-regulated circulator that automatically changes speed to maintain constant differential pressure. A differential temperature controller prevents inadvertent heat transfer from the return side of the distribution system into thermal storage.

Domestic water heating is provided though a stainless-steel brazed plate heat exchanger heated by water from the upper portion of the thermal storage tanks. Tank water passes through the primary side of the heat exchanger, propelled by circulator (P4), which is turned on by a flow switch whenever the domestic hot water flow rates is 0.6 gallon per minute or higher. Domestic water passes in counterflow through the secondary side of the heat exchanger. The heat exchanger has been sized to operate with an approach temperature difference of 5°F under full design domestic hot water flow rate. Supplemental domestic water heating, if needed, is supplied by an electrical tankless water heater. The water delivered to the building's hot water plumbing is limited to 115°F by an ASSE 1017, anti-scald mixing valve. Valving is provided that allows the brazed plate heat exchanger as well as the electric tankless water heater to be isolated and flushed, if necessary, to remove scaling.

Figure 8-5a. Piping schematic for system 5

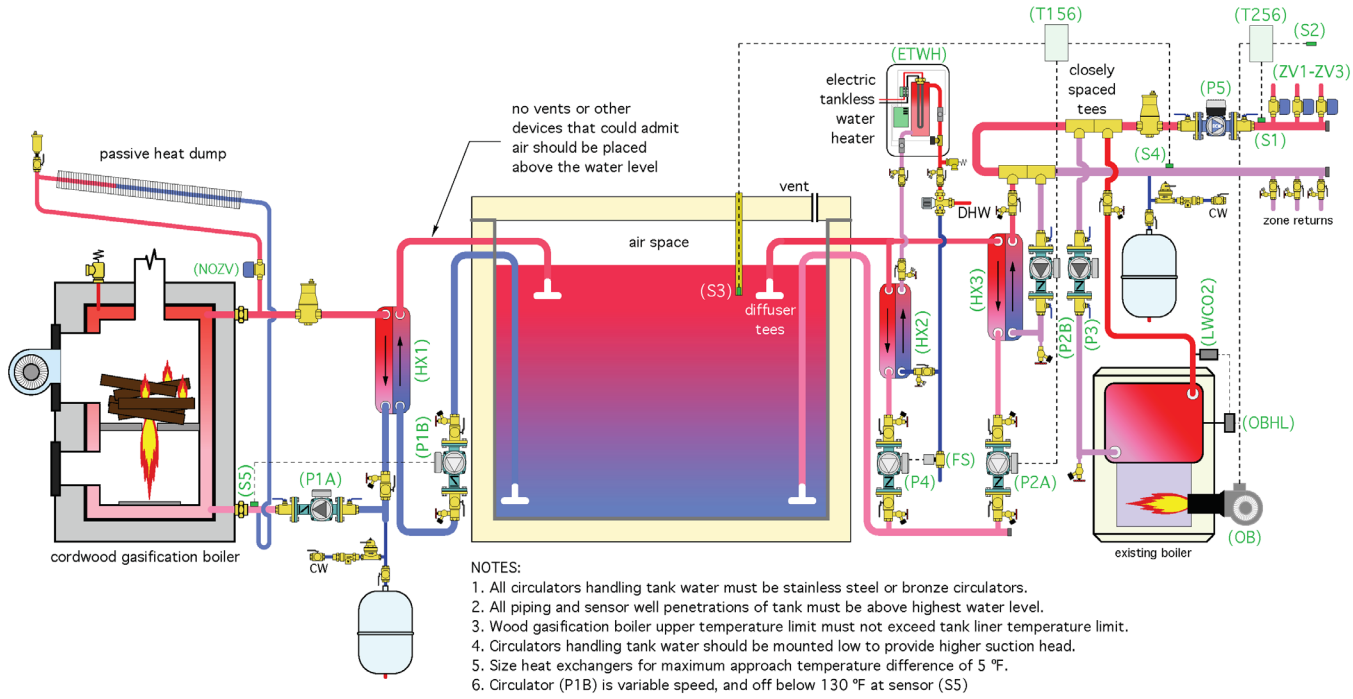
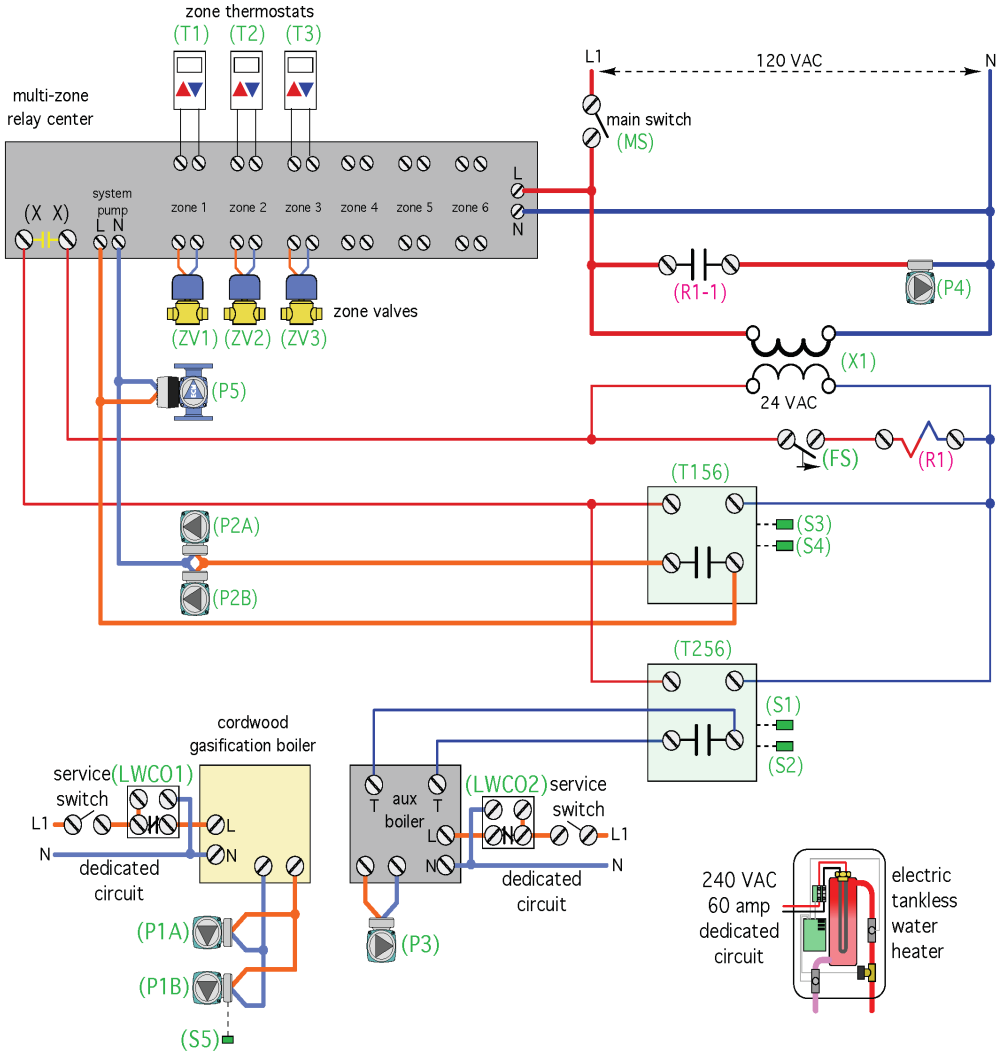


Figure 8-5b. Electrical schematic for system 5



8.5.1 Description of Operation

Power supply: Power for the cordwood gasification boiler is 120 VAC and 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.

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

Power for circulators (P2A, P2B, P4, P5), the 24 VAC transformer (X1), the multi-zone relay center (MZRC), controllers (T156, T256), and relay coil (R1) 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 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 (P1A) and boiler-to-tank circulator (P1B). The cold port of the loading unit is fully closed, and the bypass port is fully open when the boiler is fired from a cold start. This prevents heat from the boiler from reaching the load or thermal storage. As the water temperature leaving the loading unit rises above 130ºF, 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 148ºF 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 available to either the load or thermal storage tanks.

During a power outage the normally open zone valve (NOZV) opens to provide a thermosiphon path through the passive heat dump circuit.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 terminals (T T) 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°F, 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°F. NOTE: The 195°F and 175°F temperatures associated with the boiler high-limit controller are, in effect, safety settings. The operating controller for the boiler is the (T256) outdoor reset controller. It will only allow the burner to operate up to a supply water temperature at sensor (S1) and under design load conditions of 190°F.

Space heating distribution system operation: On a call for heating from any zone thermostat (T1, T2, T3), the associated zone valve (ZV1, ZV2, ZV2) is turned on the by the multizone relay center (MZRC). Variable speed circulator (P5) is also turned on when any zone calls for heating. Circulator (P5) automatically adjusts speed depending on how many zone circuits are active.

The (X X) contacts of the (MZRC) close passing 24 VAC 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°F 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°F 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.

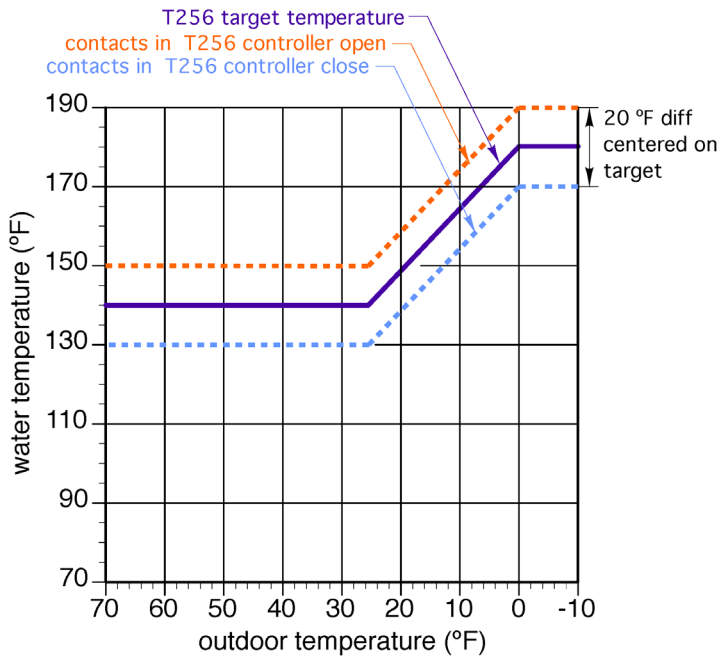
The (X X) contacts of the (MZRC) also pass 24 VAC power to outdoor reset controller (T256.) The (T256) measures outdoor temperature at sensor (S2) and calculates a target supply water temperature for the distribution system. If the temperature of the water passing sensor (S1) on the supply side of the distribution system is 10°F 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 run. 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, the flow switch (FS) closes, passing 24 VAC 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 the heat exchanger (HX1) and is heated to within 5°F of the temperature at the top of the thermal storage tanks.

