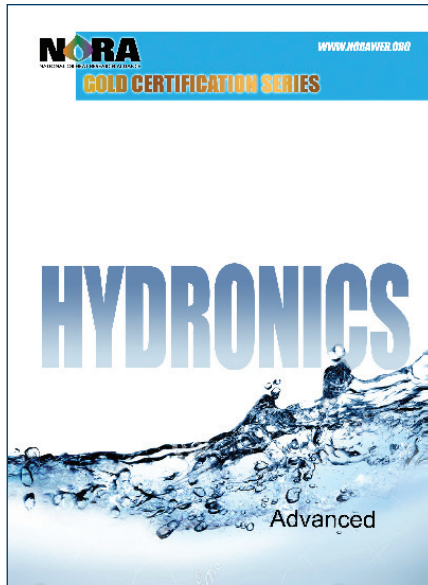# NORA
NATIONAL OILHEAT RESEARCH ALLIANCE

GOLD CERTIFICATION SERIES

HYDRONICS

Advanced

This publication is designed to serve as a training guide and to be used in conjunction with a course taught by a qualified instructor.

The reader should use local codes and equipment manufacturer's specifications and instructions in setting up and maintaining equipment.

The editors have attempted to present accurate information, however, NORA does not make any representations or guarantees and does not assume or accept any responsibility or liability with respect thereto.

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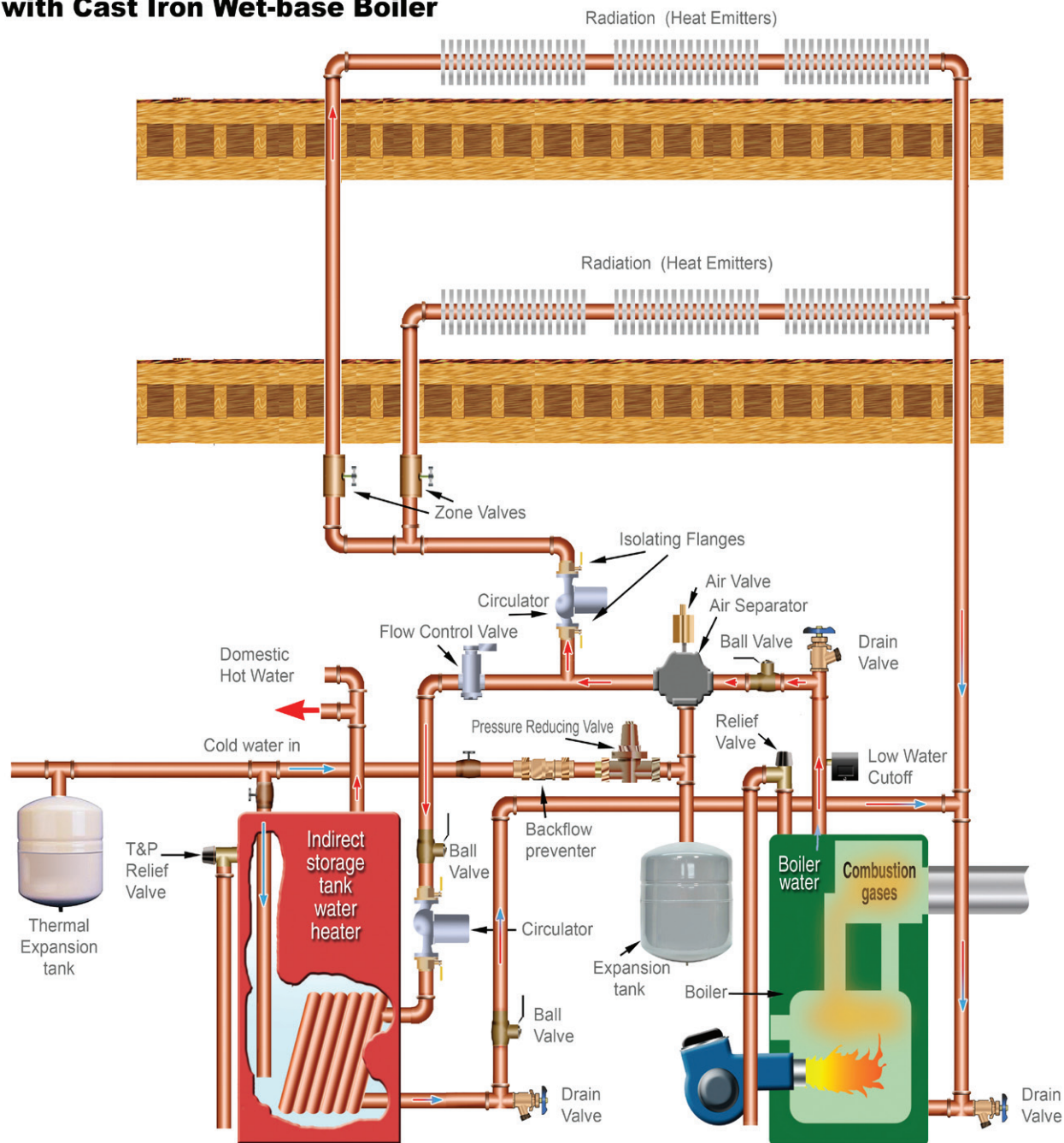
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Typical Hot Water Heating System with Cast Iron Wet-base Boiler

Figure 1

Radiation (Heat Emitters)

Radiation (Heat Emitters)

Zone Valves

Isolating Flanges

Circulator

Air Valve
Air Separator

Flow Control Valve

Ball Valve

Drain Valve

Domestic Hot Water

Pressure Reducing Valve

Relief Valve

Cold water in

Low Water Cutoff

T&P Relief Valve

Indirect storage tank water heater

Ball Valve

Backflow preventer

Boiler water

Combustion gases

Thermal Expansion tank

Circulator

Expansion tank

Boiler

Ball Valve

Drain Valve
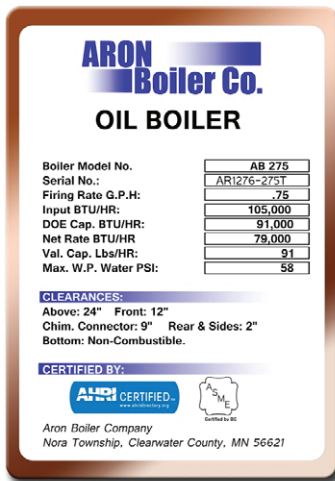
Drain Valve

Chapter 1
Hydronic System Components

Introduction

A hot water heating system is made up of components that work together to provide and maintain comfortable temperature in a structure. A typical hot water heating system is shown in Figure 1.

1 **Boiler**—the boiler/burner combination is used to heat water which is then circulated through piping connected to a variety of terminal units (heat emitters), including radiators, convectors, baseboards, fan coils, radiant, indirect water heaters and others.

Boiler nameplates (Figure 2) contain a significant amount of information; a typical boiler nameplate looks like this:

Figure 2

ARON Boiler Co.

OIL BOILER

Boiler Model No.	AB 275
Serial No.:	AR1276-275T
Firing Rate G.P.H:	.75
Input BTU/HR:	105,000
DOE Cap. BTU/HR:	91,000
Net Rate BTU/HR:	79,000
Val. Cap. Lbs/HR:	91
Max. W.P. Water PSI:	58

CLEARANCES:
Above: 24"   Front: 12"
Chim. Connector: 9"   Rear & Sides: 2"
Bottom: Non-Combustible.

CERTIFIED BY:

AHRI CERTIFIED
www.ahridirectory.org

Certified by BC

Aron Boiler Company
Nora Township, Clearwater County, MN 56621

Firing Rate

This tells us the firing rate of the appliance, also known as the burner capacity. In this case, the boiler is rated for .75 gallons per hour (gph). It's important to note that this is NOT the nozzle size. To determine the firing rate, fuel unit pressure must be considered. For example, if the pressure is 100 psi, then a .75 gph nozzle is correct; however if the pressure is 150 psi, a .60 gph nozzle is correct.

DOE Cap. (Capacity)

In this case, this unit is rated by the US Department of Energy at 91,000 Btus per hour capacity when fired at the specified burner input. This is also referred to as "gross output."

Net Rate (formerly I=B=R)

This rating is used to select a properly sized boiler based on a heat loss calculation performed prior to installation, plus any additional load, such as domestic hot water. It includes a 15% allowance for piping and pick-up losses. The term pickup losses describes the energy required to heat the boiler and piping before the system contributes any heat to the home.

2 **Pressure Relief Valve**—The pressure relief valve protects the boiler from over-pressurization. If the pressure rises to the system's maxi-
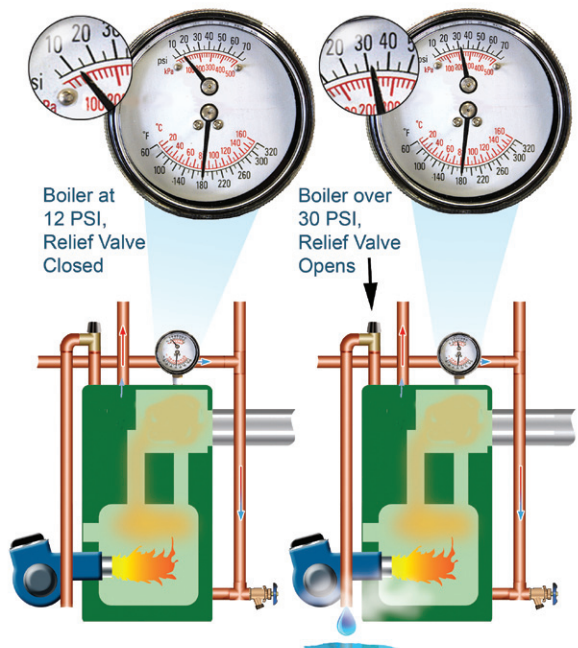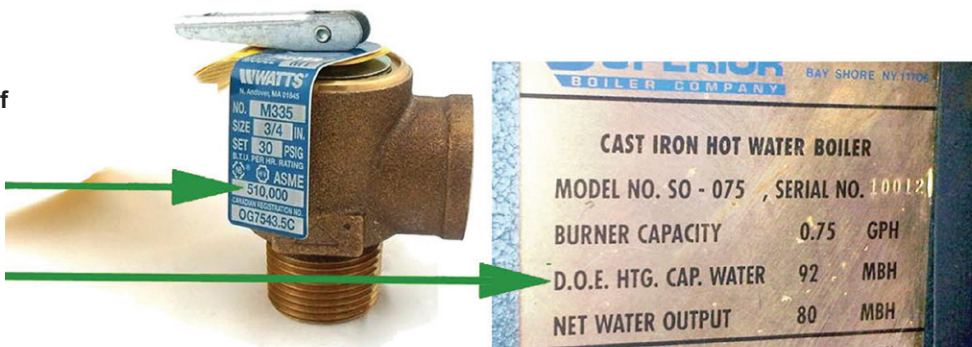
Figure 3

Boiler at 12 PSI, Relief Valve Closed

Boiler over 30 PSI, Relief Valve Opens

Figure 4

Pressure Relief Valve Rating Must Match or Exceed the DOE Heating Cap.

mum operating pressure, the relief valve is designed to open and release water from the system, reducing the pressure. Most residential hot water systems are equipped with relief valves that open at 30 PSI, but which may actually release and weep around 27 psi. See Figure 3 on previous page.

The relief valve MUST be properly sized. The rating MUST meet or exceed the boiler's DOE heating capacity rating. See Figure 4 above.

3 **Low water cut-off**—LWCOs protect boilers against damage and are installed at or above the boiler's minimum safe water level. They utilize an electronic probe—when water is in contact with the probe, it completes a circuit between the probe tip and the boiler surface or a tee. If the water level drops below the probe, the circuit opens and shuts off the burner. Figure 5.

Figure 5

4 **Air elimination device**—Air elimination devices are used to help control air bubbles in the heating system. If a system has too much air, it can't transfer heat efficiently and can be very noisy. A properly designed and installed hydronic system should be virtually silent and very efficient.
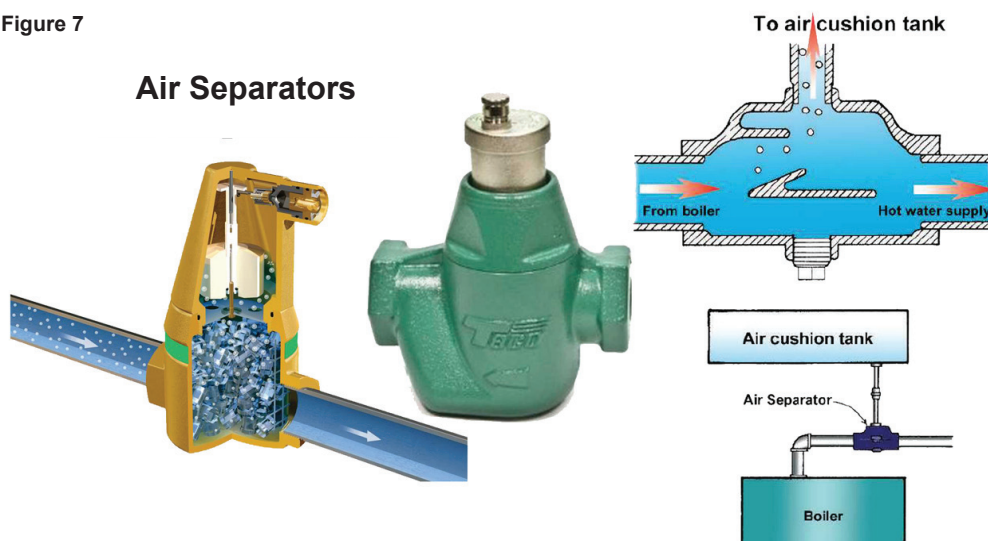
There are a number of different types of devices available to remove air from the circulating water including air scoops and air separators equipped with automatic air vents.

Air scoop

The inside of an air scoop is larger than the pipe feeding into it. When water enters this larger area, its velocity slows down and the pressure decreases slightly, causing the air bubbles to separate from the water. Vanes inside the device "scoop" the bubbles into an upper chamber where they pass out through an air vent at the top of the scoop. (Figure 6)

It's important to understand that the scoop will only work if there is a minimum of 18 inches of straight pipe on the inlet side. The air bubbles need to be on the top of the flow as the water enters the scoop, otherwise the vanes won't catch the bubbles and the scoop won't remove the air. The 18 inch minimum length is needed to create laminar flow, meaning the air will float to the top. If the scoop is installed closer to an elbow, the flow will be turbulent, the air will be mixed with the water and the scoop will be unable to remove the air.

Air Scoop **Figure 6**

Figure 7

Air Separators

Air Separator

These devices offer enhanced air separation characteristics. They do not require a run of straight pipe on the inlet side and their design enables them to capture and remove smaller bubbles. They should be placed on the supply pipe as close to the boiler as is possible (air turns to bubbles more easily in hot water.) Figure 7.

5 **Air vents**—These devices are installed in the system piping to remove air bubbles. There are two types of air vents:

Automatic air vents

Automatic air vents have a float which lowers and opens a spring loaded venting valve to purge air from the system. When
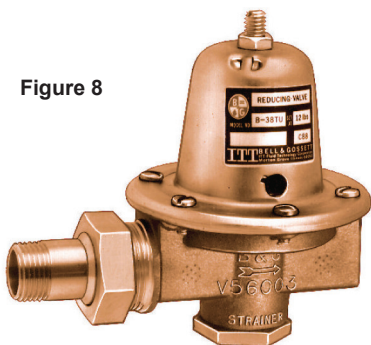
Figure 8

the air is vented, the float rises and closes the vent.

When using automatic air vents, the system pressure at all vent locations should always be at least 3 psi above atmospheric pressure to prevent air from being pulled into the system.

Manual air vents

Manual air vents are normally installed on individual terminal units and are used to remove air during system startup and when troubleshooting air problems in the system.

6 **Pressure reducing valve (PRV)** Figure 8. PRV's serve two functions. First, they reduce the home's higher water pressure to the lower pressure required by the heating system. The water pressure in most homes is typically from 40 to 80 psi, depending on whether the water is supplied from a well (lower pressure) or is city-supplied (higher pressure).

