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HVAC FUNDAMENTALS

Volume 3: Air Conditioning, Heat Pumps, and Distribution Systems

ALL NEW 4TH EDITION

James E. Brumbaugh

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Volume 3
Air-Conditioning, Heat Pumps, and Distribution Systems

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WILEY

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Text Design & Composition: TechBooks

Published simultaneously in Canada

Library of Congress Control Number:

eISBN: 0-7645-7626-7

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

For Laura, my friend, my daughter.

Contents

Introduction

The purpose of this series is to provide the layman with an introduction to the fundamentals of installing, servicing, troubleshooting, and repairing the various types of equipment used in residential and light-commercial heating, ventilating, and air conditioning (HVAC) systems. Consequently, it was written not only for the HVAC technician and others with the required experience and skills to do this type of work but also for the homeowner interested in maintaining an efficient and trouble-free HVAC system. A special effort was made to remain consistent with the terminology, definitions, and practices of the various professional and trade associations involved in the heating, ventilating, and air conditioning fields.

Volume 1 begins with a description of the principles of thermal dynamics and ventilation, and proceeds from there to a general description of the various heating systems used in residences and light-commercial structures. Volume 2 contains descriptions of the working principles of various types of equipment and other components used in these systems. Following a similar format, Volume 3 includes detailed instructions for installing, servicing, and repairing these different types of equipment and components.

The author wishes to acknowledge the cooperation of the many organizations and manufacturers for their assistance in supplying valuable data in the preparation of this series. Every effort was made to give appropriate credit and courtesy lines for materials and illustrations used in each volume.

Special thanks is due to Greg Gyorda and Paul Blanchard (Watts Industries, Inc.), Christi Drum (Lennox Industries, Inc.), Dave Cheswald and Keith Nelson (Yukon/Eagle), Bob Rathke (ITT Bell & Gossett), John Spuller (ITT Hoffman Specialty), Matt Kleszezynski (Hydrotherm), and Stephanie DePugh (Thermo Pride).

Last, but certainly not least, I would like to thank Katie Feltman, Kathryn Malm, Carol Long, Ken Brown, and Vincent Kunkemueller, my editors at John Wiley & Sons, whose constant support and encouragement made this project possible.

James E. Brumbaugh

About the Author

James E. Brumbaugh is a technical writer with many years of experience working in the HVAC and building construction industries. He is the author of the *Welders Guide, The Complete Roofing Guide,* and *The Complete Siding Guide.*

Chapter 1

Radiant Heating

Heat is lost from the human body through radiation, convection, and evaporation. Radiation heat loss represents the transfer of energy by means of electromagnetic waves. The convection loss is the heat carried away by the passage of air over the skin and clothing. The evaporation loss is the heat used up in converting moisture on the surface of the skin into vapor.

Heat transfer, whether by convection or radiation, follows the same physical laws in the radiant heating system as in any other; that is, heat flows from the warmer to the cooler exposure at a rate directly proportional to the existing temperature difference.

The natural tendency of warmed air to rise makes it apparent that this induced air current movement is greater at the cooler floor and exterior walls of the average heated enclosure than at its ceiling. It is through absorption by these air currents that the radiant panel releases the convection component of its heat transfer into the room air.

The average body heat loss is approximately 400 Btu per hour; total radiation and convection account for approximately 300 to 320 Btu of it. Because this is obviously the major portion, the problem of providing comfort is principally concerned with establishing the proper balance between radiation and convection losses.

It is important to understand that bodily comfort is obtained in radiant heating by maintaining a proper balance between radiation and convection. Thus, if the air becomes cooler and accordingly the amount of heat given off from the body by convection *increases*, then the body can still adjust itself to a sense of comfort if the heat given off from the body by radiation is *decreased*. The amount given off from the body by radiation can be decreased by raising the temperature of the surrounding surfaces, such as the walls, floor, and ceiling. For comfort, the body demands that if the amount of heat given off by convection increases, the heat given off by radiation must decrease, and vice versa.

The principles involved in radiant heating exist in such commonplace sources of heat as the open fireplace, outdoor campfires, electric spot heaters, and similar devices. In each of these examples, no attempt is made to heat the air or enclosing surfaces surrounding the individual. In fact, the temperature of the air and surrounding surfaces may be very low, but the radiant heat from the fireplace or campfire will still produce a sensation of comfort (or even discomfort from excess heat) to those persons within range. This situation can occur even though a conventional thermometer may indicate a temperature well below freezing. Radiant heat rays do not perceptibly heat the atmosphere through which they pass. They move from warm to colder surfaces where a portion of their heat is absorbed.