The heated water leaving the 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°F (assuming it enters the heater at a lower temperature). If the water entering the heater is above 115°F, 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°F.

Suggested initial controller settings: Figure 8-5c shows how the outdoor reset controller (T256) is set.

Figure 8-5c. Setting the outdoor reset controller (T256) in system 5



The minimum target water temperature has been limited to 140°F to prevent the oil-fired boiler from operating with sustained flue-gas condensation. If the oil-fire boiler was equipped with an anti-condensation mixing valve, the minimum water temperature could be lowered to 90°F.

- T256 outdoor reset controller—monitors supply temperature 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 ≥ 10°F above low-temperature sensor
    - Contacts open if high-temperature sensor ≤ 6°F above low-temperature sensor
- Cordwood gasification boiler high-limit temperature = 170°F
- Oil-fired boiler high-limit temperature = 195°F
- Oil-fired boiler differential = 20°F (below target temperature)

8.6 System 6

This system uses a cordwood gasification boiler as its primary heat source for space heating and domestic hot water. An existing oil-fired boiler is configured for supplemental space heating, or to handle all heating if the cordwood gasification boiler is not operating.

Unlike system 5, this system uses a single, brazed plate, stainless-steel heat exchanger to interface the closed-loop portion of the system with the non-pressurized thermal storage tank.

Unlike system 5, this system uses a single, brazed plate, stainless-steel heat exchanger to interface the closed-loop portion of the system with the non-pressurized thermal storage tank.

Unlike system 5, this system uses a single, brazed plate, stainless-steel heat exchanger to interface the closed-loop portion of the system with the non-pressurized thermal storage tank. The flow direction through this heat exchanger is such that counterflow is always maintained. This is done using two stainless-steel circulators and a motorized diverting valve.

Thermal storage is provided by an unpressurized tank that has a liner rated for 175°F continuous duty. The tank is insulated to R-24 (°F•hr•ft2/Btu). The cordwood gasification boiler is interfaced to the thermal storage tank via a single, external brazed plate stainless-steel heat exchanger with low-pressure drop and sized for a low approach temperature. All flows passing into or out of the tank water are directed horizontally using tees at the end of the inlet and outlet piping. All piping passing through the tank shell penetrates at

least 2 inches above the high-water level of the tank (e.g., the water level when the tank water is at its maximum temperature). An air space above the water in the tank provides expansion space for the water in the tank.

The cordwood gasification boiler is protected against sustained flue-gas condensation by a variable speed shuttle circulator (P1B). Circulators (P2) and (P3) interface the heat exchanger (HX1) to the non-pressurized thermal storage tank. Both circulators must be constructed of stainless steel to prevent corrosion. These circulators, in combination with a diverter valve (DV1) allow flow to pass through the heat exchanger in different directions so that counterflow heat exchange is always created regardless of operating mode.

Purging flanges are provided on both sides of circulators (P2) and (P3) to ensure rapid filling and purging of the piping from the tank water through the external heat exchangers. A normally open zone valve (NOZV) opens during a power outage to allow forward thermosiphoning between the cordwood gasification boiler and a passive heat dump constructed of finned-tube elements.

The distribution system consists of three (or more) zones of fin-tube baseboard that require 180°F supply water temperature at design load conditions. An outdoor reset controller allows the distribution system to operate down to the lowest possible temperature that can maintain building comfort before turning on the oil-fired boiler. Flow through space heating zones is provided by a variable speed pressure-regulated circulator that automatically changes speed to maintain constant differential pressure.

A differential temperature controller prevents inadvertent heat transfer from the return side of the distribution system into thermal storage. Figure 8-6a shows the system piping schematic in the mode where heat from the cordwood gasification boiler is used by the load or sent into the thermal storage tank, or both.

Figure 8-6a. Piping schematic for system 6 showing heat from cordwood gasification boiler being sent to load or thermal storage.

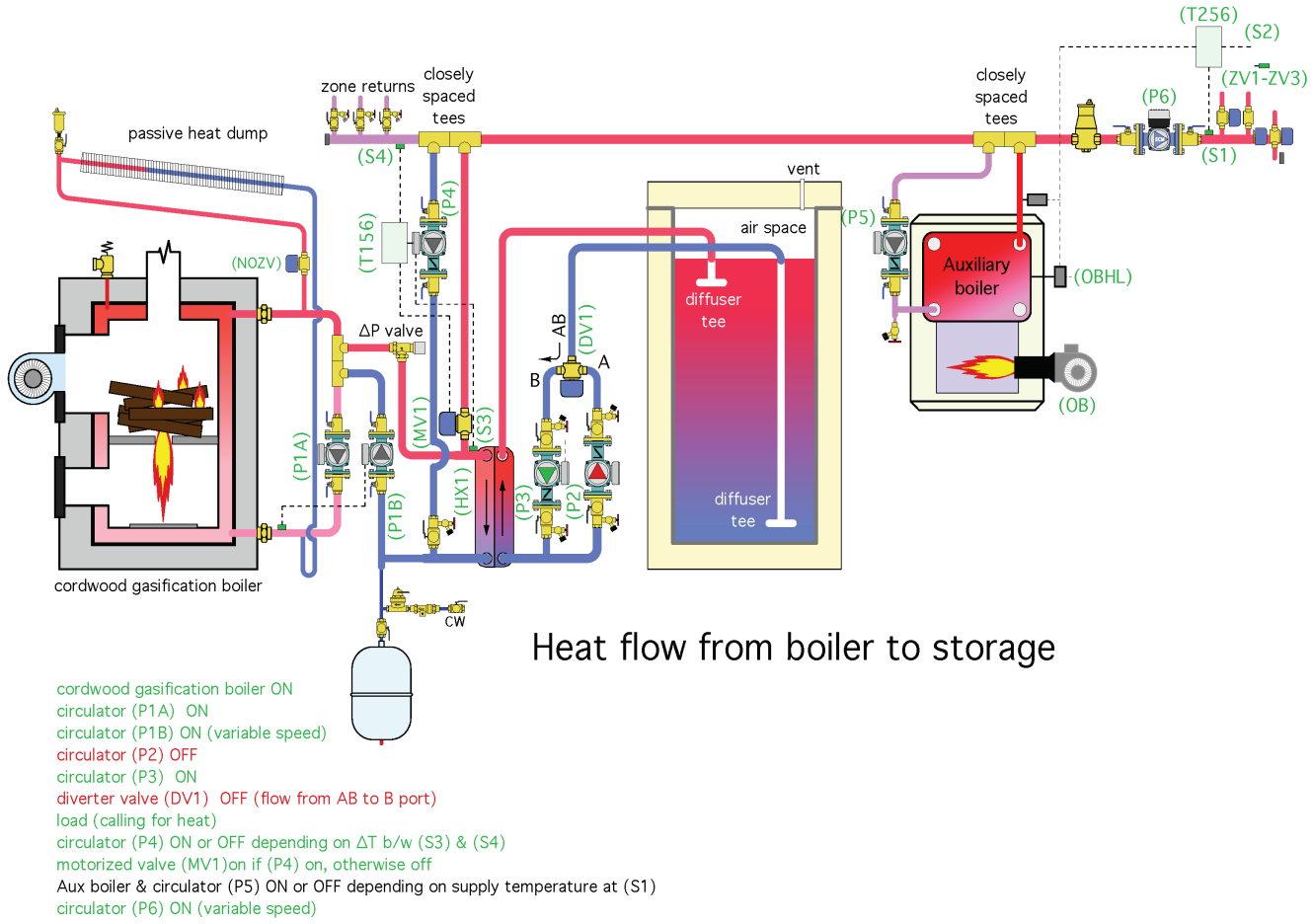
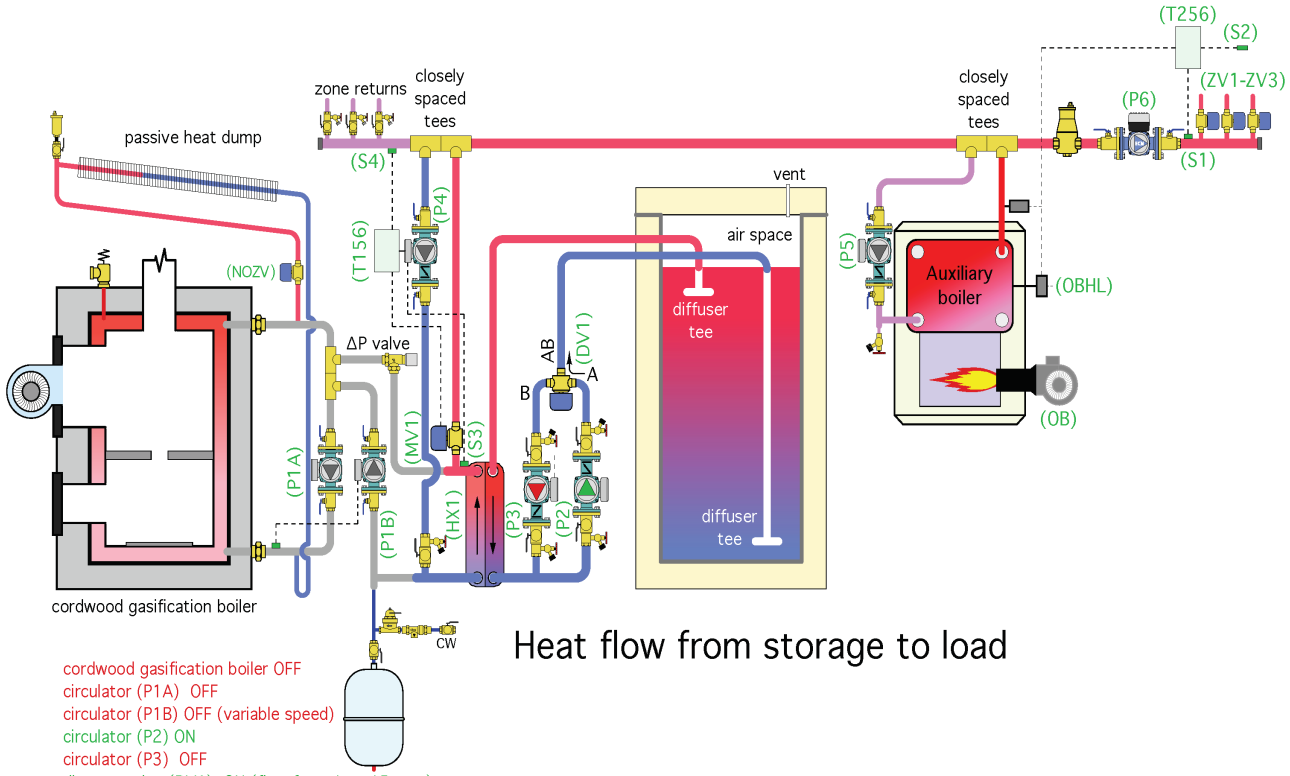