The PRV also fills the system with enough water that the water at the top of the system is under sufficient pressure to vent all of the air in the system while allowing water to circulate.

Most residential PRVs are set at 12 psi, which is enough pressure for a typical two-story house with the heating system in the basement.

The amount of pressure needed is calculated as follows:

1 psi will lift water 2.31 feet.

If the total distance from the PRV to the top of a radiator on the second floor is 18 feet, then:

18÷2.31 = 7.8 psi

Just less than 8 psi will lift water to the top of the system, but it won't be at enough pressure to circulate water throughout the system, therefore 3-4 psi are added to give positive pressure at the system's highest point. This PRV should be adjusted to provide 12 psi.

If the building is higher, use this formula:

Height from PRV to top of radiation on highest floor x 2.31 + 4 = recommended pressure setting.

For example, a home where there is 30 feet from the PRV to the top of the radiator on the highest floor should be set to operate at 17 psi:
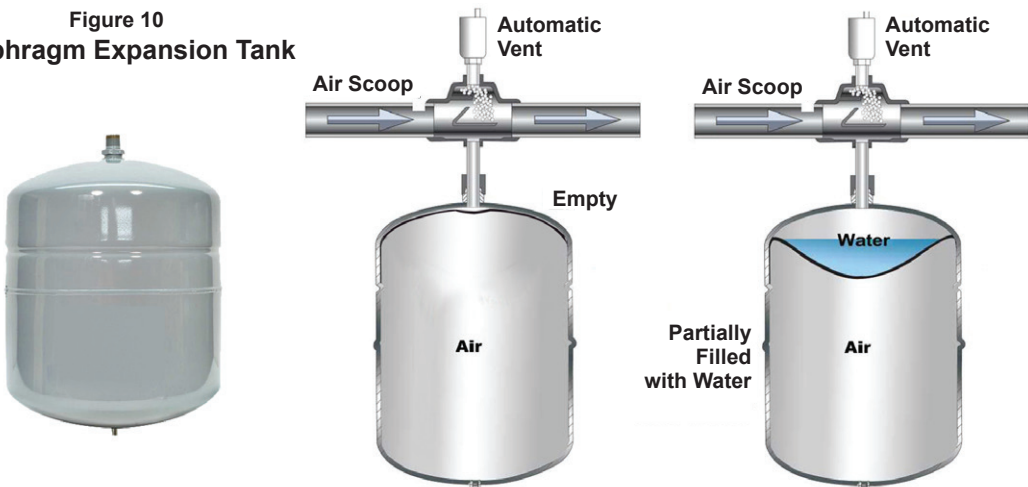
(30 ÷ 2.31 = 13) + 4 = 17 psi

7 Backflow preventer—These devices are installed on boiler feed lines to prevent contaminants in the heating system water from flowing back into, and contaminating, the potable water supply when supply pressure is lower than system pressure. Figure 9.

Figure 9

8 Expansion tank—Since the water in a closed heating system expands by about 5% when it is heated, the system needs a place for the "expanded" water to go as well as provide a way for that water to return to the system after it cools. Without that added space, the system pressure would rise and the relief valve would discharge, lowering the water level in the system just about every time the burner cycled. Then, when the

**Figure 10
Diaphragm Expansion Tank**

Automatic Vent

Air Scoop

Empty

Air

Automatic Vent

Air Scoop

Water

Partially Filled with Water

Air

water cools down and "condenses," the system would not have enough water to operate properly.

Expansion tanks are designed to enable the expansion and contraction of the system water so the system can continue to operate effectively.

There are two main types of expansion tanks in use today—diaphragm tanks and steel compression tanks.

Diaphragm Tanks (Figure 10)
 These tanks have an internal rubber diaphragm that separates the heating system water on one side from compressed air on the other side.

Before the tank is installed on the system, the diaphragm is fully expanded and flush with the inside wall of the tank at the system tapping. This is because the air side of tank is normally pre-charged by the manufacturer to 12 psi. Once the tank is installed on the system, the water pressure pushes against the diaphragm. As the system heats up, the "expanded" water forces its way into the tank. As the water cools, the air pressure forces the water back out of the tank.

The air side of the tank should be charged to the system's operating pressure. If the PRV is set to provide 17 psi, the air side of the diaphragm should be pumped up to 17 psi. If the air side pressure doesn't match the water pressure, the relief valve may discharge because the water pressure might push the diaphragm all the way back before the water expands.
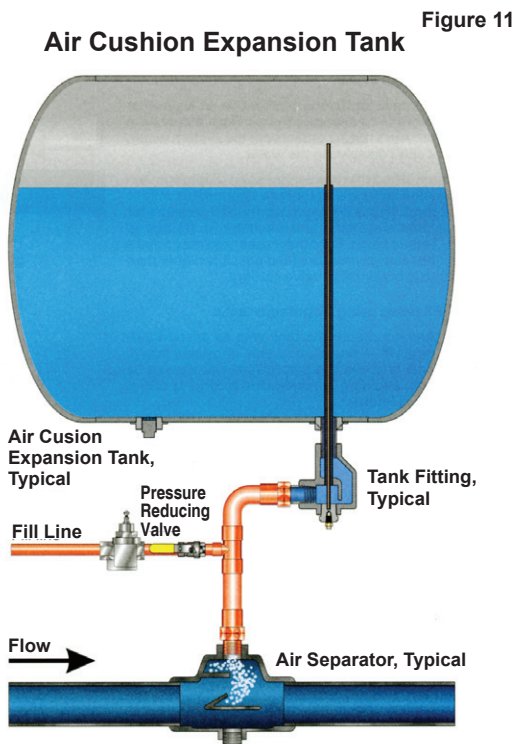
Diaphragm tanks work best when installed on an air separator with an automatic air vent.

Steel Compression Tanks (Also called air cushion tanks, Figure 11). Under

normal operation, these tanks are typically about 2/3 full of water and 1/3 full of air during the off cycle. As the system water heats up, it expands by about 5% and pushes against the air in the top of the tank compressing it and creating a pressure increase of about 1 psi. As the water cools down during the off cycle, the water condenses and the air expands back to its original volume.

These tanks can become full of water, or "water logged." When this happens there is no air for the water to compress and no room for expansion. The water pressure will increase and the boiler relief valve will discharge. Once the tank is drained to the proper level again, the system will operate normally.

9 **Circulator**—A circulator's job is to take water from the boiler, move it through the terminal units where heat is emitted and then return it

Figure 11

Air Cushion Expansion Tank

Air Cusion Expansion Tank, Typical

Fill Line

Pressure Reducing Valve

Tank Fitting, Typical

Flow

Air Separator, Typical

to the boiler where it can be reheated. It circulates water in a closed loop system by creating a pressure differential, meaning it takes the fluid that comes into it at a given pressure and sends it out at a higher pressure All the circulator has to do is create enough of a pressure differential to produce adequate flow through the system.

To produce the necessary pressure differential, an impeller is used. How this impeller is designed and installed is critical to the operation of the circulator, and should be understood by anyone installing or servicing hydronic systems.

When the circulator is in operation, water flows into the suction side of the volute—a part of the circulator which is always wider and larger than the discharge side—and then into the eye of the impeller. As the impeller rotates, the vanes "slap" the water from the inside of the impeller to the outside of the impeller. This adds velocity to the fluid. The fluid then moves to the discharge side of the volute, which is smaller and narrower. The collection chamber on the discharge side turns the kinetic energy of the fluid – (energy due to velocity) into pressure. Thus water comes into the circulator at a certain pressure and leaves at a higher pressure.

The thickness, diameter and construction of impellers all play a role in the performance of the circulator. The thickness of the impeller determines its flow capacity—the thicker the impeller, the more flow the circulator will be able to produce.


Open Vane impeller
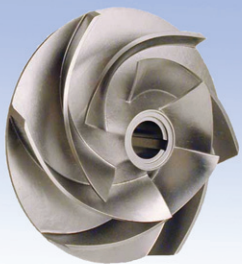
The diameter of the impeller is also important. The larger the diameter, the more velocity the circulator can impart to the fluid. The more velocity, the more pressure the circulator can produce.

Open vane impellers are used in circulators designed to provide high flow and rela-

tively low head. These types of circulators are called flat curve circulators – as will be apparent when looking at performance curves.

Flat curve circulators are used in radiator and baseboard applications which require higher flow rates but have lower overall head losses.

Closed vane impellers are used for higher head and medium to high flow circulators. They are designed for lower flow systems that

Closed Vane Impeller

produce higher head losses, which are typically found in most radiant applications.
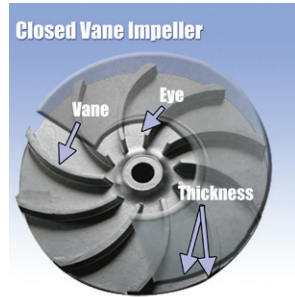
10 **Zones**—A zone is an area of the house controlled by a dedicated thermostat. A common residential zoning system has one zone for the first floor and one zone for the second floor. This system requires either two thermostats and two circulators OR two thermostats, two zone valves and one circulator.

11 **Zone valves**—Zone valves are two-position valves: they are either open or closed and are wired to the thermostats in the house. The valve is usually closed and will open only when there is a call for heat from a thermostat in a particular area of the home. Once the valve is fully open, the circulator will start and water will begin flowing to the rooms that need heat. Figure 12.

12 **Flo-Control Valve** —Some systems have a dedicated circulator for each zone and do not use zone valves. These systems utilize flo-control valves that are installed in the supply piping to prevent gravity circula-

tion of hot water when the thermostat is not calling for heat.

Without a flo-control valve, gravity circulation occurs because hot water tends to rise through a system's piping simply because it weighs less than the colder water in the piping.

Flo-conrol valves open, allowing water to move through the system when a circulator operates and they close when the circulator stops running.

Flo-control valves can be used in systems with multiple zones to allow heat to flow only into the zones that are calling for heat. Most can be opened manually to allow for temporary gravity flow if the circulator malfunctions.

While they are normally installed in the supply piping, there are situations in which an additional flo-control valve is required on a return line.

Flo-control valves are also used in primary-secondary systems on both the feed and return lines of all secondary circuits except those that are below the primary circuit's piping.
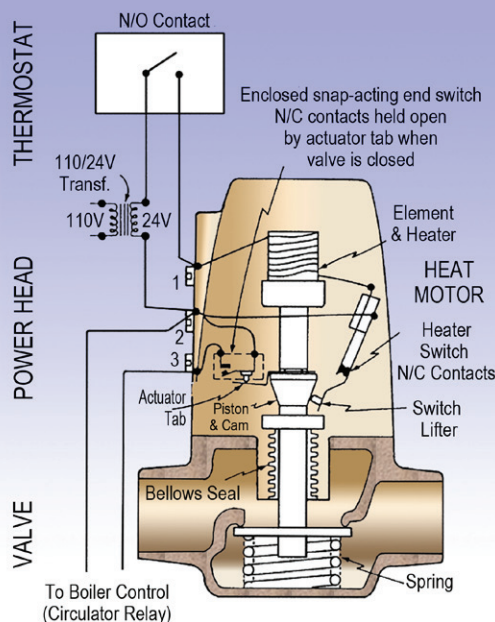
13 **Indirect water heater**—Indirect water heaters are storage tanks with internal heat exchangers. They are equipped with an aquastat that controls a circulator to move hot boiler water through the inside of the heat exchanger, heating the domestic water in the tank.

14 **Thermal expansion tank** —Domestic water expands when it is heated and 50 gallons of cold water becomes about 52 gallons of hot water. Thermal expansion tanks will take-up the excess water, preventing continual discharges from the relief valve.

These tanks are necessary when back flow devices are installed; back flow devices prevent the expanding water from flowing back into the water main.

15 **Temperature & Pressure relief valve (T&P)**—The T&P valve provides automatic temperature and pressure protection for the water heater. Typically, PRVs open and release water when the water temperature reaches 210 º F and/or the water pressure reaches 150 psi.

Figure 12

THERMOSTAT

N/O Contact

110/24V Transf.

110V 24V

POWER HEAD

Enclosed snap-acting end switch N/C contacts held open by actuator tab when valve is closed

Element & Heater

HEAT MOTOR

Heater Switch N/C Contacts

Switch Lifter

1
2
3

Actuator Tab

Piston & Cam

Bellows Seal

VALVE

Spring

To Boiler Control (Circulator Relay)

16 Heat emitters/Terminal units

16 **Heat emitters/Terminal units**—Modern hydronic systems can have many types of radiation to provide heat throughout a structure, including baseboard, convectors, radiators, hydro air coils, radiant, etc.

Heat emitters receive heat from the hot water circulating through the piping and deliver heat to the areas where they are installed.

Types of Heat Emitters (aka terminal units)

Typical hot water heating systems deliver heat by convection. They circulate water through heat emitters, warming the air around them. As the air is heated, it expands, becomes less dense and rises. As the warm air rises, the colder air it displaces falls, creating heat convection currents. These convective currents don't require a mechanical means to move the air.

Baseboard Heating

Finned-tube baseboard and cast-iron baseboards use convection to circulate heat. Cooler air at the floor level enters the bottom of the baseboard and because of the heated material in the baseboards, heat is transferred to the air which then moves up the wall. Baseboard location is usually along outside walls to help these convective currents and to remove the feeling of a cold wall or window.

Finned- tube baseboard features copper tubing with aluminum fins attached. Manufacturers have different types, sizes and numbers of fins per inch. With these variables, the manufacturer rates the Btu output per linear foot based upon a given supply water temperature. Typical finned-tube baseboard is ¾" copper tubing with ½" and 1" available. One inch is typically for commercial applications and has a higher heat output, ½" and ¾" are similar in output, but overall length of the loop is shorter with ½".

Finned-tube baseboard heats up rapidly and dissipates its heat quickly. Surface temperatures of the units are not an issue as they are protected with covers. This system works well when there is enough clearance to create convective currents. Cool air enters the bottom and the heated air comes out the top front grates. Furniture placement in front and proper space under the cabinet are critical for the finned-tube baseboard to work properly. See below, Figure 13 for Ratings Charts.

Cast iron baseboard heats up slowly and cools off slowly. Surface temperatures are high and there are no protective enclosures. Cast iron baseboard also provides radiant heating because the large mass of iron stays hot even after the circulator shuts off, and slowly releases energy into the space.

Convectors

Convectors are similar to fin tube baseboard, but tend to be higher, thicker, and not as long. They heat up quickly and cool off quickly. Surface temperatures are not an issue as they are protected with covers. Like finned-tube baseboard, they need enough room in front to create convective currents.

Radiators

Cast iron radiators deliver heat in a way that is similar to cast iron baseboard; they heat up slowly and cool off slowly, but surface temperatures are high and there are no protective enclosures. They are relatively large and have higher water content than baseboard heating.

Figure 13

Hot Water Ratings: BTU/HR. per linear ft. with 65°F entering air																
Element	Water Flow	Pressure drop⁺	110°F	120°F	130°F	140°F	150°F	160°F	170°F	180°F	190°F	200°F	210°F	215°F	220°F
NO. 30-75 baseboard with 3/4" E-75 element	1GPM	47	160*	210*	260*	320*	360	450	510	580	640	710	770	810	840
	4 GPM	525	160*	220*	270*	340*	400	480	540	610	680	750	810	860	890

Flat Panel Radiators

Flat panel radiators are a cross between finned-tube baseboard and radiators. There is not as much mass as a radiator and also fewer fins on the back side. These are typically steel and manufactured to a variety of lengths and heights. The steel mass adds to the radiant energy into the room and the fins help create convective currents.

Fan Coils

Fan coils are small convectors with fins installed in ductwork. The hot water enters the fan coils and air is circulated in the home by the unit's own fan blowing across the fins.

Radiant Panel Heating

Radiant heating systems deliver warmth by radiant heat transfer.

A typical radiant floor system heats the terminal unit (floor) anywhere from 75° to a maximum of 85°F. (Figure 14). Supply system temperature can be significantly lower than required in a system relying on convection. Depending upon the radiant installation method, the water temperature needed for heating can be as low as 100°F and up to 180°F. This difference in temperatures can create some challenges when working on a hybrid system, as when, for example, the home has a radiant zone, a baseboard zone and an indirect water heater.