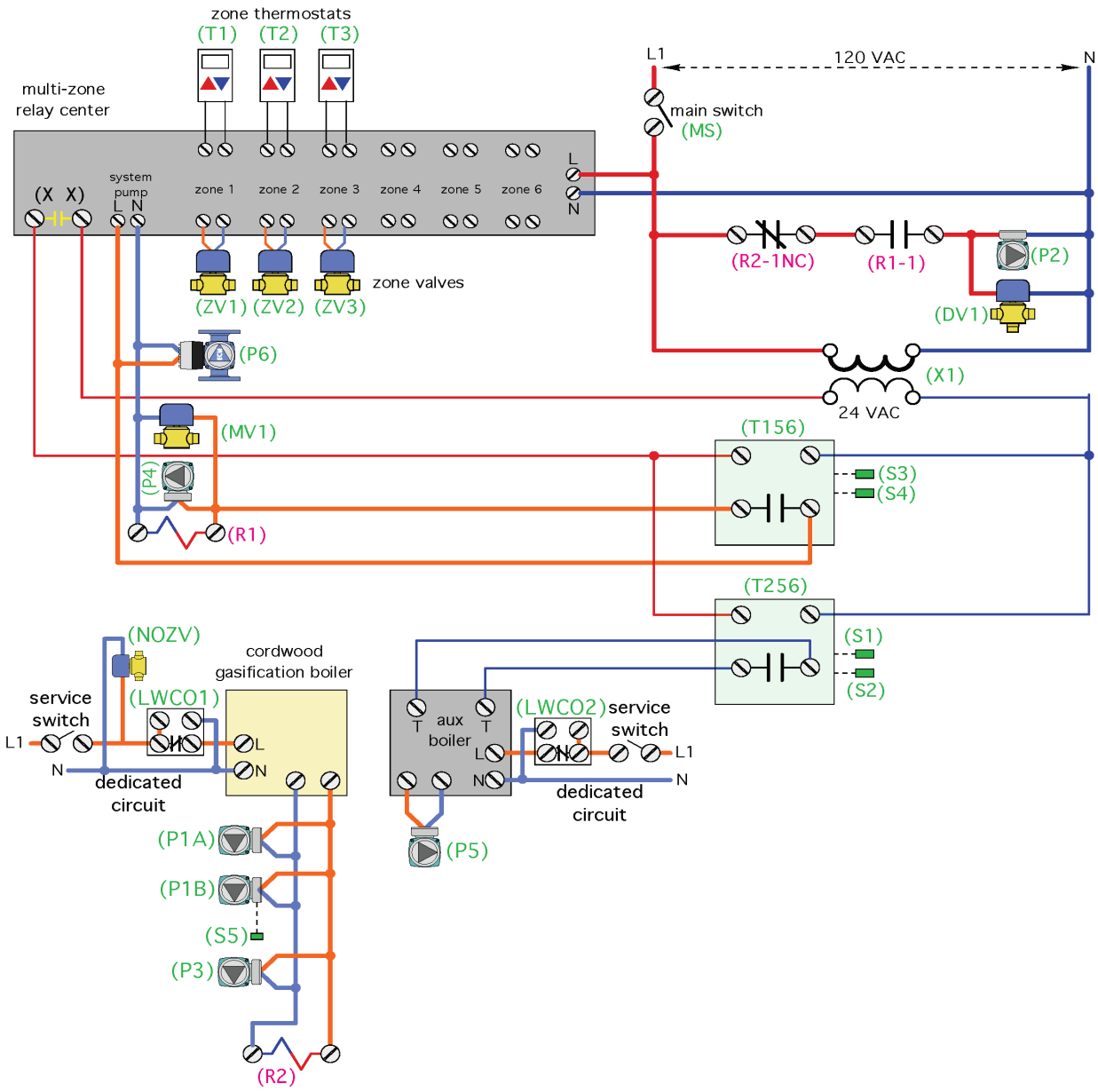
Figure 8-6b shows the system piping schematic in the mode where heat is being extracted from storage and sent to the heating load(s). The cordwood gasification boiler is off.

Figure 8-6b. Piping schematic for system 6 in which heat is extracted from storage and sent to heating load



cordwood gasification boiler OFF
circulator (P1A) OFF
circulator (P1B) OFF (variable speed)
circulator (P2) ON
circulator (P3) OFF
diverter valve (DV1) ON (flow from A to AB port)
load (calling for heat)
circulator (P4) ON or OFF depending on ΔT b/w (S3) & (S4)
motorized valve (MV1)on if (P4) on, otherwise off
Aux boiler & circulator (P5) ON or OFF depending on supply temperature at (S1)
circulator (P6) ON (variable speed)

Figure 8-6c. Electrical schematic for system 6



8.6.1 Description of Operation

Assuming a distribution system with high-temperature heat emitters requiring 180°F supply water temperature at design load.

Power supply: Power for the cordwood gasification boiler is 120 VAC and 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.

Power for the oil-fired boiler is 120 VAC and 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 (P2A, P2B, P4, P5), the 24 VAC transformer (X1), the multizone relay center (MZRC), controllers (T156, T256), and relay coil (R1) 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 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 boiler-loop circulator (P1A), the variable speed shuttle circulator (P1B), circulator (P3), and relay coil (R2).

Boiler anti-condensation protection is provided by controlling the speed of shuttle circulator (P1B) based on the inlet water temperature to the gasification boiler as measured by sensor (S5). When the temperature at sensor (S5) temperature is below 130°F, circulator (P1B) is at minimum speed with a differential pressure of about 1 psi. As the water temperature entering the boiler increases above 130°F the speed of circulator (P1B) increases. (P1B) reaches full speed when the boiler's entering water temperature is 140°F or above. The forward opening pressure of the ΔP valve must be set so that there is no flow through it when circulator (P1B) is at minimum speed. A suggested initial setting is 1.5 psi. When the speed of the circulator (P1B) increases above minimum, it will generate sufficient differential pressure to open the ΔP valve, allowing heated water to leave the boiler loop and pass through the primary side of heat exchanger (HX1). Circulator (P3) is running and provides flow from the lower portion of the thermal storage tank through the secondary side of heat exchanger (HX1). Heat from the heat exchanger passes into the upper portion of the thermal storage tank.

Power outage protection: During a power outage the normally open zone valve (NOZV) opens to provide a thermosiphon path for heat dissipation to the passive heat dump.

Space heating distribution system operation: On a call for heating from any zone thermostat (T1, T2, T3), the associated zone valve (ZV1, ZV2, ZV2) is turned on by the multizone relay center (MZRC). Variable speed circulator (P6) is also turned on when any zone calls for heating.

The (X X) contacts of the (MZRC) close passing 24 VAC 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 at the top of heat exchanger (HX1) measured at sensor (S3). If the temperature at (S3) is at least 8°F higher than the temperature at (S4), the normally open contacts in the (T156) controller close. This passes 120 VAC to circulator (P4) to create flow to the

closely spaced tees in the distribution system. It also energizes relay coil (R1). If the temperature at (S3) is 4°F or less above the temperature at sensor (S4) the contacts in the (T156) controller is open, preventing operation of circulator (P4). This action prevents heat created by the oil-fired boiler from inadvertently entering the thermal storage tank but also allows heat to flow from the biomass portion of the system to the load whenever a positive energy contribution to the load is possible.

If the gasification boiler is not operating, relay coil (R2) is off, and relay contact (R2-1 NC) is closed. Assume there is a call for heat from one or more zones, and that the storage temperature is high enough to contribute heat, as determined by the (T156) controller, contact (R1-1) closes to pass 120 VAC to circulator (P2) and diverter valve (DV1). This allows flow from the upper portion of the thermal storage tank to pass through heat exchanger (HX1), which transfers heat to the load via circulator (P4). If the gasification boiler **is** operating, relay contact (R2-1 NC) is open, which prevents circulator (P2) and diverter valve (DV1) from operating. Instead, circulator (P3) is on to allow heat transfer to storage. Hot water from the gasification boiler must, however, pass across the riser supplying (P4) before it can be sent through (HX1) and to storage. This allows heat to be supplied from the boiler to the distribution system as a priority over sending that heat to storage.

The (X X) contacts of the (MZRC) also pass 24 VAC power to outdoor reset controller (T256). The (T256) measures outdoor the 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°F or more below the calculated target supply water temperature, the contacts in the (T256) controller close across the terminals (T T) of the oil-fired boiler, high-limit controller (OHLC), enabling it to fire and circulator (P5) to operate. Heat from the oil-fired boiler is injected into the distribution system at the downstream pair of closely spaced tees.