In a radiant system, the boiler is typically at a high temperature (around 180ºF) while the radiant system operates at a lower temperature, creating the need for a mixing device. Mixing devices (mixing valve, injection mixing) will send out a lower temperature to the floor panel system by blending the return water from the radiant panel with the boiler water. When a mixing device is used, there must be a circulator after the mixing device to insure flow through the radiant panel.

Figure 14

Ordinary Heating

Radiant Heating
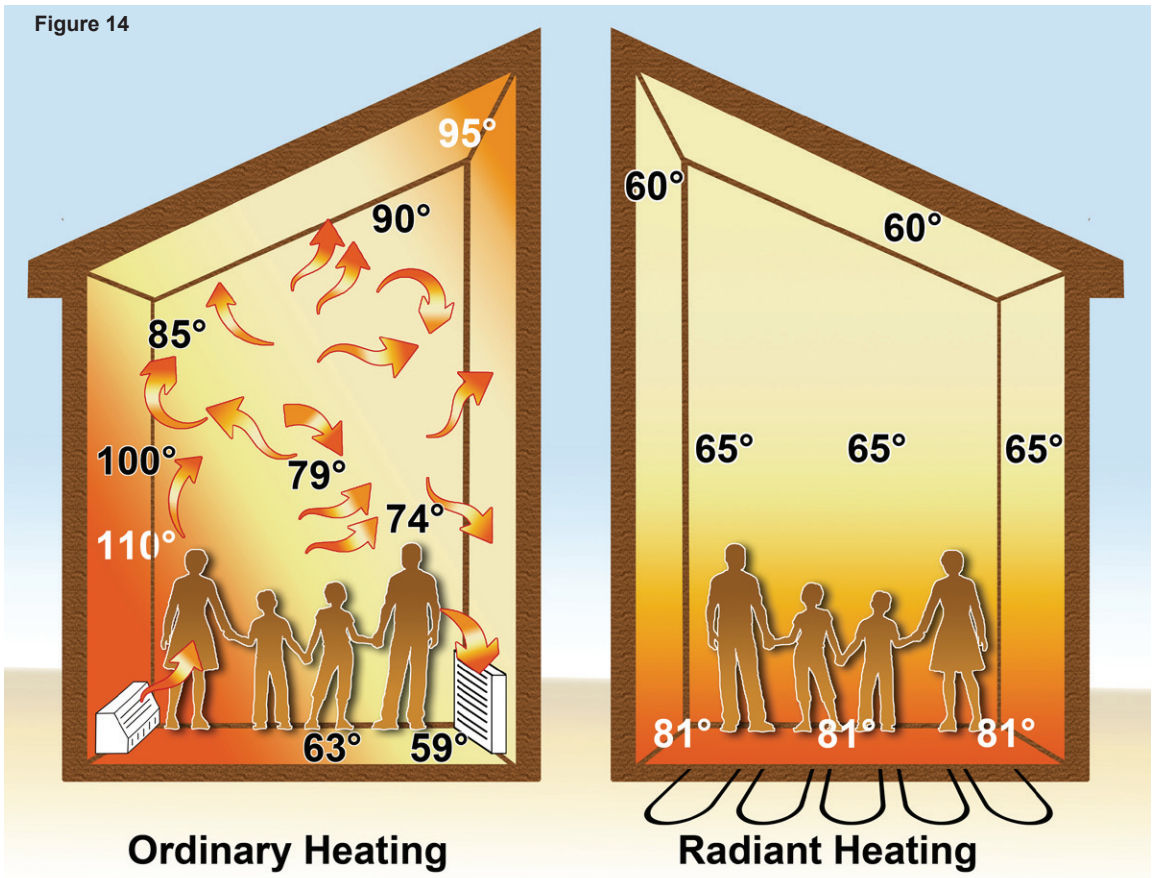
Chapter 2

Hydronic System Piping

One of the main advantages of hydronic heating is its flexibility. There are a wide variety of hot water heating systems in operation today, this section will examine the following systems:

- Series Loop

- One Pipe

- Two pipe

- Radiant

- Primary-Secondary

It's important to understand that an individual home (or building) can have several different types of systems. For example, there may be a one pipe system on the main floor, radiant heat in the basement and a series loop on the second floor.

Each of these systems would typically be piped as a separate zone using circulators, zone valves, manifold telestats and/or solenoid valves.

Zoning gives the occupants better control of their comfort and reduces energy consumption as different temperatures can be maintained in different areas of the structure.

A **series loop** (Figure 1) is the simplest and most common hydronic heating system design. Each zone is made up of a single run of piping or radiation and the water flows from the boiler supply through each heat emitter (finned-tubed baseboard, cast-iron baseboard) in series and back to the boilers return. When there are multiple zones for the project this might be referred

Figure 1

The Series Loop
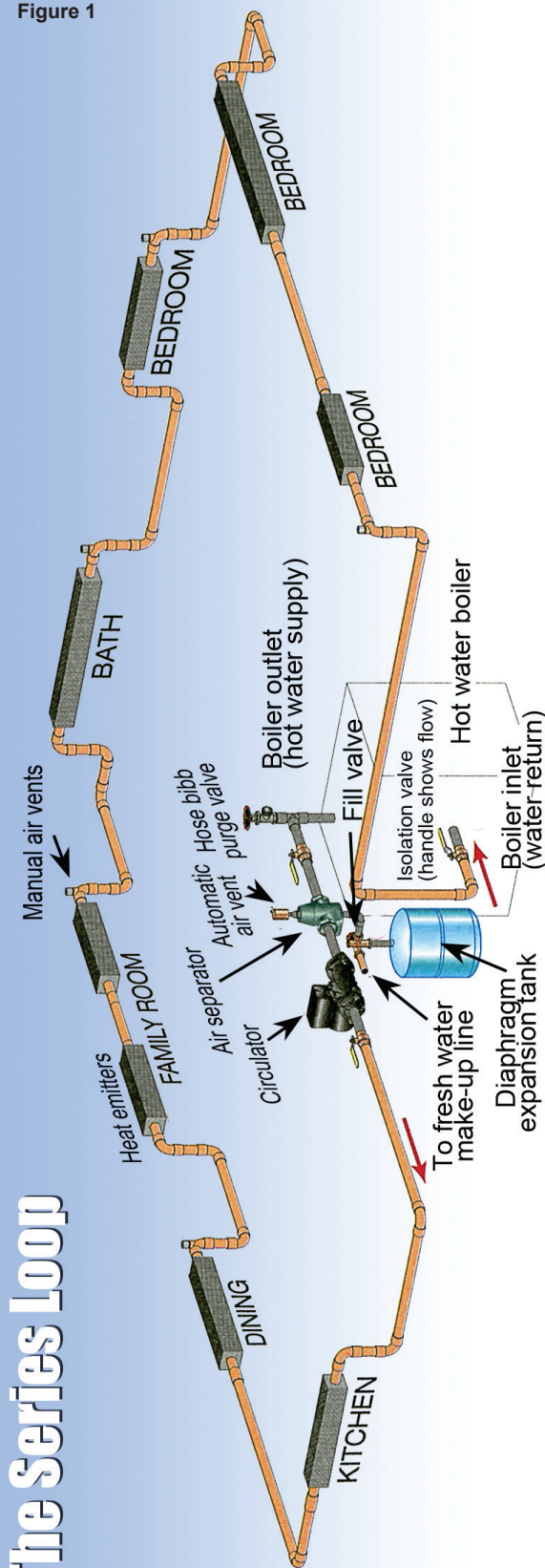
to as a "branch header system". When there are multiple zones, each loop is piped parallel to each other, but the loop itself is series piped.

Advantages
- Requires less pipe and fittings than other systems

- Relative lower cost to install

- No special valves or fittings required

Disadvantages
- Temperature at the first heat emitter is significantly higher than what is supplied to the last heat emitter. Rooms at the beginning of the loop may over-heat while rooms at the end may under-heat. Care should be taken when sizing and selecting the heat emitters due to the temperature drop of the fluid and the heat output of the emitter with reduced temperatures.

A **split series loop** (Figure 2) system overcomes some of the disadvantages of a standard series loop by dividing the radiation into separate zones.

These systems have either a common supply or a common return and literally "split" the radiation into separate zones. These two "loops" can be on the same zone or split into separate zones, each with its own balancing valve, thermostat and/or zone valve/circulator.

Advantages
- Better control of temperature and thus more comfortable than a standard series loop.

- Smaller diameter pipe can be used due to shorter runs.

    Disadvantages
- Requires additional pipe, fittings and components.

- Slightly more expensive to install

Figure 2

Series-loop piping (split-loop—2 circuits)
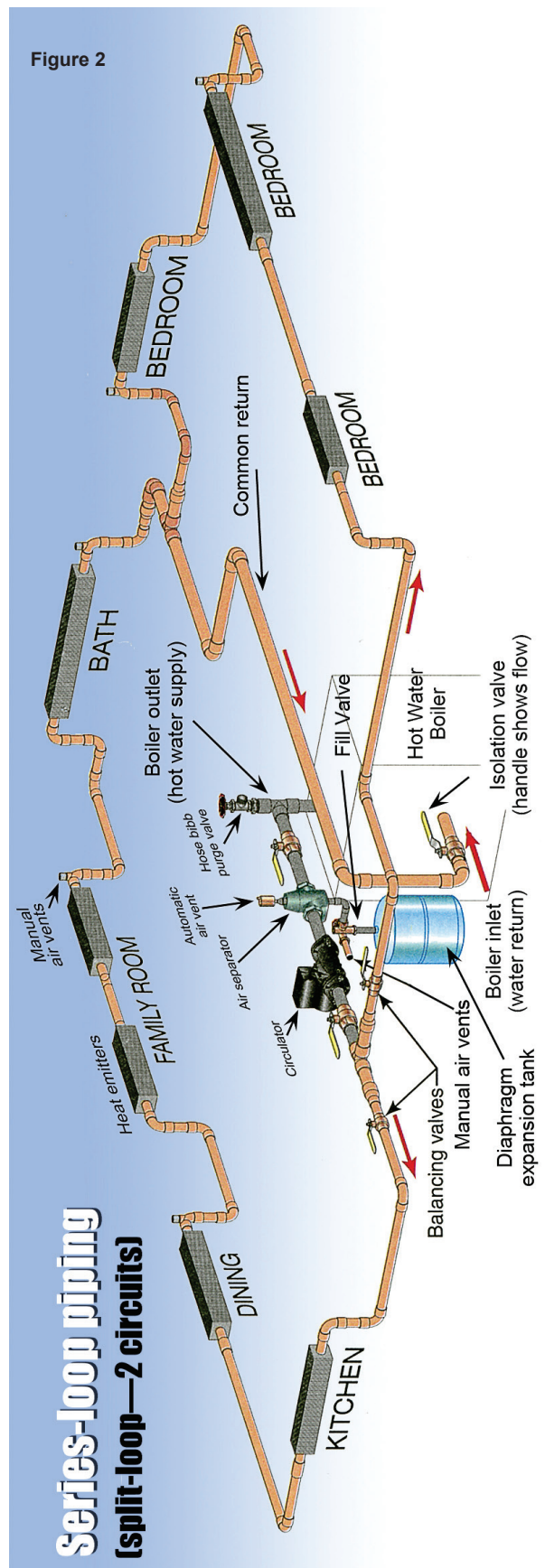
The **one pipe** (Figure 3) system utilizes one main pipe that connects from the boiler supply to the boiler return. The heat emitter is connected to the main by two smaller (feed and return) pipes that are fitted with diverter (aka Mono-flow, Venturi, Jet, or One pipe) tees that cause a portion of the water circulating in the main to be routed through each section of the attached emitters. Typically, one standard tee and one diverter tee are used for each emitter unit. It is important to follow the manufacturer's instructions regarding the spacing between the tees and which pipe (feed or return) to install the diverter tee on.

Sometimes it is necessary to provide two mono-flow tees for a single heat emitter to produce sufficient water flow through that radia-
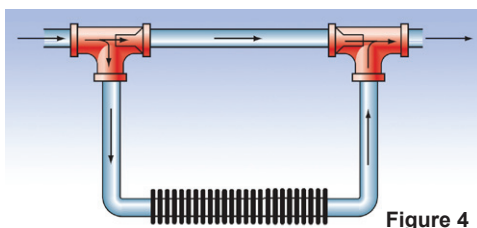

Figure 4

tion. For example, if a radiator is lower than the main pipe, the buoyancy effect of the cold water at the bottom and hot water at the top will cause insufficient flow. In this situation, two diverter tees must be used and the spacing between them should be the same as the width of the heat emitter. Figure 4.

Another situation where two diverter tees may be needed is when a radiator has been removed and replaced with baseboard heating. In those situations, the diverter tees can be relocated to compensate for the additional pressure drop through the baseboard or an additional diverter tee can replace the standard tee. Figure 5 on following page.
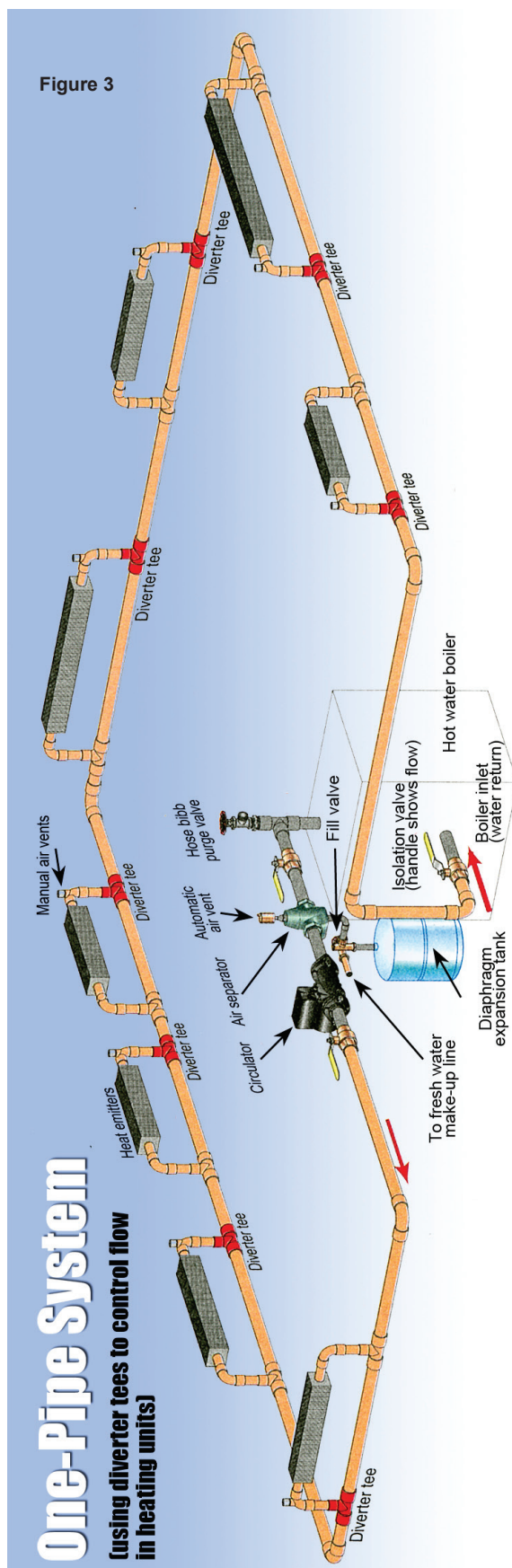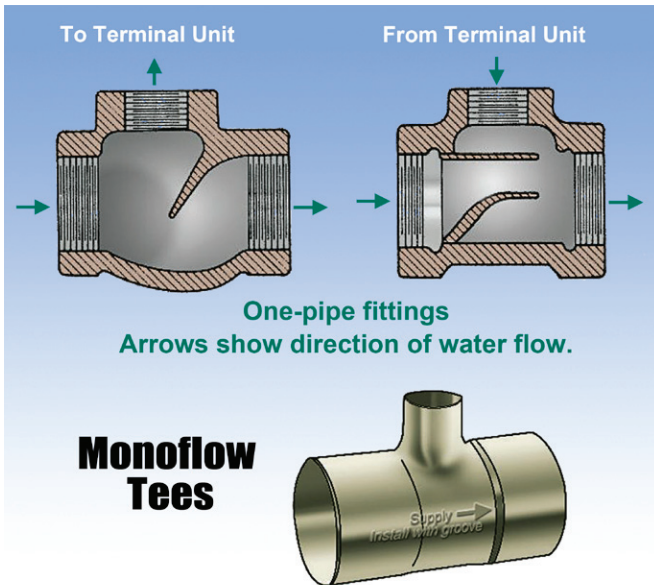
Figure 3

One-Pipe System
[using diverter tees to control flow in heating units]

Figure 5

To Terminal Unit   From Terminal Unit

One-pipe fittings
Arrows show direction of water flow.