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 (P5) is turned on and the burner is enabled to fire. Assuming the circuit across the (T T) terminals remains closed, the burner fires until the boiler's water temperature reaches 195°F, at which point the (OHLC) turns the burner off, while circulator (P5) remains on. The burner will fire again when the water temperature in the boiler drops to 175°F. NOTE: The 195°F and 175°F 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 until the temperature at sensor (S1) is a few degrees above the calculated target supply water temperature. At design load conditions this target temperature will be 190°F.

8.7 System 7

This system uses a pellet boiler as the primary heat source for a commercial-scale floor heating system. Auxiliary heating is provided by two modulating/condensing boilers fueled by natural gas or propane.

The pellet fired boiler is operated to maintain the thermal storage tank temperature between the minimum usable temperature for meeting the heating load and a fixed high-limit temperature. The pellet boiler is protected against sustained flue-gas condensation by a variable speed circulator that is controlled based on the boiler inlet temperature. Hardware is included to allow the pellet boiler to move residual heat to thermal storage by forward thermosiphoning during a power outage.

Heat from the pellet boiler or thermal storage is conveyed to the distribution system using a variable speed injection circulator (P3), which is controlled using a 0-10 VDC output from a multiple boiler controller (T265). The speed of the injection circulator is regulated to maintain a supply water temperature to the floor heating circuits based on outdoor reset control.

If heat input from the pellet boiler or storage is insufficient to achieve the target supply water temperature, one of the auxiliary boilers is turned on and its output is modulated by an independent 0-10 VDC signal from the multiple boiler controller (T265). A second (identical) modulating/condensing boiler can also be turned on and modulated by the multiple boiler controller (T265) if necessary to achieve and maintain the target water temperature to the floor heating circuits.

Heat from the pellet boiler or storage is always treated as the “fixed lead” stage of heat input. The two modulating/condensing boilers are treated as stages two and three of heat input. The firing order of the two modulating/condensing boilers is automatically rotated by the multiple boiler controller (T265) to provide approximately equal run time.

The variable speed injection circulator (P3) is only allowed to operate when the temperature at the tee on top of the thermal storage at sensor (S3) is at least 6°F above the temperature on the return side of the distribution system at sensor (S4). This prevents heat from the auxiliary boilers from being inadvertently added to the thermal storage tank. It also allows the thermal storage tank to contribute heat to the distribution system to relatively low temperatures.

This system uses a pellet boiler as the primary heat source for a commercial-scale floor heating system. Auxiliary heating is provided by two modulating/condensing boilers fueled by natural gas or propane.

The distribution system consists of three independently controlled zones of floor heating, each served by a manifold station. The system is designed for constant flow in all floor circuits. This helps prevent cold areas on the floor near large overhead doors. When a zone thermostat calls for heat, the motorized diverter valve on each zone directs heated water from the supply header into the supply pipe of the manifold station.

The pressure dynamics of the zone circulators are isolated from those of the injection circulator and auxiliary boiler circulator by a hydraulic separator. The hydraulic separator also provides air and dirt separation for the system. The number of zones shown on this system is only representative. Additional zones using the same piping and control concepts could be added.

Figure 8-7a. Piping schematic for system 7

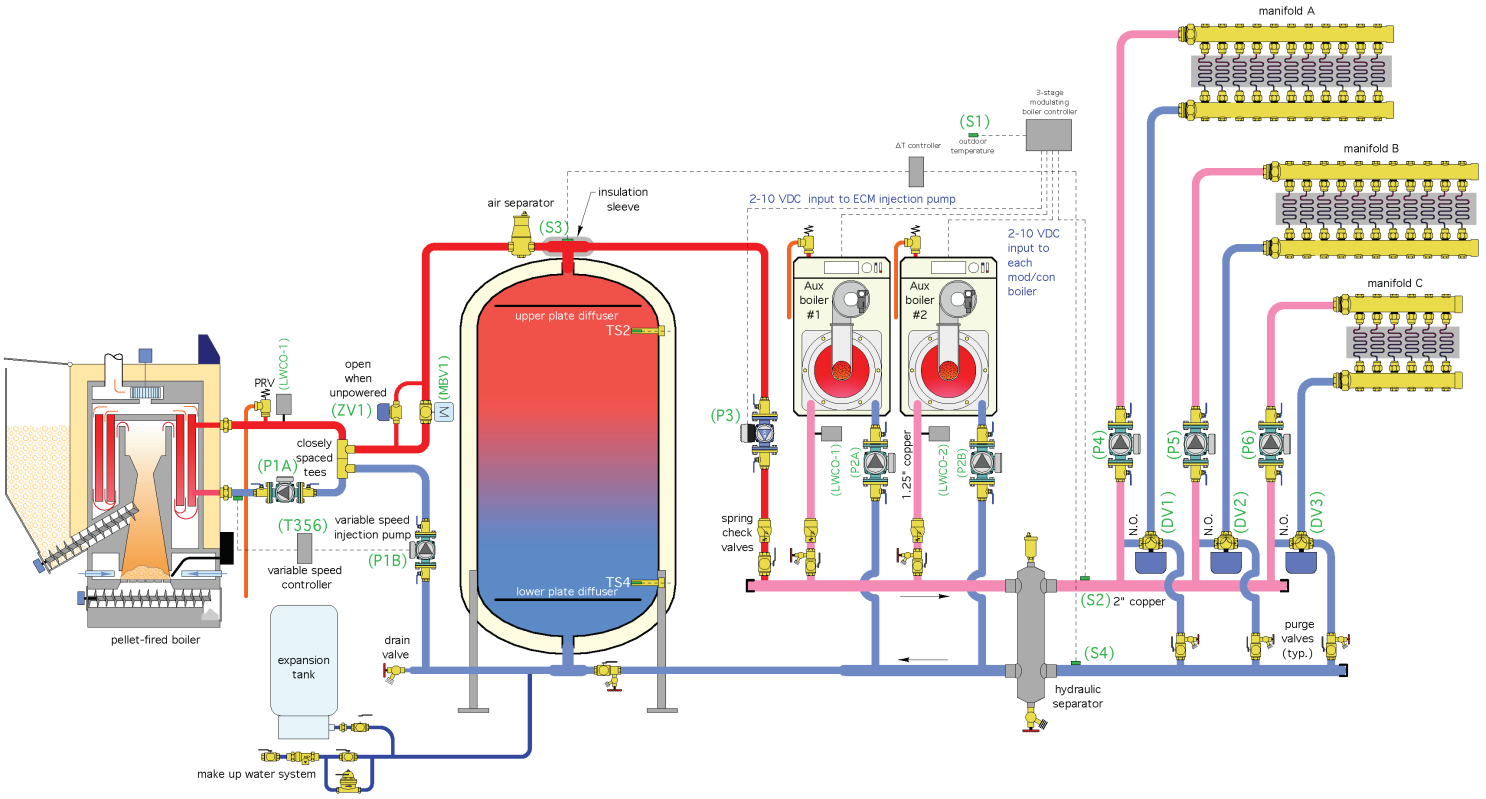
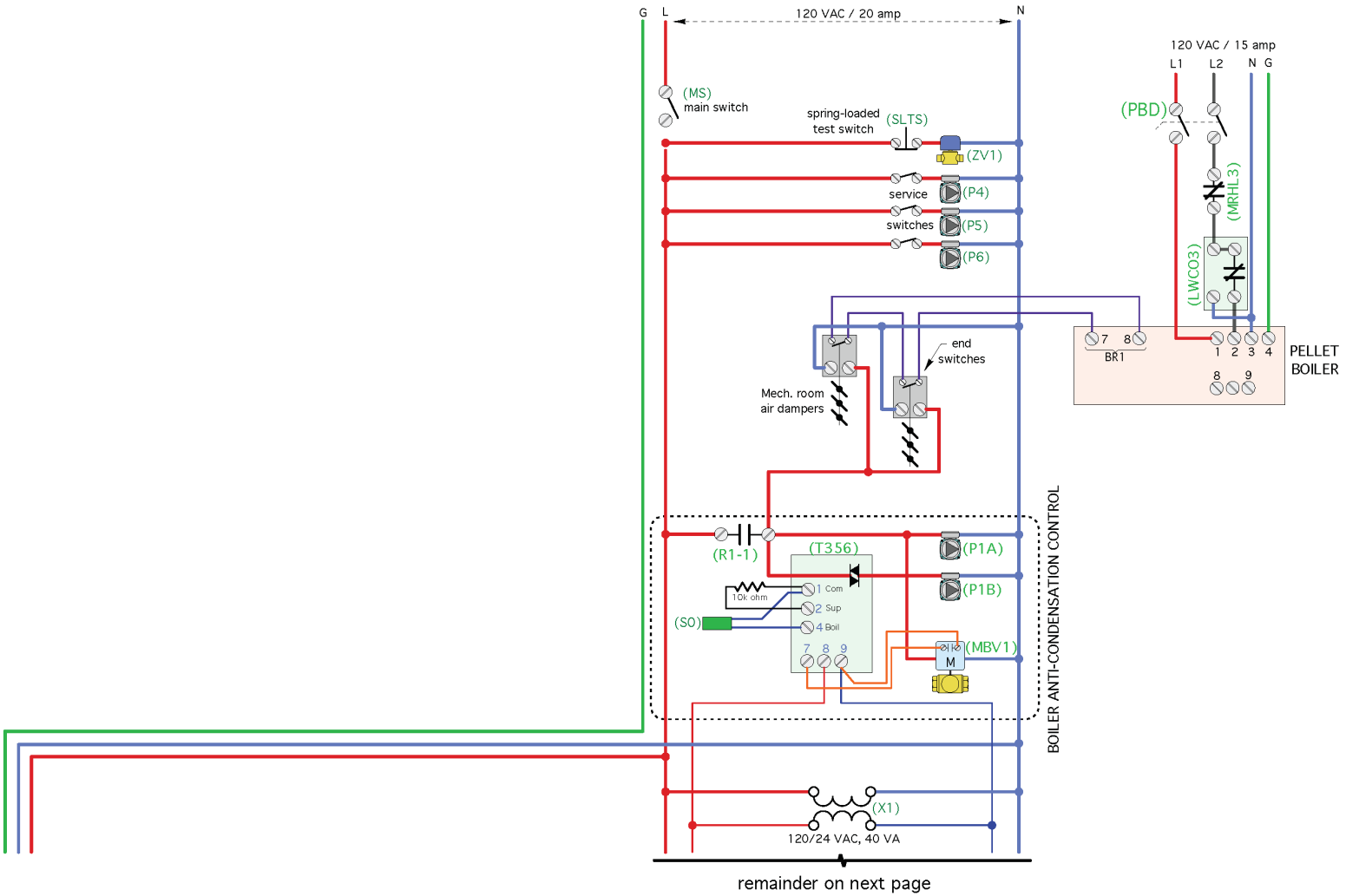
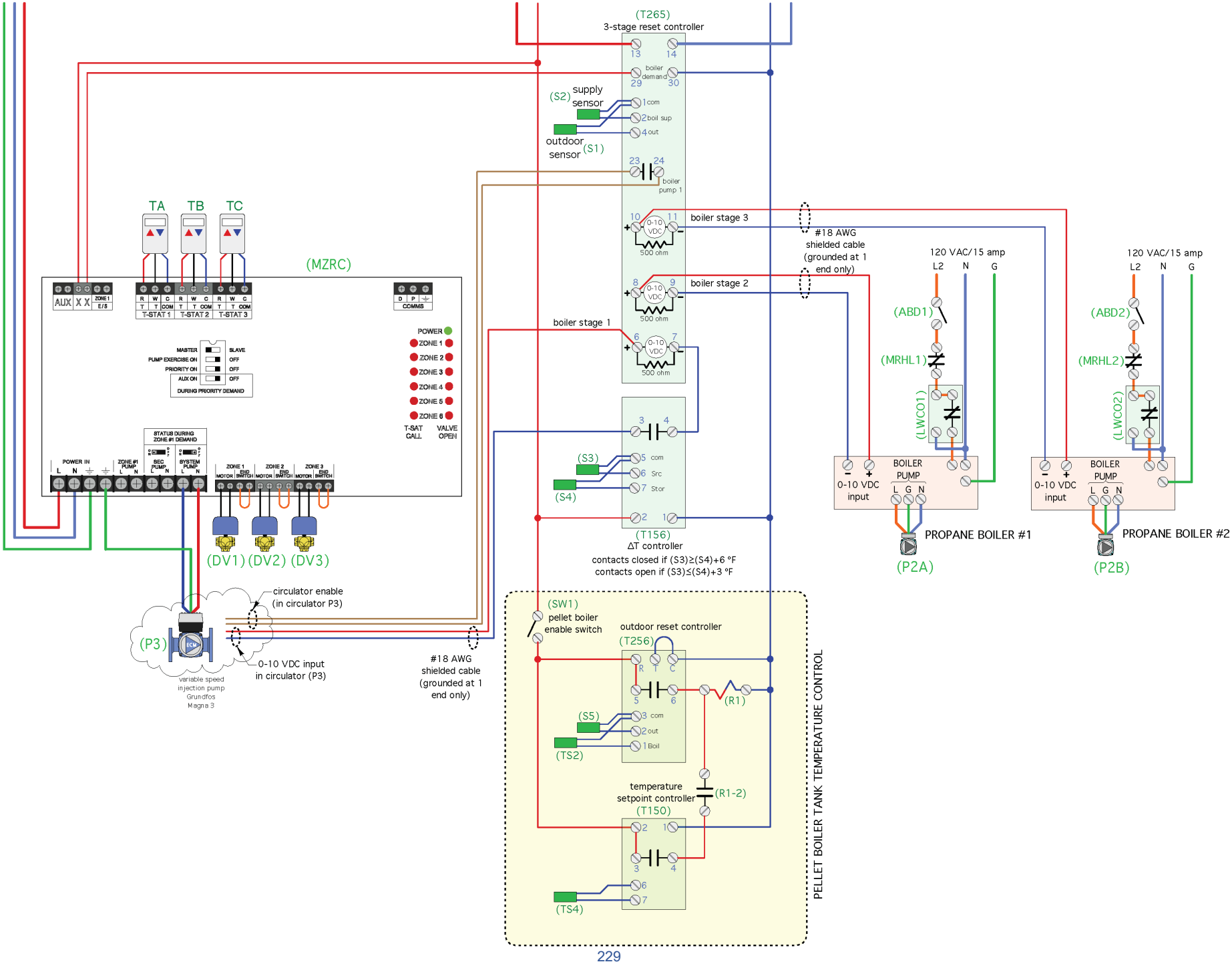


Figure 8-7b. Electrical schematic for system 7




(T265)
3-stage reset controller
boiler demand
(S2) supply sensor
outdoor sensor (S1)
boiler pump 1
boiler stage 3
boiler stage 2
boiler stage 1
0-10 VDC
500 ohm
#18 AWG shielded cable (grounded at 1 end only)
120 VAC/15 amp
L2 N G
(ABD1)
(MRHL1)
(LWCO1)
(ABD2)
(MRHL2)
(LWCO2)
BOILER PUMP
0-10 VDC input
PROPANE BOILER #1
PROPANE BOILER #2
(P2A)
(P2B)
TA TB TC
(MZRC)
AUX
T-STAT 1
T-STAT 2
T-STAT 3
COMMS
POWER
ZONE 1
ZONE 2
ZONE 3
ZONE 4
ZONE 5
ZONE 6
T-SAT CALL
VALVE OPEN
MASTER
SLAVE
PUMP EXERCISE ON
PRIORITY ON
AUX ON
DURING PRIORITY DEMAND
STATUS DURING ZONE #1 DEMAND
POWER IN
ZONE #1 PUMP
BIO PUMP
SYSTEM PUMP
ZONE 1 ZONE 2 ZONE 3
MOTOR
ZIRC SWITCH
(DV1) (DV2) (DV3)
(S3)
(S4)
(T156)
ΔT controller
contacts closed if (S3)≥(S4)+6 °F
contacts open if (S3)≤(S4)+3 °F
circulator enable (in circulator P3)
(P3)
0-10 VDC input in circulator (P3)
variable speed injection pump Grundfos Magna 3
#18 AWG shielded cable (grounded at 1 end only)
(SW1)
pellet boiler enable switch
outdoor reset controller
(T256)
(R1)
(S5)
(TS2)
temperature setpoint controller
(T150)
(R1-2)
(TS4)
PELLET BOILER TANK TEMPERATURE CONTROL

8.7.1 Description of Operation

Power supply to control circuit: Power to the controller circuit requires the main switch (MS) to be closed.

Pellet boiler operation: The pellet boiler is controlled based on the temperature at two sensors in the thermal storage tank. Upper tank sensor (TSU) determines when the pellet boiler is turned on. Lower tank sensor (TSL) determines when the pellet boiler is turned off.

The pellet boiler turns on when the temperature at the upper tank sensor (TSU) drops slightly below the target temperature, which is continuously calculated based on the outdoor temperature at sensor (S6) and the settings of the outdoor reset controller (T256). The target temperature at (TSU) is 110°F when the outdoor temperature is -5°F. This target temperature decreases to a minimum of 80°F when the outdoor temperature is 51°F or above.

A contact closure in the (T256) controller passes 24 VAC to the coil of relay (R1). Normally open, contact R1-1 closes to supply 120 VAC directly to circulator P1A and to the line voltage lead on the variable speed circulator controller (T356) operating circulator (P1B), and to both motorized air dampers. 120 VAC is also supplied through R1-1 to operate motorized ball valve (MBV1). When the motorized ball valve is fully open, its internal end switch closes passing 24 VAC to the low-voltage circuits in the (T356) controller.

When both motorized air dampers are fully open, their internal end switches close (in series) to provide a completed circuit between the external demand terminals of the pellet boiler, turning it on. The (T356) monitors the temperature of water entering the pellet boiler. When this temperature rises to 130°F, the (T356) controller begins to ramp up the speed of the circulator (P1B), which transports heat from the pellet boiler recirculation loop to thermal storage or load. The speed of the circulator (P1B) increases as the return water temperature rises above 140°F and slows to a very low speed if the return water temperature decreases below 140°F.

Through contact (R1-2), 24 VAC also passes through the closed contact of the (T150) setpoint controller. This contact maintains 24 VAC to relay coil (R1) after the contacts in the (T256) controller open as the tank temperature begins to rise.

The pellet boiler continues to operate until the temperature at the lower tank sensor (TSL) increases to 170°F. This causes the contacts in the (T150) controller to open, interrupting 24 VAC to relay (R1) and turning off the pellet boiler. Circulators (P1A), (P1B), and the (T356) controller also turn off. The motorized ball valve (MBV1) also closes, using its internal spring return mechanism. This prevents flow through the pellet boiler when it is off.

Zone valve (ZV1) remains closed whenever the master switch is on and electrical power is available to the system. During a power outage (ZV1) opens to allow passive thermosiphoning between the pellet boiler and thermal storage tank. A spring-loaded test switch (SLTS) can be periodically pushed to interrupt 120 VAC power to zone valve (ZV1) to test its operation.

Heat input to distribution system: There are three stages of heat input to the distribution system. All three stages are controlled by the modulating boiler controller (T265). This controller is turned on by a call from any of the three zone thermostats (TA, TB, TC).

When any thermostat calls for heat, 24 VAC from transformer (X1) passes through the contacts (X X) in the multizone relay center (MZRC) to the (T265) controller. This turns the (T265) on in outdoor reset mode. The (T265) controller measures outdoor temperature at sensor (S1) and uses this reading along with its settings to calculate the target supply water temperature to the distribution system. It compares this calculated target temperature to the measured temperature at sensor (S2). If the measured temperature at (S2) is slightly below the target temperature, the (T265) uses its first stage 0-10 VDC output to ramp up the speed of circulator (P3). Stage one output is fixed as the lead stage.

Injection circulator (P3) is enabled to operate by the closure of relay contact in the (T265) controller. This contact closure occurs whenever the (T265) initiates stage one operation. The speed of circulator (P3) is determined by the 0-10 VDC signal supplied by the (T265) controller.

If the temperature at sensor (S2) cannot be maintained by injection of hot water from thermal storage and/or the pellet boiler, a 0-10 VDC output from stage two and three of the (T265) controller activates to provide modulated heat input from auxiliary boilers 1 and 2. Stages two and three periodically rotate firing order so as to provide approximately equal run time for the auxiliary boilers.