Monoflow Tees

Supply
Install with groove

As you can see in Figure 6 below, the heat emitter closest to the boiler has the shortest run of piping while the heat emitter farthest away from the boiler has the longest piping run. In this example, the water must flow a total of:

38' to travel from the boiler, through the first heat emitter and back to the boiler.

58' to travel from the boiler, through the second heat emitter and back to the boiler.

78' to travel from the boiler, through the third heat emitter and back to the boiler.

In the **two pipe direct return** systems, one pipe carries water from the boiler to the heat emitters and another pipe brings water back to the boiler. Heat emitters on these systems are connected to the supply and return piping like the rungs on a ladder.

Less water will flow through the heat emitters that are further away from the boiler and they will generate less heat. On these systems, balancing valves must be installed on each heat emitter's piping to increase the resistance of the shorter piping circuits to even out the flow of water through each circuit.
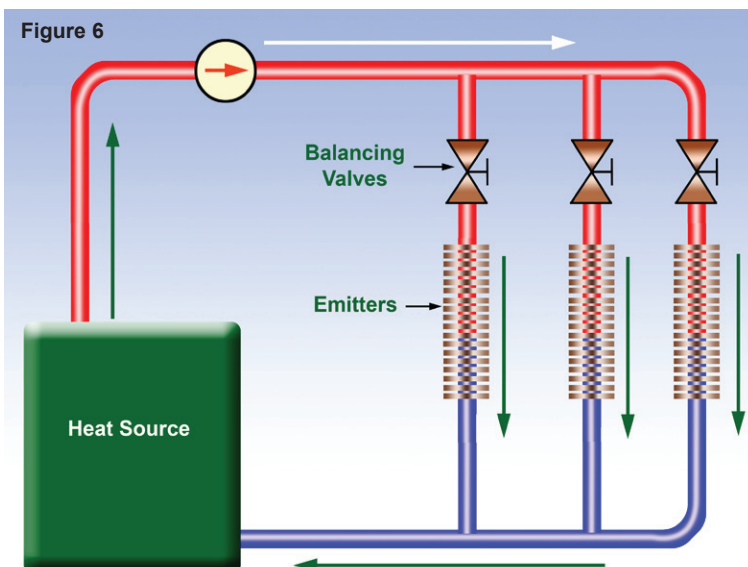
The terminal units in a **two pipe reverse return** system are piped in "parallel" to separate supply and return pipes. For proper operation, these systems rely on a "first supplied, last returned" piping arrangement.

Figure 7, on following page, illustrates that the supply connection of the first terminal unit is the *closest* one to the boiler and the return connection is the *furthest* one from the boiler. The first unit supplied

Figure 6

Balancing Valves

Emitters

Heat Source

is connected to the end of the return pipe and the last unit supplied is connected to the beginning of the return pipe.

By piping the system this way, the water flowing through each terminal unit has to travel approximately the same distance. As a result, the flow through each terminal unit is about the same.

Multi-zoned two pipe system

Similar to splitting series loop systems, splitting two pipe systems into separate zones provides better comfort and reduces energy consumption. For the best performance, rooms should be combined into zones based on similarities in usage. Figure 8.

Primary secondary

Primary-secondary piping arrangements provide better flow control and temperature control than other types of systems. They are very popular and common in residential systems because of the popularity of radiant heat. This piping system also helps to prevent flue gas condensation caused by low temperature return water. Primary/secondary piping also hydraulically isolates the loops from one another.
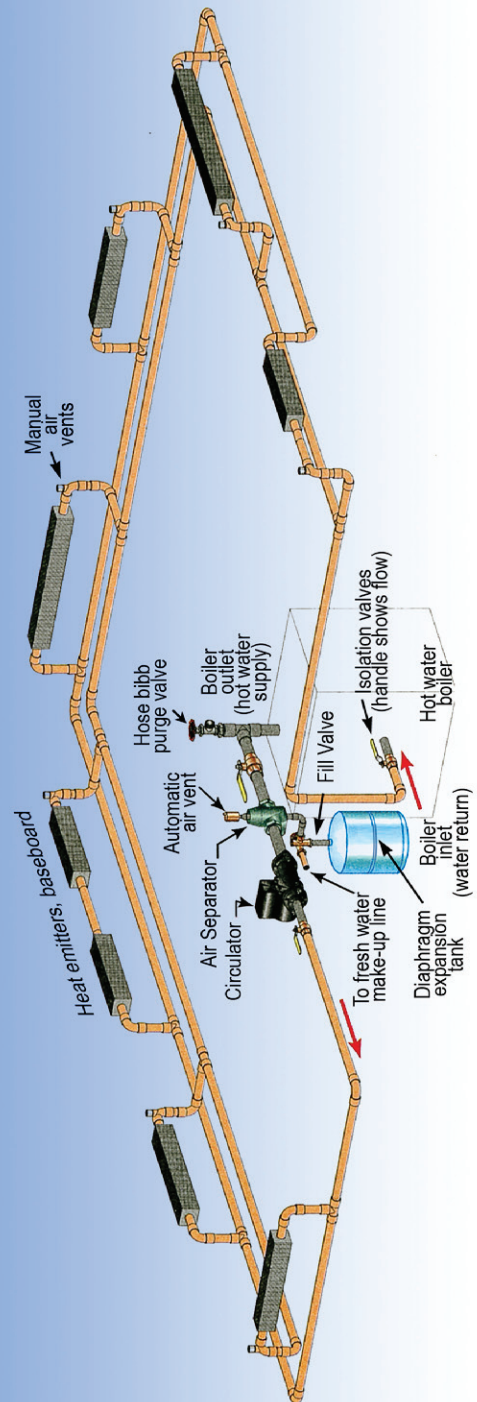
There are two types of primary-secondary piping arrangements- one-pipe and two-pipe. One-pipe are the most common for residential applications.

The piping is similar to a mono-flow system with each secondary circuit (zone) connected off a primary "loop"- BUT with standard tees instead of diverter tees. Figure 9.

Each secondary circuit has its own circulator that must be piped to pump water away

Figure 7

Two-Pipe System
(reverse-return—closest supply unit has longest return)

Manual air vents

Heat emitters, baseboard

Hose bibb purge valve

Boiler outlet (hot water supply)

Automatic air vent

Air Separator

Circulator

Fill Valve

Isolation valves (handle shows flow)

Hot water boiler

Boiler inlet (water return)

To fresh water make-up line

Diaphragm expansion tank

from the primary loop. The tees that connect the secondary circuit should be no more than 12″, or 4 pipe diameters – whichever is less, apart. If the secondary circuit is piped in ¾", the tees should be 3" apart.

Because the water temperature drops as it circulates through the primary loop, it's important to connect the secondary circuits that require the hottest water (baseboard) at the beginning of the primary loop and those that require lower temperatures (radiant) towards the end.

When there is a call for heat, both the primary and secondary circulators operate and the secondary circulator pulls water from, and returns it to, the primary loop.
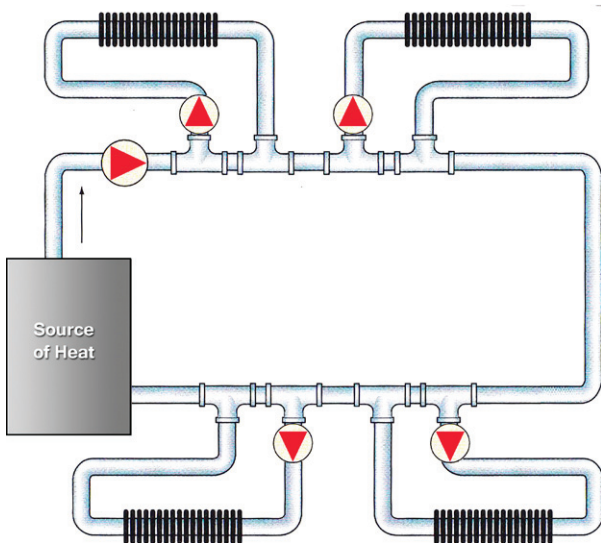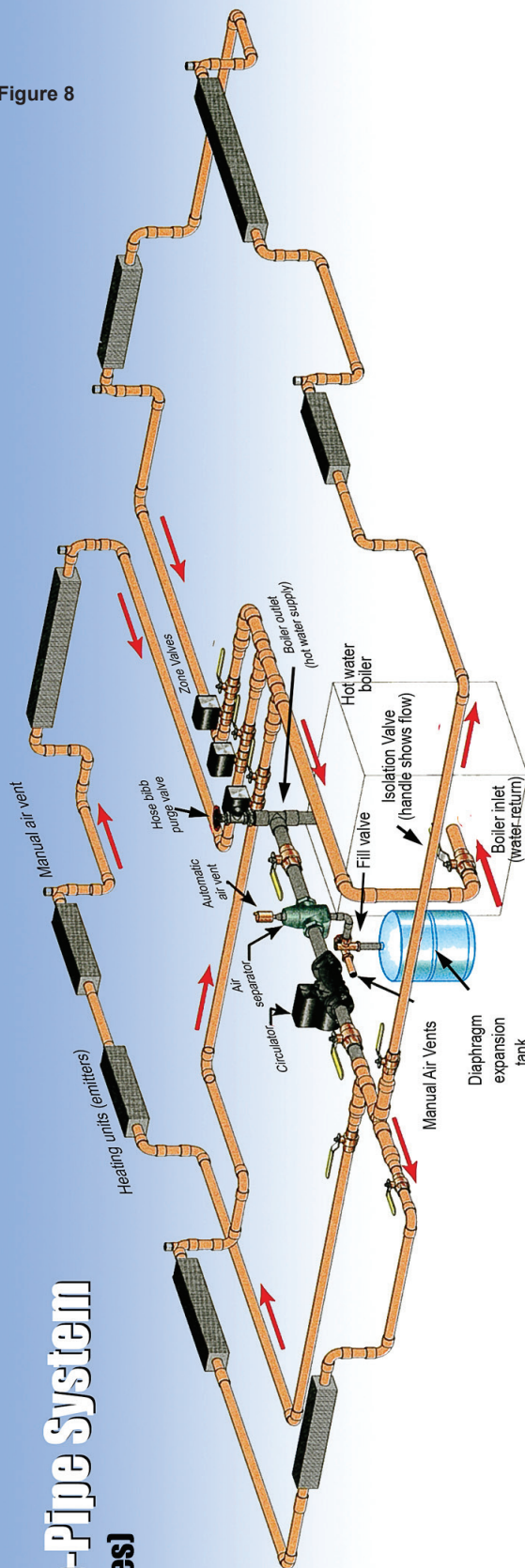

Figure 8

Two-Pipe System
(3 zones)

Manual air vent

Zone Valves

Boiler outlet
(hot water supply)

Hot water boiler

Isolation Valve
(handle shows flow)

Boiler inlet
(water-return)

Fill valve

Hose bibb purge valve

Automatic air vent

Air separator

Circulator

Manual Air Vents

Diaphragm expansion tank
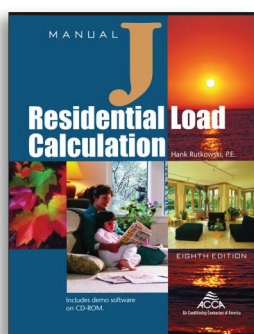
Heating units (emitters)

Figure 9

Source of Heat

Chapter 3
Equipment Sizing

The various components that are used in hot water heating systems were covered in Chapter 1.

The proper sizing and installation of those components (boilers, circulators, piping and expansion tanks) is essential to ensure trouble-free comfort for your customer.

Figure 1

All hydronic system installations need to start with a heat loss calculation for the building. This establishes a target for the heating system and provides some documentation for the customer. There are many heat loss calculation methods–the most recommended are the Hydronics Institute guide H-22 and the Air Conditioning Contractors of America's Manual J, Figure 1. Boiler manufacturers often provide free load calculation software as well.

Programs can also be obtained online: www. acca.org, www.wrightsoft.com and www. elitesoft.com

Additionally, there are heat loss calculators available in software form. They may differ slightly, but will provide a reasonable estimate of the heating needs of the building. All heat loss formulas have a built-in safety margin, so designers/installers should not adjust these carefully derived estimates to add more heat!

The ONLY way to properly size a heating system is to perform a heat loss calculation on the building. Many authorities having jurisdic-tion (AHJ) or building inspectors, require that a heat loss be performed when installing a new or replacement boiler.

Heat is lost two ways—the first is air infiltra-tion, or heat lost due to heated air leaking from the inside of the house to the outside, being replaced by cold air coming in. This replace-ment, or infiltration air, will need to be heated up to comfortable levels. Infiltration heat loss is, along with window loss, the largest single heat loss element.

The second method of heat loss is conductive heat loss. Heat loss calculations also include conductive heat transmission through walls, ceiling and floors, doors, windows and sky-lights. A house is extremely variable and these heat load calculations will not be precise. Thus, some rounding and estimating will still provide for acceptable results.

In addition to a whole house heat loss evalu-ation, it is also important to do a room by room heat loss analysis. This enables correct sizing of the terminal units—baseboard, radiators, ra-diant floor heat—for each room, ensuring that each room in the house is comfortable.

Example
A simple 10′ by 15′ room with 9′ ceilings and two outside walls with windows.

When conducting a heat loss analysis, the indoor design temperature (the desired indoor temperature) needs to be known. In most cases, the number to use is 70° F. The outdoor design temperature, or the "coldest day of the year," needs to be determined. A heating system should be able to maintain the structure at 70° F when the outdoor design temperature is reached.

Figure 2

OUTDOOR DESIGN TEMPERATURES

Outdoor design temperature
(example: Ithaca, NY)

The Air-Conditioning, Heating and Refrigeration Institute (AHRI) and the American Society for Heating Refrigeration and Air-Conditioning Engineers (ASHRAE) publish recommended design temperatures for different parts of the country. (Figure 2 on previous page).

Figure 4	Windows	Without storm sash			With storm sash		
	Frame	Aluminum		Wood/Vinyl	Aluminum		Wood/Vinyl
	Thermal break	No	Yes	n/a	No	Yes	n/a
Single glass or acrylic		1.155	1.045	0.990	0.650	0.525	0.475
Low emittance single glass (e=0.60)		1.071	0.696	0.918	0.572	0.462	0.418
Double glass		0.725	0.609	0.551	0.490	0.385	0.341
Low emittance double glass		0.475	0.399	0.361	0.378	0.297	0.263
Tripple glass		0.546	0.439	0.380	0.378	0.311	0.263
Low emittance triple glass		0.448	0.360	0.312	-	-	-
Jalousie windows		1.100	-	-	0.500	-	-

In the following example, the room is located in Ithaca, NY which has an Outdoor Design Temperature of 0° F.

The practice of lowering the outdoor design temperature below the published guides, done to ensure that customers have "enough heat" if the temperature ever drops below the recommended temperature, often leads to needless oversizing of a boiler. This increases the installation costs and lowers the overall efficiency of the system.

In this example, the indoor design temperature is 70° F, with an outdoor design temperature of 0° F. This information is used to calculate the Design Temperature Difference (DTD), which is the difference between the desired indoor temperature and the outdoor design temperature. The homeowner will want 70° F degrees indoors when it's 0° F outdoors—a DTD of 70° F.