Prevention of inadvertent heat flow into thermal storage: Heating of the thermal storage tank by the auxiliary boilers is prevented by continuously measuring the difference between the temperature on the piping at the tee on top of the thermal storage tank at sensor (S3) and the temperature returning from the distribution system at sensor (S4). If $S3 \geq S4 + 6°F$, the normally open contact in the differential temperature controller (T156) is closed allowing the 0-10 VDC speed control signal from the stage one output of the (T265) controller to operate circulator (P3). If $S3 \leq S4 + 3°F$, the contact in the (T156) controller opens to prevent circulator (P3) from operating. This allows the thermal storage tank to contribute heat to the distribution system whenever possible, but prevents heat produced by the auxiliary boilers from heating thermal storage.

All heat input to the distribution system passes through the hydraulic separator, which isolates the pressure dynamics of the injection circulator (P3) and the auxiliary boiler circulators (P2A) and (P2B) from the distribution circulators (P4, P5, P6).

Heating distribution: All three radiant floor heating zones operate with constant circulation. This improves heat distribution across the floor areas and helps protect the high-heat loss areas of the slab near the overhead doors from potential freezing. Circulators (P4), (P5), and (P6) operate whenever the main switch (MS) of the heating system is closed and their respective service switches are closed.

Diverter valves (DV1), (DV2), and (DV3) are off whenever their associated zone thermostat is not calling for heat. In this mode, they route flow returning from each radiant floor zone back to the supply manifold for that zone and thus allow no heat input to the zone. When a zone thermostat (TA, TB, TC) call for heat, 24 VAC is supplied to the actuator of the associated diverter valve. This routes flow returning from that zone back to the hydraulic separator and passes heated water to the zone. Verify proper operation so that normally open port is open when actuator is off.

8.7.2 Suggested Initial Controller Settings

- Supply water temperature to floor circuits at design load (set on T265) = 105°F
- Supply water temperature to floor circuit at no load (set on T265) = 70°F.
- Maximum supply water temperature (set on T265) = 105°F
- Minimum supply water temperature (set on T265) = 75°F
- Stage one to stage two delay (set on T265) = 15 minutes
- Stage two to stage three delay (set on T265) = 10 minutes
- Set (T265) controller to rotate firing order of stages two and three.
- Minimum pellet boiler inlet temperature (set on T356) =130°F
- Pellet boiler ON temperature at upper tank sensor (set on T256) = 110°F
- Pellet boiler OFF temperature at lower tank sensor (set on T150) = 170°F

8.8 System 8

This system uses two identical pellet boilers as the primary heat sources. Auxiliary heat is provided by a single oil-fired boiler. The load is a multiple zone space heating system that could use either high-temperature or low-temperature heat emitters. If low-temperature emitters are used the oil-fired boiler must be protected against sustained flue-gas condensation. This can be done using a thermostatic mixing valve set for a boiler inlet temperature not lower than 130°F.

The two pellet boilers are fired in stages based on the temperature at several locations within the thermal storage tank. The first boiler is fired when the temperature at sensor S2 drops below a minimum setpoint. It continues to fire until the temperature at sensor S4 reaches a temperature of 175°F. The second boiler fires if the temperature at sensor S1 drops below another relatively low setpoint (indicating that the load is dissipating heat faster than the first pellet boiler can produce heat). The second boiler continues to fire until the temperature at sensor S3 reaches 175°F.

The order in which the pellet boilers are fired can be manually switched using a 4PDT switch. The system operator would change the setting of this switch once each heating season. The goal is to achieve approximately the same number of operating hours on each pellet boiler over the life of the system. Also, if one pellet boiler is out of service, the switch can be used to operate the remaining boiler as the lead boiler.

This system uses two identical pellet boilers as the primary heat sources. Auxiliary heat is provided by a single oil-fired boiler. The load is a multiple zone space heating system that could use either high-temperature or low-temperature heat emitters.

Anti-condensation control for the pellet boilers is provided by a single variable speed circulator (P6) that monitors the return water temperature to these boilers at sensor (S0). At temperatures below 130°F, circulator (P6) is off. Under this condition the flow created by circulators (P1) or (P2) does a U-turn at the closely spaced tees and returns to the boilers. As the return water temperature at sensor (S0) rises above 130°F, the speed of circulator (P6) increases. When the return temperature to the boilers is 140°F or higher, circulator (P6) operates at full speed.

A motorized ball valve (MV1) opens whenever either of the pellet boilers is operating. It closes at other times to prevent flow returning from the load from partially bypassing of the thermal storage tank through circulator (P6).

Circulator (P3) is operated as a variable speed injection circulator. Its speed is controlled to keep the supply water temperature as sensor (SS2) close to a calculated target value based on outdoor reset control. Circulator (P3) is only allowed to operate when the temperature at sensor (SH) on the upper tank header is at least 6°F above the temperature at sensor (SL) on the return side of the distribution system. This prevents inadvertent transfer of heat produced by the oil-fired boiler into the thermal storage tank.

The oil-fired boiler and its associated circulator (P5) are turned on when the supply water temperature to the distribution system is 5°F below the target temperature for the distribution system. Assuming the load persists, this boiler continues to operate until the supply water temperature at sensor (SS1) is 5°F above the target supply water temperature. The oil-fired boiler automatically provides heat input to the distribution system if the pellet boiler subsystem is not operating. The distribution system, as shown, has five independent heating zones controlled by zone valves. Flow to all zones is provided by a single variable speed pressure-regulated circulator (P4).

Figure 8-8a. Piping schematic for system 8

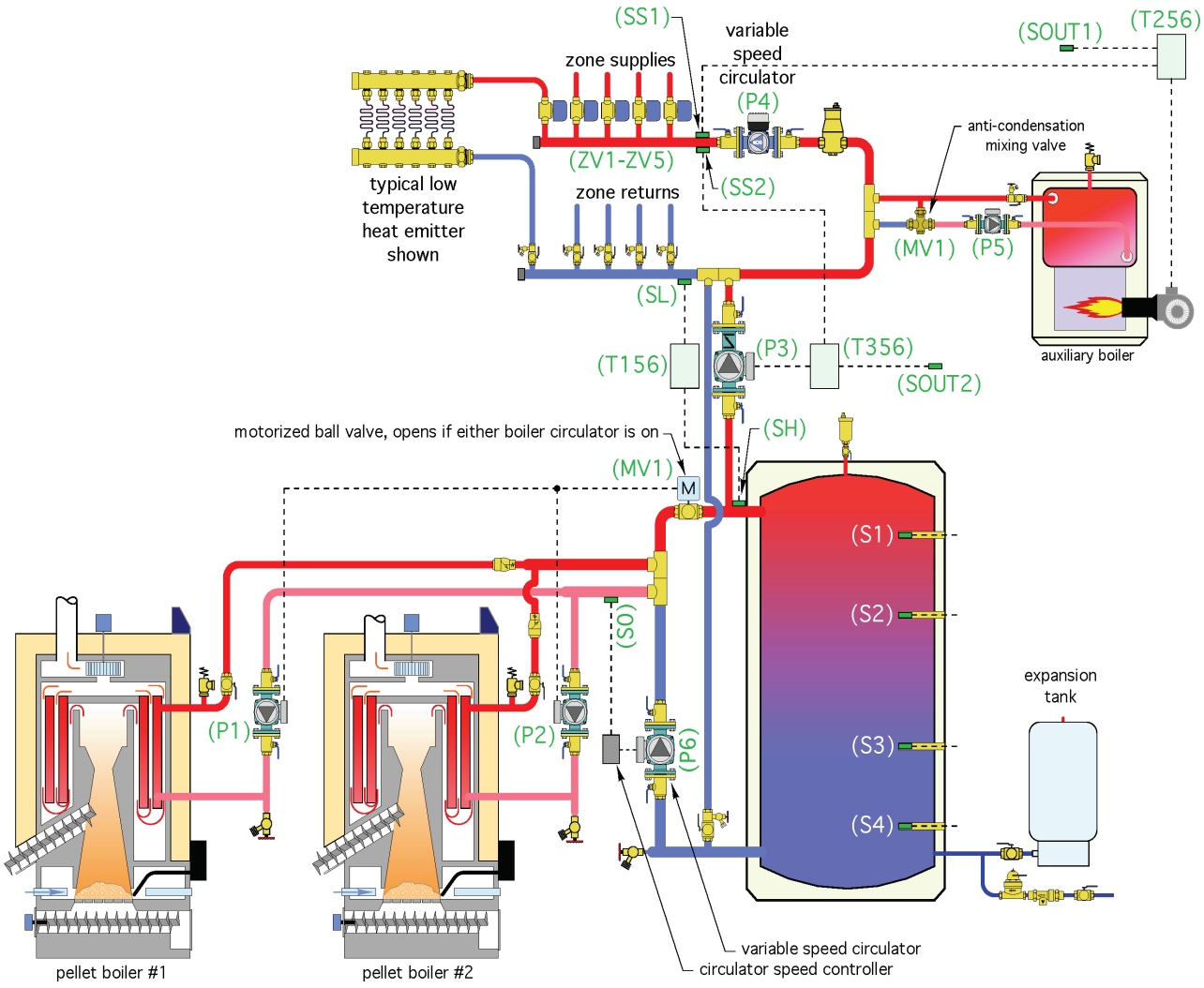
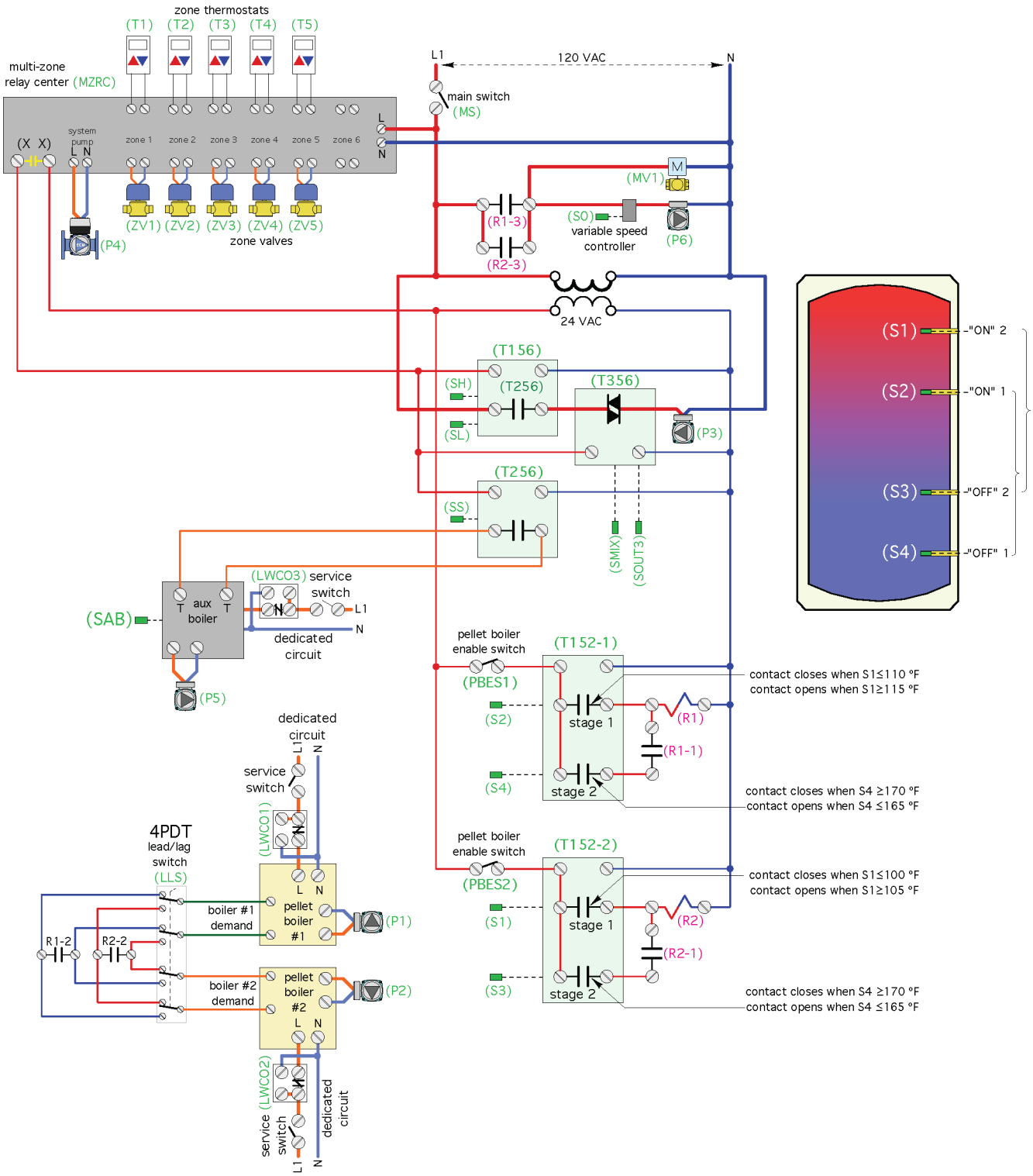