The infiltration factor is important in establishing heat loss, Figure 3. This number deter-

mines the rate of air leakage and varies based by how old and how well sealed the house is. New construction tends to have rather low infiltration rates, while older homes tend to have higher ones. Continuing with this example, the IBR factors for infiltration are used:

In buildings with windows and doors weather stripped or equipped with storm sash:

- 0.012 for rooms with windows or exterior doors on one side only
- 0.018 for rooms with windows or exterior doors on two sides
- 0.027 for rooms with windows or exterior doors on three sides

These factors (Figure 4 above), come from ACCA's H-22 Heat Loss Calculation Guide available from www.acca.org

An outside wall with a factor of 0.012 represents two-thirds of an air change per hour and the Btus needed to warm that air to 70° F. Technically, 0.012 is the amount of heat needed to raise two-thirds of a cubic foot of air one degree.

To find the infiltration heat loss, find the volume

Figure 3	Infiltration heat loss factors	
Windows/doors ARE weatherstripped OR WITH storm sash		Factor
Room with windows or doors ONE side only		0.012
Room with windows or doors TWO sides		0.018
Room with windows or doors THREE sides		0.027
Entry hall		0.027
Sun room with many windows on THREE sides		0.036

of air in cubic feet in the room by multiplying the length times the width times the height. The cubic footage of the room is then multiplied by the DTD and then by the infiltration factor. Here is how it looks in this example:

L x W x H x DTD x Infiltration factor = infiltration loss in Btus per hour.

10 x 15 x 9 x 70 x .018 = 1,701 Btuh

Now calculate the conductance heat loss through the walls, ceiling (if there's a cold space above), floor (if there's a cold space below), windows, doors and skylights.

The formula for all these losses is the same: *L x W X DTD x U.*

Length times width gives the area and DTD is the design temperature difference. U represents the U-Value, which is the assembly's ability to conduct heat from one side to the other. A lower U-value represents less heat loss. In fact, U-value is the inverse of R-value, which is an assembly's ability to resist the flow of heat. If you know the R-value, simply divide 1 by the R-value and you'll get the U-value.

(1/R)=U or (1/U)=R

Starting with the windows: There are two 3′ x 5′ windows on one wall and one 6′ x 5′ window on the other. Windows have U-values on their stickers when they are installed. However, there is much data available in heat loss computer programs to help determine the U-value of existing windows.

Assume you have standard wood framed, double-pane, low-E windows, which have an average U-value of .36. To find the window heat loss, total the square footage of all the windows and count them as one big window—it's easier that way. In this case, the room has 60 square feet of window area. We multiply 60 times the DTD of 70° F and then multiply again by the U-value of .36, resulting in a window loss of 1,512 Btuh.

Walls are next: Use the net area of the walls (wall square footage minus window square footage) and multiply by the DTD and U-val-

Figure 5 Insulating Materials	Thickness (inches)						
	1	3 ½	5 ½	8	10	12	14
Blanket and bat type							
Glass Fiber	3.10	11	19	26	32	38	44
Rockwool	3.70	13	20	29	37	44	51
Loose fill type							
Cellulos (macerated paper or pulp)	3.70	13	20	29	37	44	51
Wood fiber, redwood, hemlock or fir	3.33	12	19	27	33	40	46
Mineral wool (glass, slag or rock)	2.20	8	12	18	22	26	32
Vermiclulite, expanded	2.30	8	12	18	23	27	33
Perlite, expanded	2.70	9	15	22	27	32	37
Board type							
Glass fiber	4.00						
Polustyrene (Styrofoam)	4.50						
Polyurethane	6.25						
Urea-Formaldehyde	5.00						
The resistance (R) factor shown may vary slightly with various manufacturers.							

ue. Our example has two outside walls—one ten feet long and the other 15 feet long. To make it easier, simply add the lengths together and make it one big wall. *(NOTE—with heating, north, south, east or west facing walls are not a factor as the room will be heated after sundown when no solar gain is applied).*

In this case, there are 25 linear feet of wall times 9 feet high for a total area of 225 square feet. Subtract the window area from that total—225 minus 60 equals 165 square feet of net wall area. This is the number to use in calculations.

The insulation (Figure 5 on preceeding page) in the wall will determine its U value—in this case, it's six-inches of fiberglass bat at an R-19. R-values for the exterior sheathing, house wrap and finish, as well as for the inside sheetrock may be available and lead to a more accurate calculation. For simplicity and to provide a safety margin, simply use the insulation R-value for the calculations. In this case, divide 1 by 19 to find the wall U-value of .05.

165 x 70 x .05 equals 578 Btuh lost through the walls.

Outside doors, if there were any, would be calculated in the same way and their area would also be deducted from the net wall area.

The ceilings and floors also need to be evaluated, but only if they are below or above unheated space. If the area above the ceiling is heated, there would be no heat loss through the ceiling, and if the floor is above a heated area, there would be no heat loss through the floor.

For the ceiling: Multiply the length times the width times the DTD times the U-value. For simplicity, this example will use insulation values. With R-38 in the ceiling, U-value would be 0.02.

10 x 15 x 70 x .02 and there is a loss of 210 Btuh.

The floors have R-19 insulation, so calculate a U-value of 0.05. Then multiply 10 x 15 x 70 x .05 for a floor loss of 525 Btuh.

Finally, add them all together:

Infiltration	1,701
Windows	1,512
Walls	578
Ceiling	210
Floors	525
Total	4,256

The total heat loss for the room is 4,526 Btuh

This procedure would be repeated for each room of the building to determine the terminal unit capacity needed. The total of heat loss for all the rooms determines the heat loss for the entire building.

Assume the complete heat loss for the building is 70,500 Btuh. A boiler of suitable output must be selected.

Depending on the manufacturer's terminology, choose a boiler based on DOE capacity, the NET IBR RATING or the output Btu/hr. In this case, the proper boiler is the EK-1 model.

SYSTEM 2000 ENERGY KINETICS — FRONTIER® OIL FIRED HOT WATER BOILER

Oil-fired boiler assembly Issue No. PI-100,061
MH28303
UL 726;
CAN/CSA-B140.7.2-67
CAN/CSA-B140.0-M87
CAN/CSA-B139-M91
Low-Press Boiler
cULus LISTED

ASME certified by EKI. Certificate plate is under the insulation on the steel vessel.

Accepted For Use City of New York Department of Buildings
MEA 140-03-E

Boiler Model	Input, Gal/Hr	Nozzle @ pump, psi	Output, Btu/Hr
EK-1	0.68	.60@ 130	83,000
EK-1	0.74	.65@ 130	90,000
EK-1	0.85	.75@ 130	104,000
EK-1	1.00	.85@ 136	121,000
EK-2	1.20	1.00@ 145	147,000
EK-2	1.40	1.25@ 125	170,500
EK-2	1.60	1.35@ 140	190,500
EK-2	1.75	1.50@ 135	206,000

For use with integral primary saftey controls.
This is a Category I appliance.
Oil not heavier than 2.
Maximum Working Pressure Water: 30 psi
Maximum Water Temperature: 250°F
Electrical rating:
120VAC, 60 Hz, less than 12 amps

Heat Surface:
EK-1 = 15 sq. ft.
EK-2 = 24 sq. ft.
Minimum Relief Valve Capacity:
EK-1 = 240 lbs./hr
EK-2 = 336 lbs./ hr

Energy Kinetics, Inc.
51 Molasses Hill Road
Lebanon, NJ 08833 USA
Patents 4,261,299, 4,425,875, 4,765,308 & 6,276,307 & Patents Pending.
09-0414 Rev 03

According to the chart, it should be fired at .68 gph for 83,000 Btuh, which is slightly over the Btuh required to properly heat the building.

Universal Hydronics formula

Once the boiler size has been determined based on heat load calculations, it is necessary to determine the right amount of heat that must be delivered to each room. In doing this work, examining piping sizes, pumps, circulators and the heat transfer in each room is necessary for this analysis. Key to this is the use of the Universal Hydronics Formula.

The Universal Hydronics formula states that Gallons per Minute (gpm) equals British Thermal Units per Hour (Btuh), divided by Designed Temperature Drop (Delta T—also written as ΔT) times 500.

gpm = Btuh/(ΔT x 500)

- gpm is gallons per minute—the flow rate required to deliver a specific amount of heat

- Btuh is the Btu per hour requirement at a given point in time—the heating load

- ΔT is the designed temperature drop across the piping circuit.

In a series loop, fin tube baseboard zone, the design ΔT is 20—that's the manufacturer's rating for the baseboard itself—meaning that if the water enters the baseboard zone at 180°F, it should return to the boiler at 160°F, 20 degrees cooler.

In most residential radiant floor heating systems, the design ΔT is usually 10 degrees—meaning the water enters the radiant loop at 130° F and returns at 120° F. This 10 degree ΔT is important in radiant because it ensures an even, comfortable floor surface temperature throughout a room. A wider ΔT might mean a noticeable drop in floor surface temperature near the end of the run.

The final element of the equation is 500—that's a shortcut representing the weight of one gallon of water (8.33 pounds), times 60 minutes in an hour, times the specific heat characteristic of the fluid (1 for 100 percent water). It takes 1 Btu to raise the temperature of 1 pound of water 1 degree in 1 hour.
8.33 x 60 x 1 = 499.8 (500)

Virtually everything in hydronics—from pipe sizing to circulator selection—stems from this formula.

For example, if the need is to distribute 70,500 Btuh (assuming piping to a zone of baseboard), the formula is:

gpm = Btuh/ ΔT X 500

gpm = 70,500 / 20 X 500

gpm = 70,500/10,000

gpm = 7.1

To properly heat this area, 7.1 gallons of hot water per minute needs to be moved.

Pipe sizing guidelines
The "rules of thumb" are as follows:
Pipe sizing guidelines
- 2-4 gpm = ¾"
- 4-9 gpm = 1"
- 8-14 gpm = 1¼"
- 14-22 gpm = 1½"

One inch pipe will suffice for this application.

There are a number of charts available, from the Hydronics Institute section of AHRI that are shown at the end of this chapter on pages 30, 31 and 32.

Head
In hydronics, pressure is typically referred to as "head pressure" or "head." Head is the total mechanical energy content of a fluid at a given point in a piping system. In hydronics, it is used to express pressure loss in the piping system. When water flows through the system,

it will encounter pressure loss due to friction in the piping. The circulator needs to produce the required amount of flow while overcoming that pressure loss.

Pressure is generally measured in pounds per square inch, or psi. In hydronics, head loss is the common term. Converting psi to head loss is very simple. A column of water 2.31 feet, or 28 inches high, will have a gauge pressure at the bottom of 1 psi. Therefore, 1 psi of pressure drop in a system equals 2.31 feet of head.

It's important to remember when sizing a circulator there is no need to take into account the height of the building. In in a closed loop system, the circulator does not need to lift the water to the top of the building, it only has to overcome the friction loss of the piping and components or the head loss of the system.

To size a circulator properly, start with a heat loss analysis of the structure. The flow rate needed for a particular job or a particular zone is based solely on the heat loss. The heat loss analysis should be conducted on a room-by-room basis, since each room will have its own unique heating requirements and will require terminal units (typically baseboard) sized for its unique needs.

After each room is calculated, group the rooms together into zones to determine what the zone's total heat loss is. This is important when zoning by circulator, since each circulator will be based on the zone flow requirement. When zoning with zone valves, it will be important to know the flow rate for the entire job so the circulator will be sized correctly.

Once the Btuh load of the zone or of the entire job is known, depending on whether zoning will be accomplished with zone valves or circulators, calculate the actual flow rate using the Universal Hydronics formula:

gpm = Btuh/(ΔT x 500).

For example, when zoning with circulators, and there is a zone that has 27,000 Btus' worth of baseboard, or roughly 45 feet. Since it is baseboard, use a 20° ΔT, (100% water—no glycol). To determine the flow rate, divide the load, 27,000, by the ΔT of 20 times 500.

GPM = Btuh/ΔT x 500

GPM = 27,000/20 x 500 = 2.7

The flow rate for the zone is 2.7 gallons per minute.

What size pipe should be used for this zone? The rule of thumb for pipe sizing is two to four gallons per minute of flow, so use ¾" M copper pipes.

These will keep flow velocities at no less than two feet per second and no more than four feet per second. At velocities greater than four feet per second, the system will produce unacceptable noise. At a velocity less than two feet per second, dissolved oxygen may be released and cause air problems within the system.

Head Loss of a zone

To determine the head loss of a zone, measure the total length of the zone, including both piping and heat emitters.

Fittings and valves produce pressure drop in a system equivalent to a few feet of pipe. To accommodate basic fittings and valves, multiply the total length of pipe by 1.5. This is the total developed length of the circuit. Other head loss items, such as flo-valves (aka flow-checks) three-way valves and other high head loss items may be evaluated later.

Next, take that number and multiply by .04. This number represents four feet of head per 100 feet of copper pipe. That head number applies as long as the pipe has been sized according to the velocity guidelines discussed above. The end product is the head loss for the zone.

For example:

We measure out a zone to be a total of 80 feet, including all the elements and the supply and return piping to the boiler.

Head = 80 X 1.5 x .04 = 4.8 foot of head.

A circulator that can provide a total of 2.7 gallons per minute and overcome 4.8 feet of head is therefore required. This information and calculation is often shown in circulator performance curves. Figure 6.
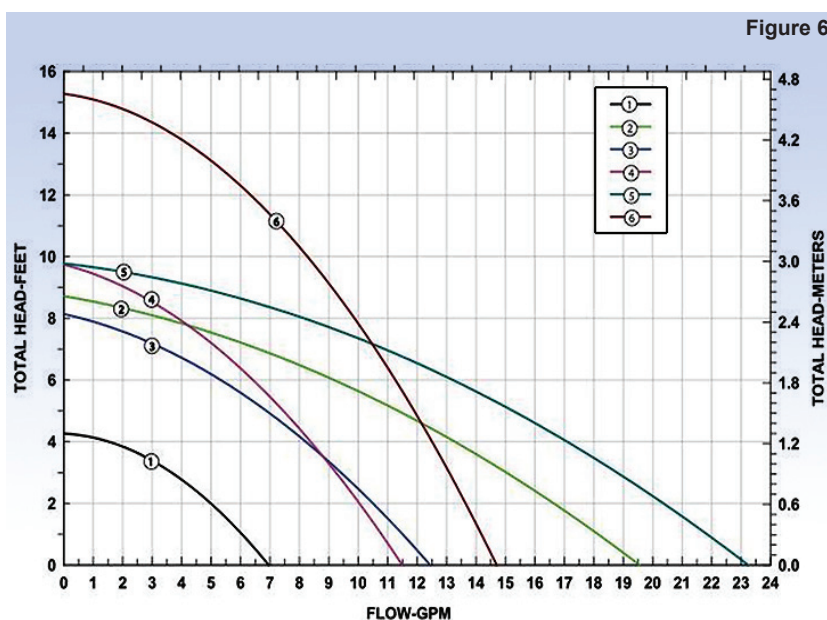

Figure 6

Looking at these performance curves, the figures along the bottom of the chart indicate flow in gallons per minute (gpm), and along the left side of the chart is the head produced in feet. The curves represent what a circulator can produce. Using the information that was calculated for the zone, 2.7 gpm with 4.8 foot of head, we plot that point on the curve.

Now look for what circulator to choose based upon the need of the system. If circulator #1 was chosen for the project, it would not heat the home adequately when it got colder outside.

The ideal circulator for this job is #3.

Three-speed circulators

Three-speed circulators are specifically designed for the wide range of flow and head requirements of today's heating systems. Their three-speed switching capabilty

provides fine tuning control to match a wide combination of system requirements. They are an ideal replacement circulator type to use in any emergency no-heat call. Figure 7.

When using a 3-speed circulator, use the same calculations as before to choose the proper speed setting the circulator will use. In this case, the setting should be Low Speed.