Figure 8-8b. Electrical schematic for system 8



8.8.1 Description of Operation

Power supply: Power for each pellet boiler is 120 VAC and supplied from a dedicated circuit. The service switch for each pellet boiler must be closed, and the low-water cutoff (LWCO1, LWCO2) for that boiler must detect water for the boiler to operate. Each pellet boiler also has an “enable switch” (PBES1, PBES2) that must be closed for the boiler to operate.

Power for the auxiliary boiler is 120 VAC and supplied from a dedicated circuit. The service switch for the auxiliary boiler must be closed, and the low-water cutoff (LWCO3) must detect water for the auxiliary boiler to operate.

Power for circulators (P3, P4, P6), the 24 VAC transformer (X1), the multizone relay center (MZRC), zone valves (ZV1-ZV5), temperature controllers (T152-1, T152-2, T156, T256, T356), relay coils (R1, R2), and motorized valve (MV1) is supplied through another 120 VAC dedicated circuit. The main switch (MS) must be closed for these devices to operate.

Pellet boiler operation: Each pellet boiler is operated based on two temperature sensors in the thermal storage tank. As shown in Figure 8-8b, pellet boiler 1 is turned on when the temperature at sensor S2 drops to or below 110°F. This causes the stage one contacts in the (T152-1) controller to close, passing 24 VAC to relay coil (R1). Relay contact (R1-1) closes to provide a second pathway for 24 VAC to reach coil (R1). That pathway passes through the stage two contact of the (T152-1) controller which closes whenever the temperature at sensor (S4) is less than or equal to 165°F. Relay contact (R1-2) closes to provide an external demand signal to pellet boiler 1, through the 4PDT switch contacts. Pellet boiler 1 turns on circulator (P1) and initiates its startup sequence. The stage one contacts in (T152-1) open when sensor (S2) reaches 115°F. However, 24 VAC can still reach relay coil (R1) through the closed stage two contacts of (T152-1) and closed relay contact (R1-1). Pellet boiler 1 continues to operate until the temperature at sensor (S4) reaches 175°F.

Pellet boiler 2 turns on when and if the temperature at sensor (S1) drops to or below 100°F. This condition causes the stage one contacts in the dual setpoint controller (T152-2) to close, passing 24 VAC to relay coil (R2). Relay contact (R2-1) closes to provide a second pathway for 24 VAC to reach coil (R2). That pathway passes through the stage two contact of the (T152-2) controller, which are closed whenever the temperature at sensor (S3) is less than or equal to 165°F. Relay contact (R2-2) closes to provide an external demand signal to pellet boiler 2, through the 4PDT switch contacts. Pellet boiler 2 turns on circulator (P2) and initiates its startup sequence. The stage one contacts in (T152-2) open when sensor (S2) reaches 105°F. However, 24 VAC can still reach relay coil (R2)through the closed stage two contacts of (T152-2) and closed relay contact (R2-1). Pellet boiler 2 continues to operate until the temperature at sensor (S3) reaches 175°F.

The 4PDT “lead/lag” switch allows the firing order of the pellet boilers to be reversed. It would typically be switched once or twice per season to allow approximately the same number of run hours on each pellet boiler.

Pellet boiler anti-condensation protection: When either pellet boiler is firing, relay contacts (R1-3) or (R2-3) pass 120 VAC to the variable speed controller for circulator (P3) and to the actuator of motorized valve (MV1). Motorized valve (MV1) opens to allow flow from the pellet boilers to reach the upper tank header. The variable speed controller keeps circulator (P3) off until the temperature of water returning to the pellet boilers measured at sensor (S0) has reached 130°F. It then increases the speed of circulator (P3), reaching full speed when the temperature at sensor (S0) has reached 140°F or higher.

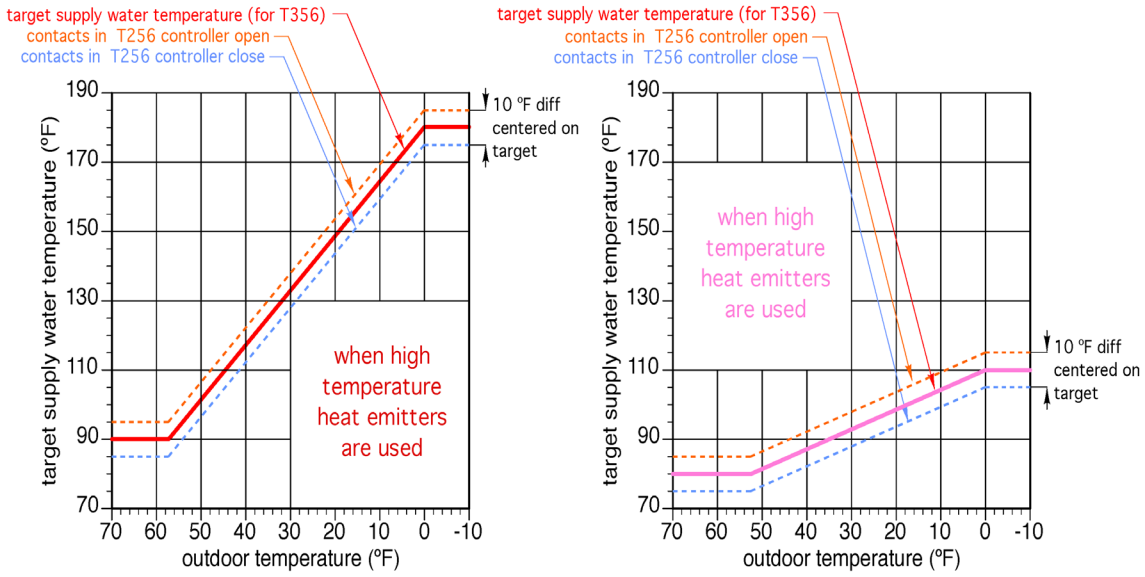
Auxiliary boiler operation: Whenever there is a heating demand, the (T256) controller monitors the supply water temperature to the distribution system at sensor (SS1). The auxiliary boiler and its associated circulator (P5) are turned on when the supply water temperature at sensor (SS1) drops 5°F below the target supply water temperature, based on the current outdoor temperature and the settings of the (T256) controller. The auxiliary boiler continues to operate until the supply water temperature at sensor (SS1) is 5°F above the target temperature and as long as one or more zone thermostats are calling for heat. When low-temperature heat emitters are used, the auxiliary boiler needs to be protected against sustained flue-gas condensation. This is done using a thermostatic mixing valve (MV1), as shown in Figure 8-8a. When the return water temperature from the heat emitters are consistently above 130°F consistently, this mixing valve is not needed.

Heat transfer from biomass subsystem to distribution: When one or more zone thermostats call for heat, 24 VAC is passed through the (X X) contacts of the multizone relay center (MZRC) to power on differential temperature controller (T156) and injection mixing controller (T356). The (T156) measures the temperature of the upper tank header at sensor (SH) and the temperature on the return side of the distribution system at sensor (SL). It closes its contacts when the temperature at (SH) is at least 6°F above the temperature at (SL). It opens its contacts when the temperature at (SH) is 3°F or less above the temperature at (SL). This control action ensures that circulator (P3) will only be allowed to operate when the biomass portion of the system can make a positive energy contribution to the distribution system. The 120 VAC pass through the closed contact of the (T156) to the (T356) injection mixing controller. The (T356) measures the outdoor temperature at sensor (SOUT2) and uses this temperature along with its settings to calculate the target supply water temperature at sensor (SS2). It then varies the speed of circulator (P3) to inject hot water from the biomass portion of the system into the distribution system so that the temperature at sensor (SS2) is directed toward the target temperature. This allows full-outdoor reset control of the supply water temperature to the heat emitters.

Space heating distribution system operation: On 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 multizone relay center (MZRC). Circulator (P4) is turned on and operates in a preset constant differential pressure mode.

Suggested initial controller settings: Figure 8-23 shows suggested outdoor reset settings for the (T256) and (T356) controllers.

Figure 8-8c. Suggested outdoor reset settings for T256 and T356 controllers in system 8



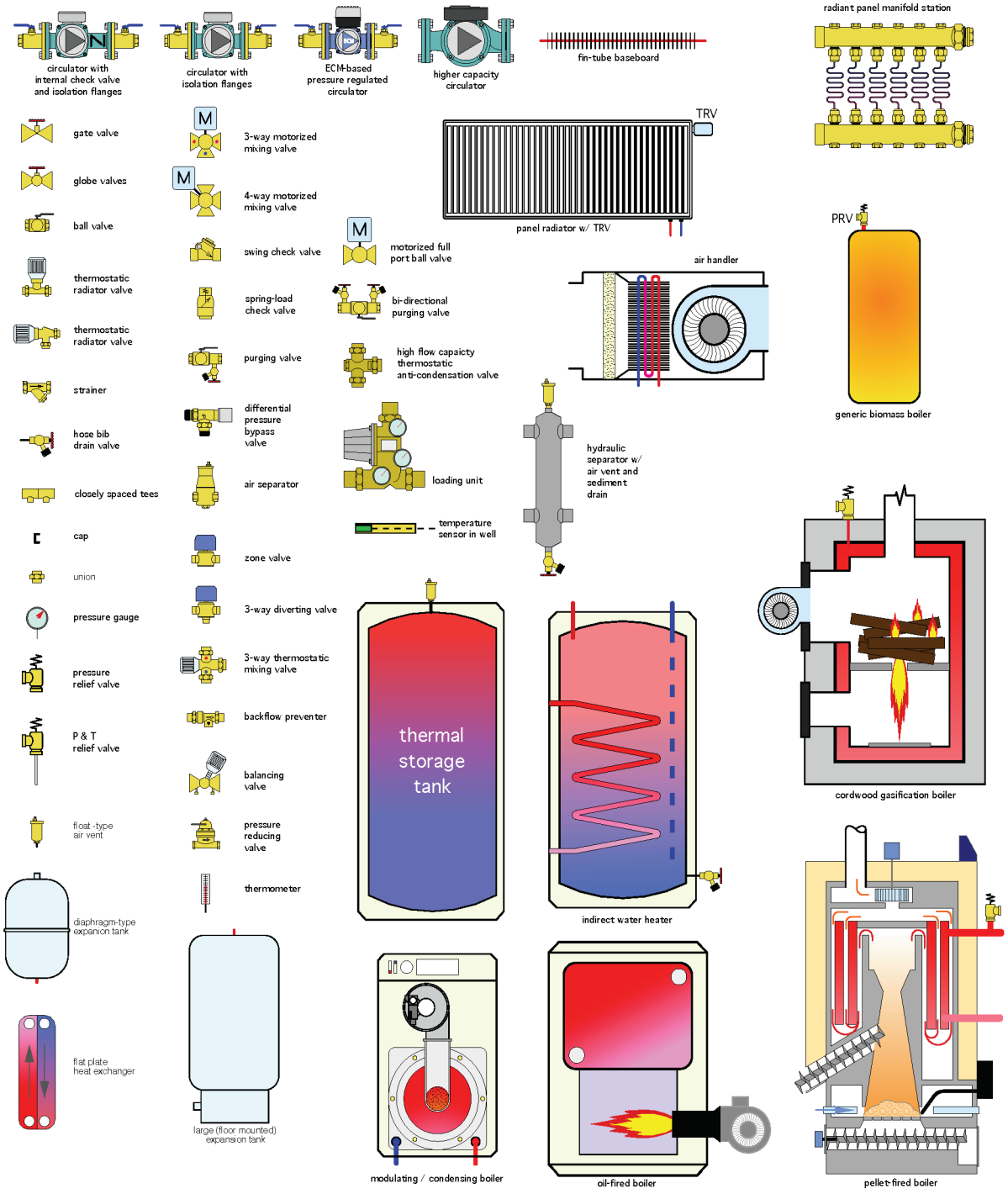
The following suggested initial controller settings assume low-temperature heat emitters that require a supply temperature of 110°F under design load conditions (0°F outdoor temperature).

- Stage one contacts in T152-1 controller: Monitor's tank sensor S2 contacts close at 110°F, open at 115°F
- Stage two contacts in T152-1 controller: Monitor's tank sensor S4 contacts close at 165°F, open at 170°F.
- Stage one contacts in T152-2 controller: Monitor's tank sensor S1 contacts close at 100°F, open at 105°F
- Stage two contacts in T152-2 controller: Monitor's tank sensor S4 contacts close at 165°F, open at 170°F
- Injection mixing controller (T356) settings:
    - No-load condition: 70°F supply water temperature when outdoor temperature is 70°F
    - Design load condition: 110°F supply water temperature when outdoor temperature is 0°F or lower
    - Minimum supply water temperature = 80°F
    - Maximum supply water temperature = 110°F

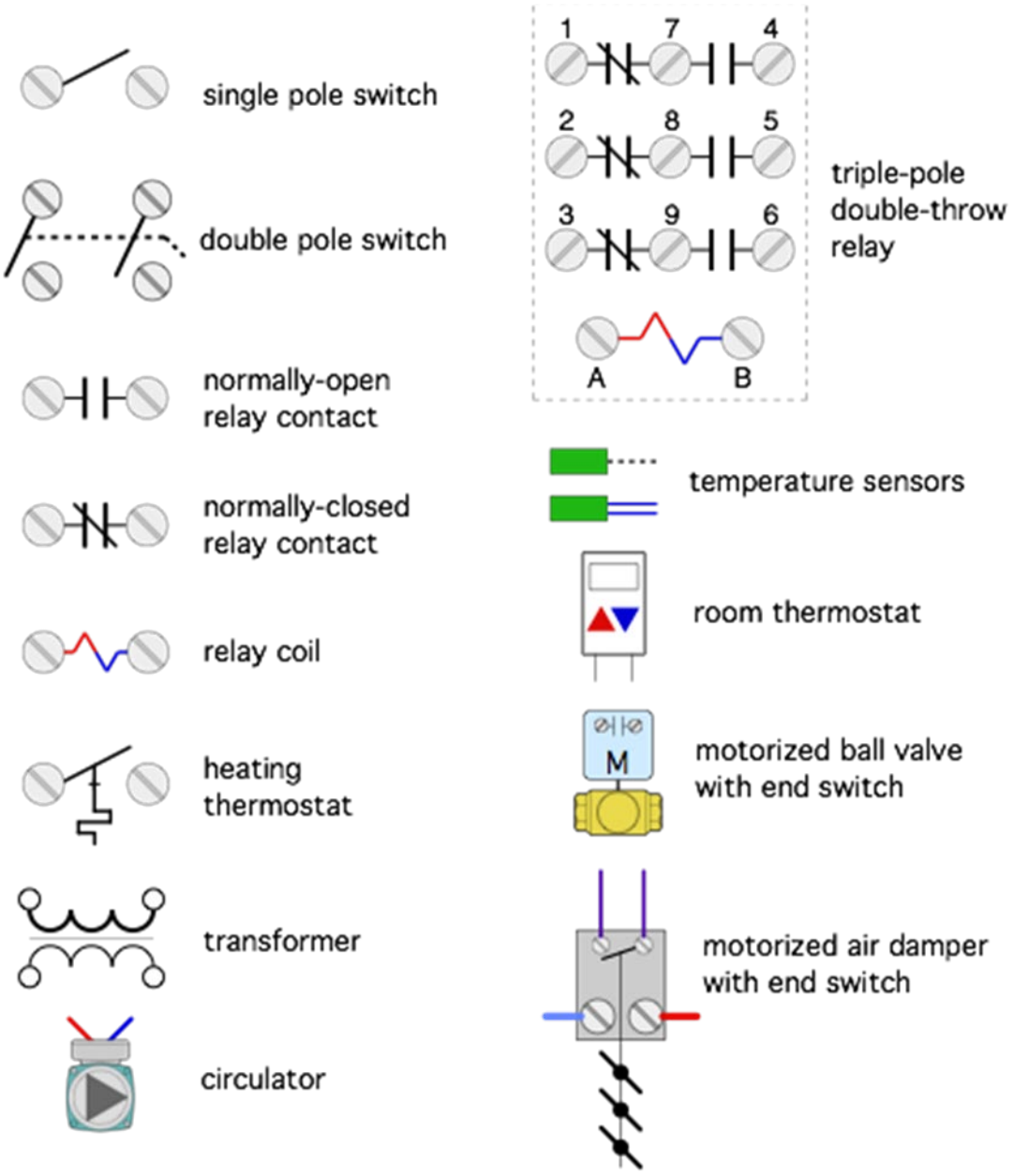
- Outdoor reset controller for auxiliary boiler (T256) setting:
    - No-load condition: 70°F supply water temperature when outdoor temperature is 70°F
    - Design load condition: 110°F supply water temperature when outdoor temperature is 0°F or lower
    - Differential = 10°F, centered on target temperature
    - Minimum supply water temperature = 80°F
- Pellet boiler settings:
    - High-limit temperature = 200°F
    - Other setting as per boiler manufacturer's recommendations
- Oil-fired boiler high-limit controller setting: 200°F
- Anti-condensation mixing valve setting for (MV1): 130°F
- Anti-condensation circulator speed controller settings
    - Circulator P6 off when sensor (S0) temperature ≤ 130°F
    - Circulator P6 at full speed with (S0) temperature ≥ 140°F
- Circulator (P4) setting:
    - Constant differential pressure at the required ΔP with all zone valves open

Appendix A: Piping symbol legend

Schematic Symbols for Piping Components



Appendix B: Electrical symbol legend



Appendix C: References

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