Figure 7

L Low—Speed 1
M Medium—Speed 2
H High—Speed 3
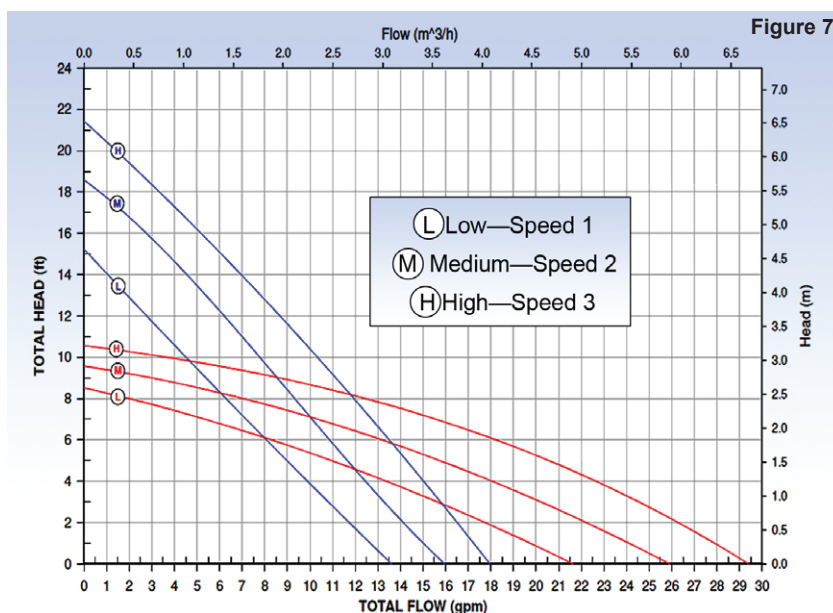
Zone Valves

When one circulator is serving multiple zones, the gpm requirement and head loss for each zone must be determined.

Zone Valve
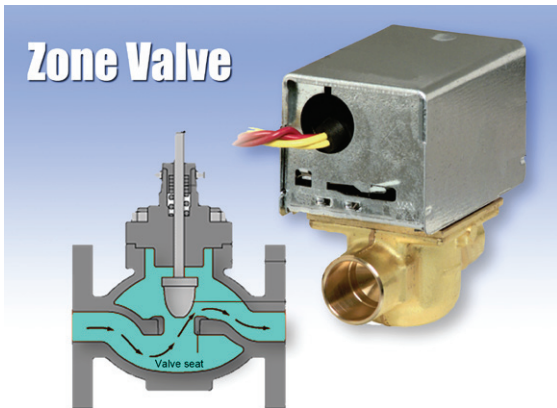
To find the total gpm, add all of the zones together. However, to determine head loss, size the largest head loss.

Example:

> Zone 1 requires 2.5 gpm with 6 foot of head loss

> Zone 2 requires 3.5 gpm with 4 foot of heat loss

Circulator demands will be 6.0 gpm with 6 foot of head loss. GPM is cumulative; head loss is not cumulative—if it can overcome a high head loss zone, then the same circulator can overcome a lower head loss zone.

Cv—coefficient of flow

An additional factor in determining total head that a circulator may need to overcome is consideration of the different components in the system. In assessing those components, coefficient of flow (Cv) through those components must be determined.

Cv is a function of the pressure drop in devices installed in hydronic systems. Every component has an associated Cv value. This is important to understand because it represents the pressure drop in that device for a certain flow rate.

For example, if a device has a Cv value of 3.5, the device has 3.5 gpm are flowing through it, will cause a 1 psi pressure drop. To equate that to foot of head loss, multiply the psi pressure drop by 2.31. A device with a Cv of 3.5 and with a design flow rate of 3.5 will have a pressure drop of 2.31 foot of head:

$(Flow/Cv)^2$ x 2.31

If the Flow rate for the system is 5 gpm, then there will be $(5/3.5)^2$ x 2.31 = 4.7 foot of head for that device. Add that additional head loss to the head loss of the associated piping and other devices for proper circulator sizing.

The higher the Cv rating for a device, the lower the pressure drop.

Does the Zone Valve affect the Circulator Choice?

In earlier calculations, it was determined that the hard piping head loss is 3.6 feet. If you are using zone valves, the head loss produced by the zone valve must also be included. Assuming a 1" valve has a Cv rating of 3.8, that means it takes 3.8 gallons per minute to create 1 psi of pressure drop through that particular valve. Different valves have different Cv ratings, so a valve that had a Cv rating of 12 would produce 1 psi of pressure drop at a flow rate of 12 gallons per minute. A valve with a Cv rating of 47 would create 1 psi of pressure drop at a flow rate of 47 gallons per minute.

The 1" valve has a Cv of 3.8 and creates 1 psi of pressure drop at a flow rate of 3.8 gallons per minute.

One 1 psi of pressure drop equals 2.31 feet of head loss, and any additional head loss through the valve needs to be added to the total head loss of the zone. However, the actual flow rate through the valve is six gallons per minute. To get the correct calculation for total head loss, use the following formula:

Head loss = (Flow/Cv)^2 x 2.31

In this example, divide 6 by 3.8 to get 1.58. Then square 1.58 to get a pressure drop of 2.5 psi. To turn that into head loss, multiply 2.5 by 2.31 for a total pressure drop through the valve of 5.8 feet. Add that to the combined head loss of the hard piping to obtain the total head loss the circulator will need to overcome, which in this case is 9.4 feet of head.

To determine the appropriate circulator for a project, you would need to know the head loss and the flow rate. Assuming a 6 gallon-per-minute flow rate and 3.6 feet of heat, it would appear that Circulator #2 or Circulator #5 would do the job. However, if a zone valve is present that increases the head loss (9.4 feet of head) then the proper choice is Circulator #6 for a single speed or the high speed setting on a three-Speed circulator

Expansion tanks

Sizing expansion tanks is easy—use the tank manufacturer's guidelines if they are available.

For example, some manufacturers' recommendations can be found at this link:
http://www.elmcoduddy.com/htx-sxht_sizing.pdf

If manufacturers' guidelines are not available, there are rules of thumb for sizing tanks:

Diaphragm tanks—1 gallon for each 7,000 Btuh of heat load. For example, if the heat load is 100,000 Btuh, the tank should be a minimum of 15 gallons (100,000/7.000 = 14.3).

Steel compression (air cushion) tanks—1 gallon for each 5,000 Btuh of heat load. For example, if the heat load is 100,000 Btuh, the tank should be a minimum of 20 gallons (1,000/5 = 20)

For detailed information on properly sizing expansion tanks see page 3-28 in IBR Manual.

HTX & SXHT Series
Hydronic Expansion Tanks

QUICK SIZING GUIDE				
Boiler Output 1000's BTUH	Copper Baseboard & Radiant	Type of Radiation		
		Convectors & Unit Heaters	Cast Iron	
			Radiators	Baseboard
25	HTX 15	HTX 15	HTX 15	HTX 15
50	HTX 15	HTX 30	HTX 30	HTX 30
75	HTX 30	HTX 30	HTX 60	HTX 60
100	HTX 30	HTX 30	HTX 60	HTX 60
125	HTX 30	HTX 60	HTX 60	HTX 60
150	HTX 30	HTX 60	HTX 90	HTX 90
175	HTX 60	HTX 60	HTX 90	HTX 90
200	HTX 60	HTX 60	HTX 90	HTX 90
250	SXHT 30	SXHT 30	SXHT 40	SXHT 30
300	SXHT 30	SXHT 40	SXHT 40	SXHT 30
350	SXHT 30	SXHT 40	SXHT 60	SXHT 40
400	SXHT 30	SXHT 60	SXHT 90	SXHT 40
500	SXHT 40	SXHT 60	SXHT 90	SXHT 40
600	SXHT 40	SXHT 90	SXHT 90	SXHT 60
700	SXHT 60	SXHT 90	SXHT 90	SXHT 60
800	SXHT 60	SXHT 110	SXHT 110	SXHT 90
900	SXHT 60	SXHT 110	SXHT 110	SXHT 90
1000	SXHT 90	SXHT 110	SXHT 110	SXHT 90

Sizing recommendations based on average size systems.
Fill pressure 12 PSI. Relief valve 30 PSI.
Average system water temperature 200°F.

Pipe Flow Capacities for Steel Pipe and Copper Tubing
(Based on maximum recommended Flow Rate Rate)

Type M Copper tube size	Max flow (gpm)	Max load (MBH at temperature difference of:)			Maximum load (Total feet of baseboard in all circuits connected to pipe)			
		20 °F TD	30 °F TD	40 °F TD	½ (480 Btuh/ft)	¾ (610 Btuh/ft)	1 (760 Btuh/ft)	1¼ (790 Btuh/ft)
½	3.17	32	48	63	55	52	42	40
¾	6.44	64	97	129	111	106	85	82
1	10.9	109	163	218	188	179	143	138
1¼	16.3	163	245	326	281	268	215	207
1½	22.8	228	342	457	394	374	300	289
2	39.5	395	593	790	681	648	520	500
2½	80.9	809	1213	1617	1394	1326	1064	1024
3	129.7	1297	1946	2594	2236	2126	1707	1642

Steel pipe size	Max flow (gpm)	Max load (MBH at temperature difference of:)			Maximum load (Total feet of baseboard in all circuits connected to pipe)			
		20 °F TD	30 °F TD	40 °F TD	½ (480 Btuh/ft)	¾ (610 Btuh/ft)	1 (760 Btuh/ft)	1¼ (790 Btuh/ft)
½	3.79	38	57	76	65	62	50	48
¾	6.65	66	100	133	115	109	87	84
1	10.77	108	162	215	186	177	142	136
1¼	18.6	186	280	373	321	306	245	236
1½	25.4	254	381	508	438	416	334	321
2	41.8	418	627	837	721	686	550	530
2½	72.9	729	1093	1457	1256	1195	959	922
3	133.0	1330	1995	2660	2293	2180	1750	1684

Pipe Capacities in MBH and GPM for 500 or 350 Milinches Per Foot Head Loss

Pipe capacity at **500** milinches restriction per foot of pipe ◆

Pipe size	MBH	Friction head ◆	Flow rate	Velocity flow of water	
Inches	Based on 20°F T. D.	Feet head per 100 feet of pipe	GPM at 20°F T. D.	Inches per second	Feet per minute
½	17	4.2	1.7	23	115
¾	39	4.2	3.9	27	135
1	71	4.2	7.1	34	170
1¼	160	4.2	16.0	40	200
1½	240	4.2	24.0	45 *	225
2	450	4.2	45.0	54 *	270
2½	750	4.2	75.0	62 *	310
3	1400	4.2	140.0	72 *	360
4	2900	4.2	290.0	80 *	400

Pipe capacity at **350** milinches restriction per foot of pipe ◆

Pipe size	MBH	Friction head ◆	Flow rate	Velocity flow of water	
Inches	Based on 20°F T. D.	Feet head per 100 feet of pipe	GPM at 20°F T. D.	Inches per second	Feet per minute
½	15	2.9	1.5	18	90
¾	31	2.9	3.1	17	85
1	59	2.9	5.9	23	117
1¼	130	2.9	13.0	26	132
1½	185	2.9	18.5	27	134
2	360	2.9	36.0	35	173

✳ These are maximum recommended flow rates.

◆ Friction loss in milinches:

- In hot water systems, friction or pressure is measured in feet of water. Because friction loss in piping is small, it is measured in milinches. A milinch is 1/1000 of an inch, or 1/12,000 of a foot.
- 12,000 milinches (1 foot) represents the pressure exerted by a column of water one foot high. Convert milinches head per foot of pipe to feet head per foot of pipe by dividing by 12,000.

Friction loss		1 foot of pipe	10 feet of pipe	100 feet of pipe
500 milinches per foot	=	0.0416 feet head	0.416 feet head	4.16 feet head *(rounds to 4.2)*
350 milinches per foot	=	0.0292 feet head	0.292 feet head	2.92 feet head *(rounds to 2.9)*

Example

What is the required head and flow rate for a circulator supplying a 120,000 Btuh (120 MBH) series loop system? The installer wants to install ¾-inch finned-tube baseboard and obtain a 20°F temperature differential.

Solution

1. Start with the 500 milinch per foot portion of Table 5.
2. The first thing we need to look at is the ¾-inch baseboard. How much head load can be handled with a ¾-inch pipe?

   Look at the ¾-inch row in the 500 milinch table. The maximum heat load in a ¾-inch line should be 39 MBH.
3. This means the system has to be pipe in multiple series loop circuits, and the maximum heating load of each circuit must be 39 MBH.
4. For each loop, find the TEL by multiplying 1.5 times the length of the circuit from the boiler supply to boiler return.
5. Pick the longest TEL for any loop. Find the number of 100 feet of TEL by dividing by 100.
6. Multiply this number (TEL/100) times 4.2 feet head per hundred feet (500 milinches per foot).

   For example, if the longest loop is 200 feet, the TEL would be 1.5 times 200, or 300 feet of pipe. Then TEL/100 = 300/100 = 3.

Multiply 3 times 4.2 feet head per hundred feet of pipe = 12.6 feet head.

7. Size the trunk line by finding a pipe size in the 500 milinch head loss table large enough for 120 MBH. Use a 1¼-inch line since it can handle up to 160 MBH.
8. The flow rate at 20°F would be 120,000 / 500 / 20 = 12 GPM.
9. The circulator must be able to flow 12 GPM against a head loss of 12.6 feet.
10. If this head is too high for the circulator you want to use, try the 350 milinch table. At 350 milinch head loss per foot of pipe:
    a. Maximum heat load per ¾-inch circuit is 31 MBH. So pipe circuits must not exceed 31 MBH each.
    b. If the longest circuit is still 200 feet, the TEL is 300.
    c. The head loss per 100 feet is 2.9, so the head total head loss is (300/100) x 2.9 = 8.7 feet.
    d. Result: By limiting circuit size to no more than 31 MBH per circuit, the circulator only has to handle a head loss of 8.7 feet. The flow rate is the same as found in step 8, or 12 GPM.
    e. The trunk line can still be 1¼ inch, since the 350 milinch table allows up to 130 MBH.
11. When piping multiple circuits, you may need to install balancing valves if the circuits are not similar lengths.
12. You can see from this example that the milinch method quickly tells you not only the trunk line size, but sets the size for each of the branch circuits as well.

Chapter 4

Best Boiler Piping Practices

In addition to proper sizing of the boiler, piping, circulators and expansion tank, for a heating system to operate properly, it is important that the various components are installed in the proper configuration. Figure 1 on following page**.**

Unless the manufacturer recommends differently, the following piping arrangement are recommended:

Relief Valve—a properly sized relief valve must be installed in the correct location and a metal "drip tube" installed that is the same size as the valve's outlet. This must be piped to a

Figure 2
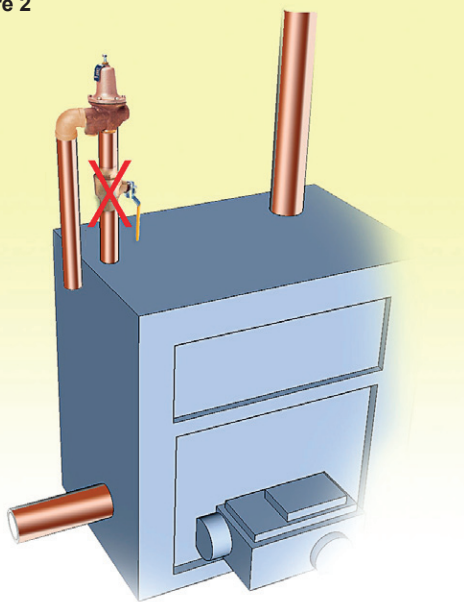
safe location to prevent scalding if the valve discharges. There should NEVER be a valve between the boiler and relief valve or in the discharge line. Figure 2.

Purge valve—this location enables the technician to quickly remove air from the entire system. By closing the isolation valve(s), manually closing the zone valves one at a time and then opening the purge valve, water can be forced to flow through, and completely fill, each zone.

Isolation valve—this valve enables quick service of system components and isolates the purge valve from the pressure reducing valve, forcing water to flow through the system and back to the purge valve. This should be a gate or ball valve; globe valves should NOT be used.

Air separator—when using a diaphragm type tank, an automatic air vent should be installed in the top tapping. Always double check
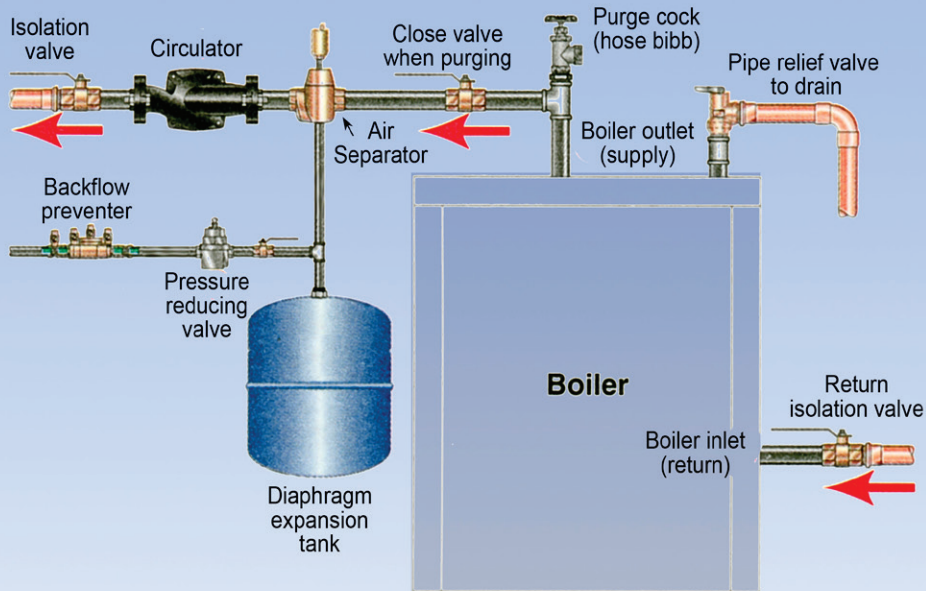

Figure 3
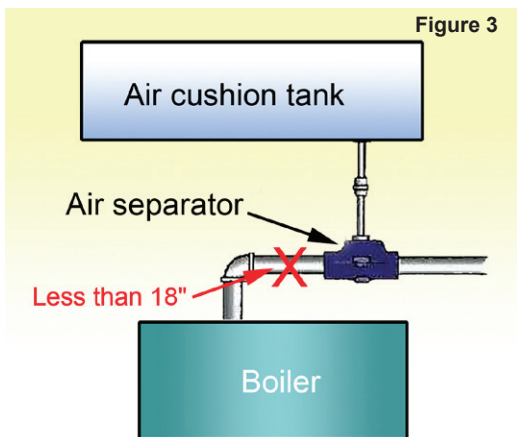
installation instructions to verify the length of straight piping required on the inlet side of the separator. Air scoops will NOT function properly if the laminar piping is not at least 18". Figure 3.
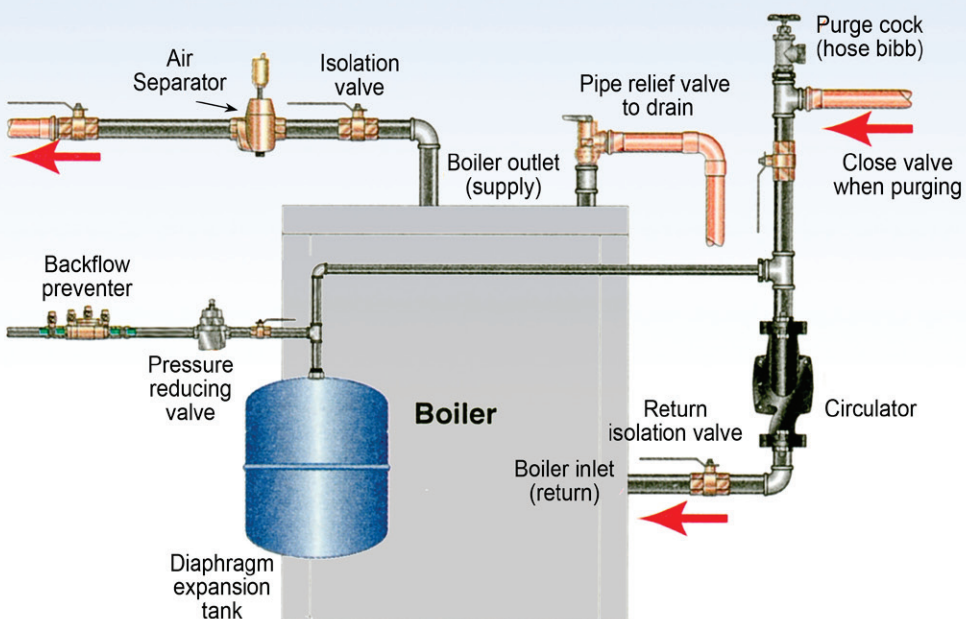
Figure 1

Near-boiler piping
Circulator on supply (preferred)

Isolation valve

Circulator

Close valve when purging

Purge cock (hose bibb)

Pipe relief valve to drain

Air Separator

Boiler outlet (supply)

Backflow preventer

Pressure reducing valve

Boiler

Return isolation valve

Boiler inlet (return)

Diaphragm expansion tank

Circulator on return (alternate)

Air Separator

Isolation valve

Pipe relief valve to drain

Purge cock (hose bibb)

Boiler outlet (supply)

Close valve when purging

Backflow preventer

Pressure reducing valve

Boiler

Return isolation valve

Circulator

Boiler inlet (return)

Diaphragm expansion tank

Pressure reducing valve (PRV)—an isolation valve (globe, ball or gate), backflow prevention device and PRV should be installed into a tee under the air elimination device. The PRV should be connected at the same point as the expansion tank so that it senses and reacts to the pressure of the tank.

Expansion tank—if a diaphragm type tank is used, it should be connected into the bottom of the tee as shown in Figure 4. It is a recommended that an isolation valve be installed to simplify service of the tank. Note that diaphragm tanks should never be installed upright or sideways as the diaphragm tends to dry out in those positions.

If a steel compression tank is used, there should <u>not</u> be an automatic air vent installed; the tank should be connected to a ¾" tapping in the top of the separator.

Circulator—the circulator should be connected so that it "pumps away" from the "point of no pressure change"—the expansion tank. This means that the suction side of the circulator should be as close as possible to the expansion tank.

Isolating flanges or isolation valves are recommended to simplify service.

Figure 4
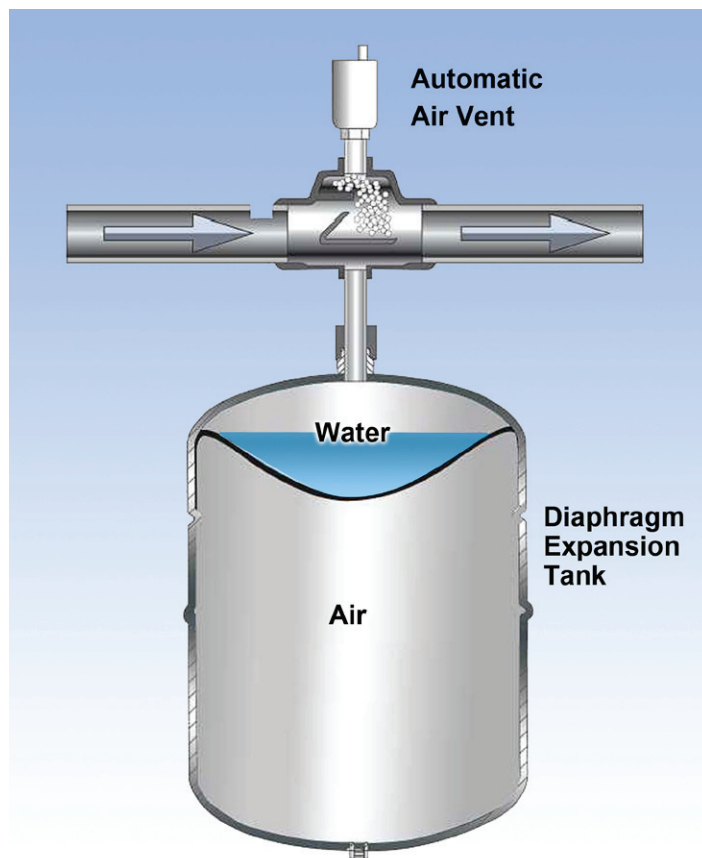
Chapter 5

Domestic Hot Water

In this section, we'll examine various ways in which Oilheat systems generate domestic hot water; sizing water heaters; piping and maintenance recommendations; safety concerns; and energy conservation strategies.

There are two basic types of water heaters: direct-fired and indirect.

Direct-fired water heaters are basically dry base vertical tube boilers; they utilize an oil burner that creates hot combustion gases that heat the water inside the tank. The gases and the water being heated are separated by the wall of the tank.

Indirect water heating uses boiler water to heat domestic water. This type features a heat exchanger that draws heat from the heating system water into the domestic water. For many years, the only indirect water heater available was the tankless coil, today there are additional options, including a separate "Indirect Water Heater" consisting of a storage tank, circulator, control and related accessories

Direct-fired water heaters

Oil-fired water heaters are typically available for residential use in sizes that range from 20 gallons to over 100 gallons. They are available in two configurations, (Figure 1), based on the path of the flue gases:

- Center flue heaters feature a path for the flue gases to travel through the inside of the tank.

- Rear flue heaters have a path for the flue gases to travel around the outside of the tank.

Direct-fired heaters are operated by an aquastat which turns the oil burner on and off to maintain water temperature.

Figure 1

Typical Rear Flue Water Heater   Typical Center Flue Water Heater
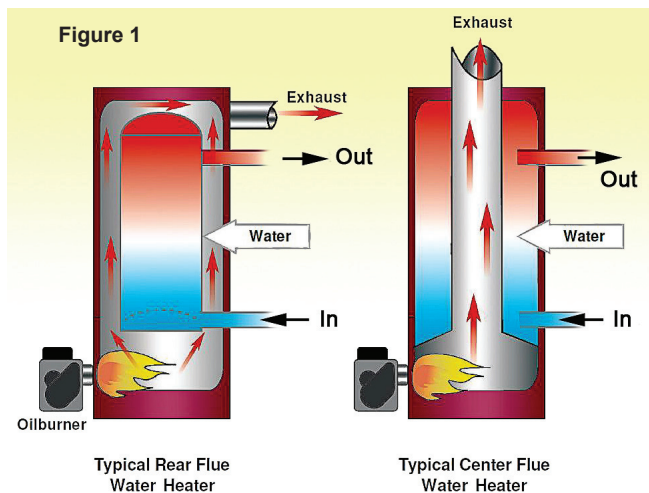
Most direct-fired water heaters feature an insulated glass-lined tank. The inside of the steel tank is coated with ceramic lining material that protects the tank from rusting and corrosion. The material is not totally impervious to water, and thus the tank can rust.

Manufacturers provide protection for the steel casing by installing replaceable sacrificial anode rods in the tank. These rods should be checked during tune ups and replaced when necessary.

Indirect Water Heating

Indirect water heating involves the use of a heat exchanger to transfer heat from the boiler water to the domestic water.

Tankless coils—there are two types of tankless coils: internal and external. The biggest disadvantage of tankless coils is that a household can easily outrun their ability to generate domestic hot water. Depending on the temperature in the boiler, and the size of the coils in the unit, a busy household may not have sufficient hot water for peak usage.

Internal tankless coils

Internal tankless coils (Figure 2) are heat exchangers that are installed inside a boiler to generate domestic hot water. These devices can operate rather efficiently during cold weather when boilers are running to produce heat, but are much less efficient during warm weather.
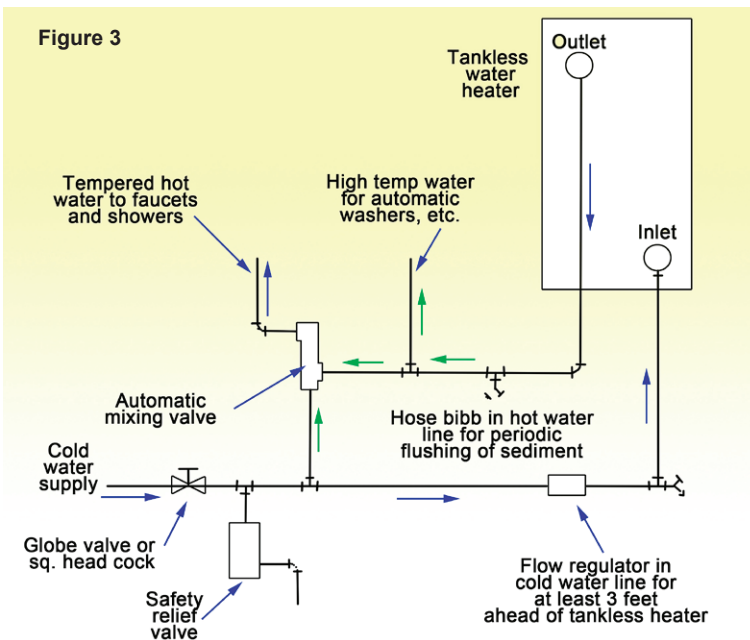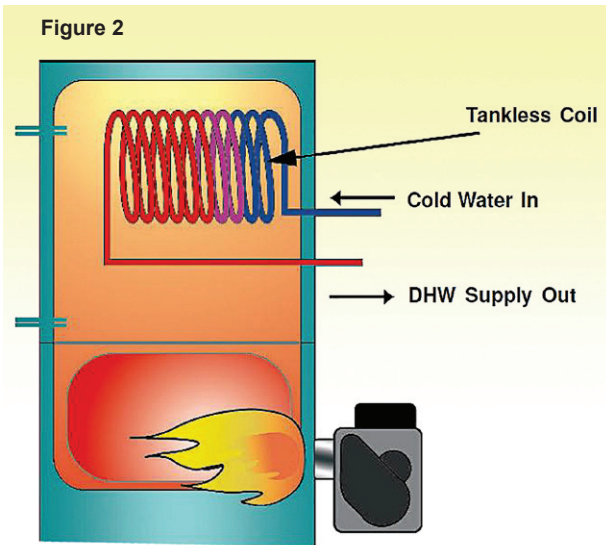

Figure 2

The coil is surrounded by the boiler water, which heats the outside of the coil; domestic water is then heated as it flows through the inside of the the coil. Tankless coils generally requre that boilers be operated at 180–200°F.

Figure 3 shows a properly piped tankless coil and includes the following:

1. Shutoff valve—typically a globe or ball valve

2. Domestic pressure relief valve—Relieves excessive pressure caused by thermal expansion

3. Flow regulator or restrictor—This device automatically limits the flow of water so it doesn't exceed the capacity of the coil.

4. Drain valves—These are installed to simplify periodic flushing of the coil.

5. Mixing valve—Thermostatic mixing valves blend hot water from the coil with cold water to deliver a desirable and selectable temperature and help prevent scalding injuries. The recommended maximum hot water temperature setting for normal residential use is 120°F. NORA recommends that thermostatic mixing valves (also known as tempering valves or anti-scald valves) be installed and used according to the manufacturer's directions to prevent scalding.

Tankless coils supply hot water on demand, BUT only up to a limit that is determined by the Btuh output of the appliance in which the coil is installed. For example, 50,000 Btuh is required to raise the temperature 1 gpm (one gallon per minute) of water from 40 degrees to 140 degrees. If you do the math, you'll see that 150,000 Btuh is required to

Figure 3

Figure 4

Boiler

Aquastat Control

Tankless Coil

Domestic Water Outlet

Storage Tank

Domestic Water Inlet

Pump

External tankless coils

Figure 5 below, shows an older style external tankless (AKA "sidearm") coil. It is a small tank with a heat transfer coil inside. As the boiler water circulates by gravity over the coil it heats the domestic water inside.

The most popular external coil today is the highly efficient plate heat exchanger (See Figure 6 on following page). It features a series of plates containing two separate water passages sand-

generate three gallons of domestic hot water per minute.

Rather than operating an oversized boiler to deliver adequate domestic hot water, a better alternative is to add a storage tank—often called an "aqua-booster"— in conjunction with the coil. Domestic hot water is generated by the coil and the tank maintains sufficient volume to satisfy larger needs. Figure 4.

wiched together. Boiler water flows through every other plate and domestic water flows through the adjoining plates allowing heat transfer while maintaining complete separation of boiler water and potable water. The domestic hot water produced is typically stored in an aqua-booster.

Flat plate heat exchangers are also used for radiant heating and snow melting applications.
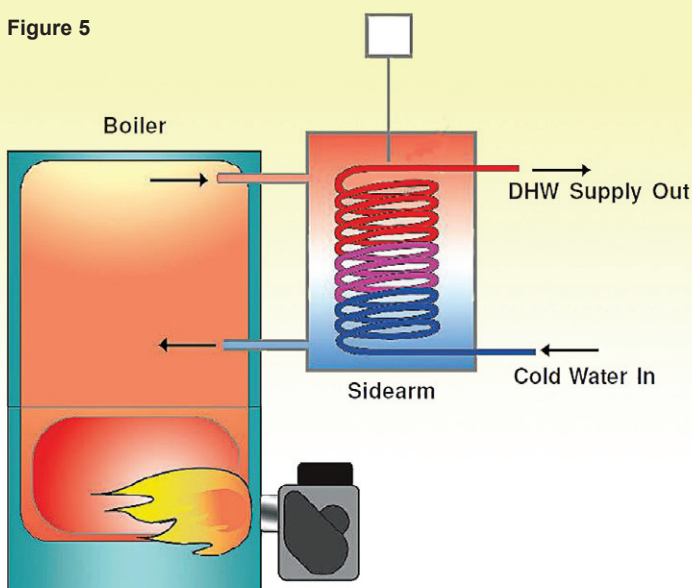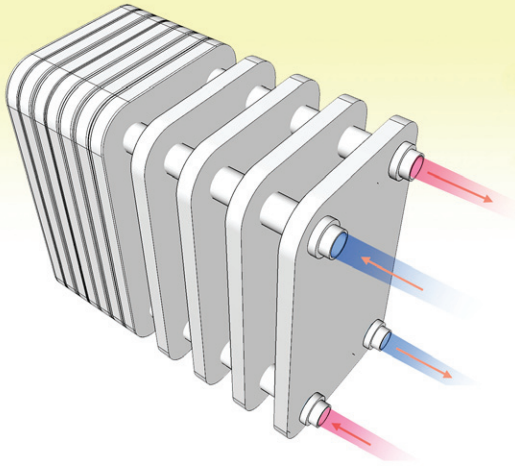
Indirect water heaters

An indirect-fired water heater is a storage tank with an internal heat exchanger. See Figure 7 on following page.

Compared to a direct-fired water heater, in which the aquastat controls the oil burner operation, in an indirect the aquastat controls a circulator that allows boiler water to flow through the heat exchanger.

In contrast to tankless heaters, indirect water heaters typically enable a smaller boiler to be used because of the amount of domestic hot water stored in the tank.

Figure 5

Boiler
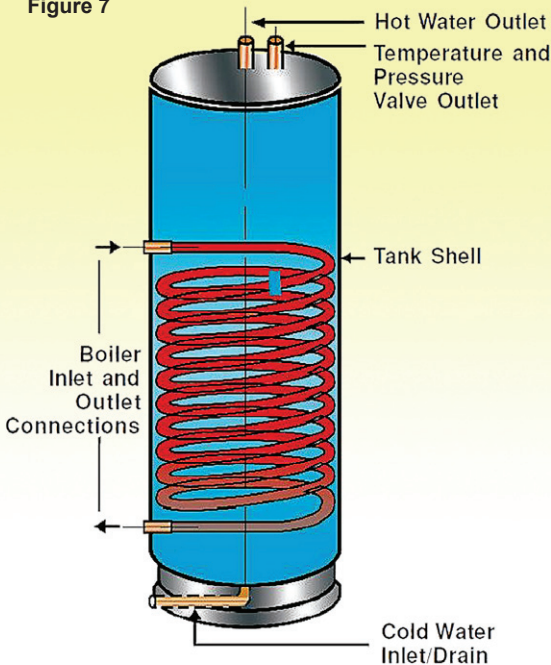
DHW Supply Out

Cold Water In

Sidearm

Figure 6

The heating capacity of an indirect heater depends on the size of the tank, the size of the heat exchanger, boiler water temperature supplied to the heat exchanger, and the flow rate.

The efficiency of indirect water heating is directly related to the efficiency of the boiler.

Figure 7
Hot Water Outlet
Temperature and Pressure Valve Outlet
Tank Shell
Boiler Inlet and Outlet Connections
Cold Water Inlet/Drain

Sizing Water Heaters

Unlike space heating, the need for hot water will vary widely between houses and families, and oversizing may not have a significant efficiency penalty. Most manufacturers provide recommendations regarding water heater sizing and installation practices. For example, see:

http://accusize.bockwaterheaters.com/IntelliSizing/NewProject.aspx

This web page is shown as Figure 8. If manufacturer-supplied information is not available, NORA reccomends using the AHRI first-hour sizing method.

Figure 8

In addition to the size of the heater in gallons, there are a number of considerations which must be taken into account when determining which water heaters best fit the needs of each individual application. For example, on a spec sheet, there are a number of capacities listed that must be considered before a model is selected.

First hour rating is the amount of hot water that a fully heated water heater can deliver in the first hour. This is normally shown as gallons per hour at a 100°F tempreature rise, unless stated otherwise.

Recovery is the amount of water per hour the heater can raise the temperature by 100 degrees.

The reason these numbers are important is that many people believe that all 30 gallon water heaters produce the same amount of hot water; however there is a HUGE difference in the amount they actually produce.

When sizing indirect water heaters, it's important to make sure that you have the right

This was discussed in Chapter 3 on page 27, under section 'Head" explaining Head Pressure Drop.

Thus, 45 x .04 =1.8 foot of head loss. Add that to 7.9 for the coil and you have 9.7 foot of head. So your circulator demands just for the indirect tank would be 10 gallons per minute with 9.7 foot of head loss. Use the performance curve to select the correct circulator. Figure 10.

Unfortunately, none of these circulators are able to meet the required performance. So, you will need to use a multi-speed circulator. An improperly sized circulator will prevent the water heater from delivering the gallons described in its specification sheet. See Figure 11 on following page.

This circulator, set on high speed, does meet the requirements.

In addition to sizing the circulator correctly, to ensure the correct amount of hot water is delivered, the boiler

Figure 9	**Pipe Sizing**									
Model	**Dimensions**		**Capacity**	**Heat Exch. Surface**	**Recomm. Flow Rate**	**Pressure Drop (Feet)**	**180° Boiler Water First Hour Ratings* (in Gallons)**		**200° Boiler Water First Hour Ratings* (in Gallons)**	
	Ht.	Dia.		(Sq. Ft.)			115°F	140°F	115°F	140°F
SSU-20	27"	19¼"	20	15	8	6.0	121	168	136	185
SSU-30	39½"	19¼"	30	15	8	6.0	154	212	172	234
SSU-30LB	29½"	23¼"	30	15	8	6.0	169	234	189.	257
SSU-45	52½"	19¼"	45	20	10	7.9	212	292	237	322
SSU-60	52½"	23¼"	60	20	10	7.9	266	370	298	40
SSU- 80	72"	23¼"	80	34	12 9.1	9.1	330	440	370	503
SSU-119	73½"	27"	119	34	14	11.3	423	564	474	645
DOE test method based on 90°F temperature rise, 50°/140°W/ boiler water at 180°F Recommended flow rate: 10 GPM Coil head loss 7.9'										

circulator to enable the the tank to supply the desired demands of hot water. The chart for the SSU-45, which is a 45 gallon indirect tank, shows that the required minimum flow rate through the coil in the indirect tank is 10 gallons per minute. See Figure 9.

With that flow rate, the pressure drop through the coil alone is 7.9 foot of head. Add the associated piping to and from the tank and the boiler to this number to get the proper circulator size.

If there is 30' feet of 1" copper to the tank, the pressure drop for that would be:
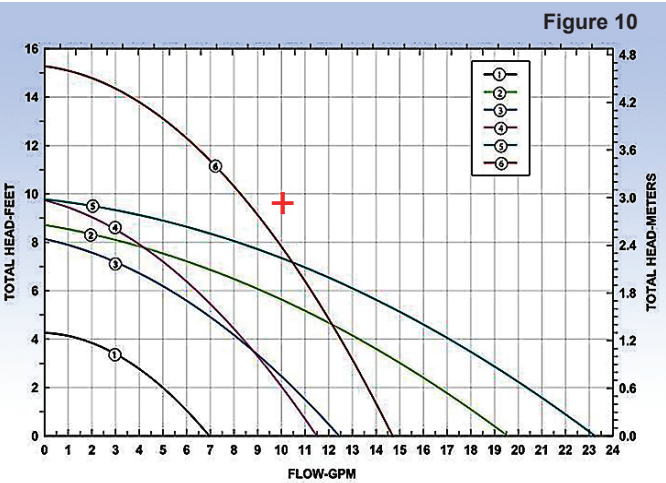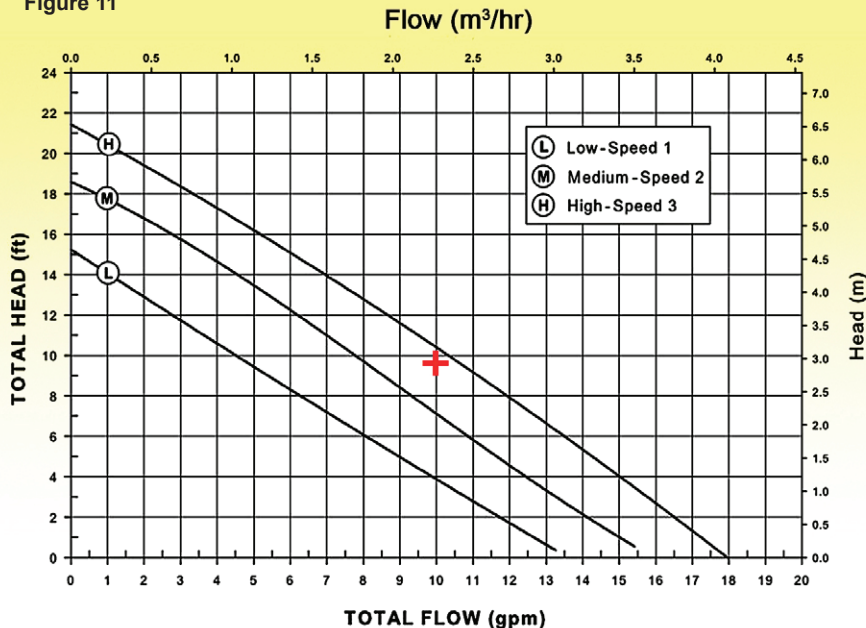
30 x 1.5 = 45

Figure 10

Figure 11

should be new copper with a minimum number of elbows.

- When piping direct and indirect water heaters, it's a good practice to install a heat trap as shown in Figure 13 to reduce standby losses.

- All piping should be checked for leakage at joints, valves and unions on an annual basis.

size and the water temperature in the boiler must be considered. Figure 12 below.

Piping and Maintenance Recommendations

The following guidelines should be followed in addition to the manufacturer's specific recommendations, unless the manufacturer recommends otherwise.

- When installing a new unit, all piping

• The temperature & pressure relief valve should be checked for proper operation on an annual basis as follows:

✓ Attach a drain line to the valve and direct the water discharge to an open drain (the water will be HOT!)

✓ Lift the valve lever several times and ensure that it operates freely and returns to its original position. If the valve does not function properly, replace it.

Figure 12

Model	A Dimensions Ht	B Diameter	C Domestic Connections	D Boiler Connections	E Floor to Boiler Supply		F Floor to Boiler Return		G Floor to Domestic Out	Capacity	Heat Exchanger Surface	Shipping Weight
SSU-20	27"	19 1/4"	3/4"	1" NPT	S1- 9 3/4"		R1- 5 1/4"		22"	20	15 SQ FT	51 LBS
SSU-30	39 1/2"	19 1/4"	3/4"	1" NPT	S1- 9 3/4"		R1- 5 1/4"		34"	30	15 SQ FT	62 LBS
SSU-30LB	28 1/2"	23 1/4"	3/4"	1" NPT	S1- 9 3/4"		R1- 5 1/4"		22"	30	15 SQ FT	71 LBS
SSU-45	52 1/2"	19 1/4"	3/4"	1" NPT	S1- 9 3/4"		R1- 5 1/4"		46"	45	20 SQ FT	72 LBS
SSU-60	52 1/2"	23 1/4"	1"	1" NPT	S1- 9 3/4"		R1- 5 1/4"		46"	60	20 SQ FT	109 LBS
SSU-80	72"	23 1/4"	1 1/2"	1" NPT	S1- 29"		R1- 6"		64 3/4"	80	34 SQ FT	143 LBS
SSU-119	74"	27"	1 1/2"	1" NPT	S1- 30 1/4"		R1- 7 1/4"		66"	119	34 SQ FT	212 LBS
SSU-45C	42	23 1/4"	3/4"	1" NPT	S1- 9 3/4"	S2- 18 3/4"	R1-5 1/4"	R2-14"	35"	45	40 SQ FT	106 LBS
SSU-60C	52 1/2"	23 1/4"	1"	1" NPT	S1- 9 3/4"	S2- 18 3/4"	R1-5 1/4"	R2-14"	46"	60	40 SQ FT	126 LBS
SSU-80C	72"	23 1/4"	1 1/2"	1" NPT	S1- 29"	S2- 29"	R1- 6"	R2- 6"	64 3/4"	80	68 SQ FT	175 LBS
SSU-119C	74"	27"	1 1/2"	1" NPT	S1- 30 1/4"	S2- 30 1/4"	R1- 7 1/4"	R2-71/4"	66"	119	68 SQ FT	242 LBS

HOT OUT

Figure 13

COLD IN

NIPPLE, TEE & DRAIN VALVE

- The tank should be drained and flushed annually to remove any accumulation of lime, iron and other minerals. If lime is found, water softening equipment should be considered.

- Anodes should be inspected at least yearly and replaced once they are down to one-third of their original size or show signs of pitting.

- If a "rotten egg" odor is present in the hot water, flush the tank with a manufacturer- approved solution and replace the magnesium anodes with new aluminum anodes.
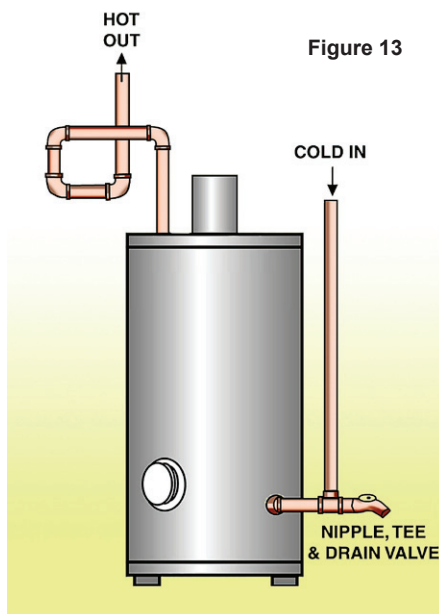
Safety considerations

Scalding and Legionnaires Disease
Water temperatures above 125°F can cause severe burns and death from scalds. Children, the disabled, and elderly are at the highest risk from being scalded. This is because they respond more slowly to exposure. The human threshold for pain is 118°F, and scalding occurs over 125°F. A proper installation will have appropriate valves to protect against scalding hazards.

NORA recommends the use of thermostatic anti-scald mixing valves on all hot water destined for domestic use. Having these devices on appliances will also help to ensure that the house has sufficient hot water.

Using mixing valves allows us to solve a significant problem that could occur if we merely set the hot water tank to 120 degrees. Low or warm water temperatures allow the bacteria that cause Legionnaires disease, a severe form of pneumonia, to thrive. It is recommended that water temperatures be set at 140°F to kill the bacteria and the mixing valve be adjusted to deliver the correct temperature to the faucets.

Temperature & Pressure (T&P) relief valve
The discharge drain tube of the T&P valve must be made of material that is rated for a minimum of 150 psi and temperatures of at least 120° F and installed so it terminates plain (not threaded) 6" above the floor drain.

Hydrogen gas
If a water heater equipped with anodes has been out of service for a period of time, the guidelines contained in UL 174 should be followed"
"Hydrogen gas can be produced in a hot water system served by this heater that has not been used for a long period of time (generally 2 weeks or more). Hydrogen gas is extremely flammable. To reduce the risk of injury under these conditions, it is recommended that the hot water faucet be opened for several minutes at the kitchen sink before using any electrical appliance connected to the hot water system. If hydrogen is present, there will probably be an unusual sound, such as air escaping through the pipe as the water begins to flow. There should be no smoking or open flame near the faucet at the time it is open."

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