This chapter is primarily concerned with a description of radiant panel heating, which can be defined as a form of radiant heating in which large surfaces are used to radiate heat at relatively low temperatures. The principal emphasis will be on hydronic and electric radiant floor heating.

Types of Radiant Panel Heating Systems

Radiant panel heating systems use water-filled tubing or electric heating mats or rolls installed in the floors, walls, and ceilings to distribute the heat. Radiant floor heating is by far the most popular installation method in residential and light-commercial construction.

Note

> The word *panel* is used to indicate a complete system of tubing loops in a single room or space in a structure. It may also be used to indicate a premanufactured radiant floor heating panel.

Floor Panel Systems

Floor panels are usually easier to install than either ceiling or wall panels. Using floor panels is the most effective method of eliminating cold floors in slab construction. Another advantage of heating with floor panels is that much of the radiated heat is delivered to the lower portions of the walls. The principal disadvantage of using floor panels is that furniture and other objects block portions of the heat emission.

Floor panels are recommended for living or working areas constructed directly on the ground, particularly one-story structures. Partial ceiling or wall treatment may be used as a supplement wherever large glass or door exposures are encountered. A typical floor installation is shown in Figure 1-1.

Ceiling Panel Systems

The advantage of a ceiling panel is that its heat emissions are not affected by drapes or furniture. As a result, the entire ceiling area can be used as a heating panel. Ceiling panels are recommended for rooms or space with 7-foot ceilings or higher. A ceiling panel should never be installed in a room with a low ceiling (under 7 feet) because it may produce an undesirable heating effect on the head.

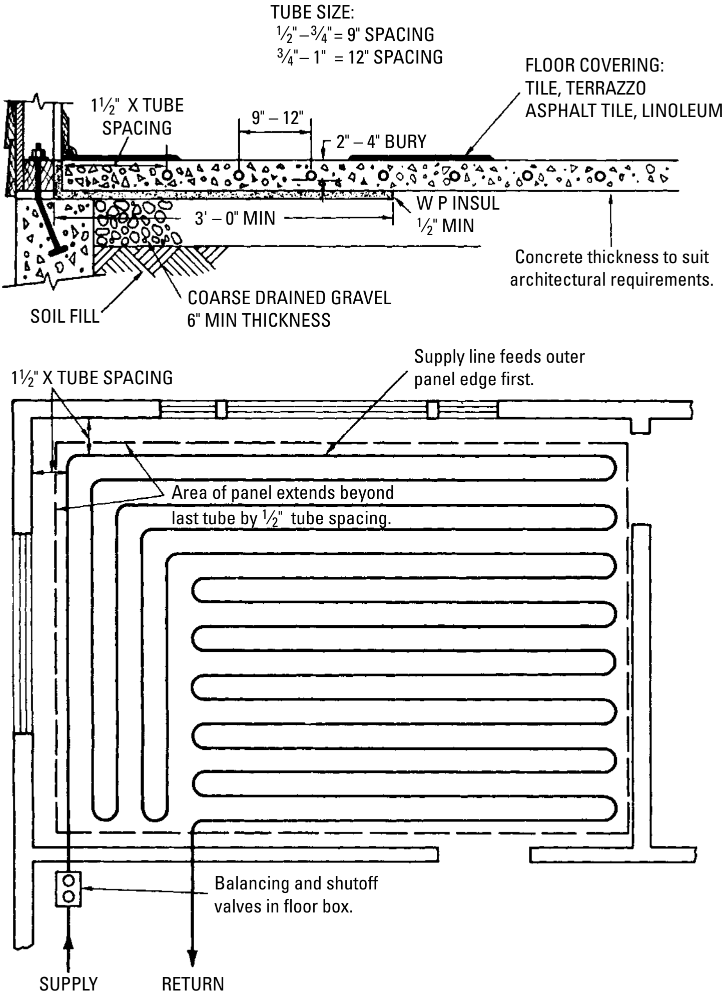


Figure 1-1 Diagram of a typical radiant floor heating installation.

In multiple-story construction, the use of ceiling panels appears to be more desirable from both the standpoint of physical comfort and overall economy. The designed utilization of the upward heat transmission from ceiling panels to the floor of the area immediately above will generally produce moderately tempered floors. Supplementing this with automatically controlled ceiling panels will result in a very efficient radiant heating system. Except directly below roofs or other unheated areas, this design eliminates the need for the intermediate floor insulation sometimes used to restrict the heat transfer from a ceiling panel exclusively to the area immediately below. It must be remembered, however, that when intermediate floor insulations are omitted, the space above a heated ceiling will not be entirely independent with respect to temperature control but will necessarily be influenced by the conditions in the space below. A typical ceiling installation is shown in Figure 1-2.

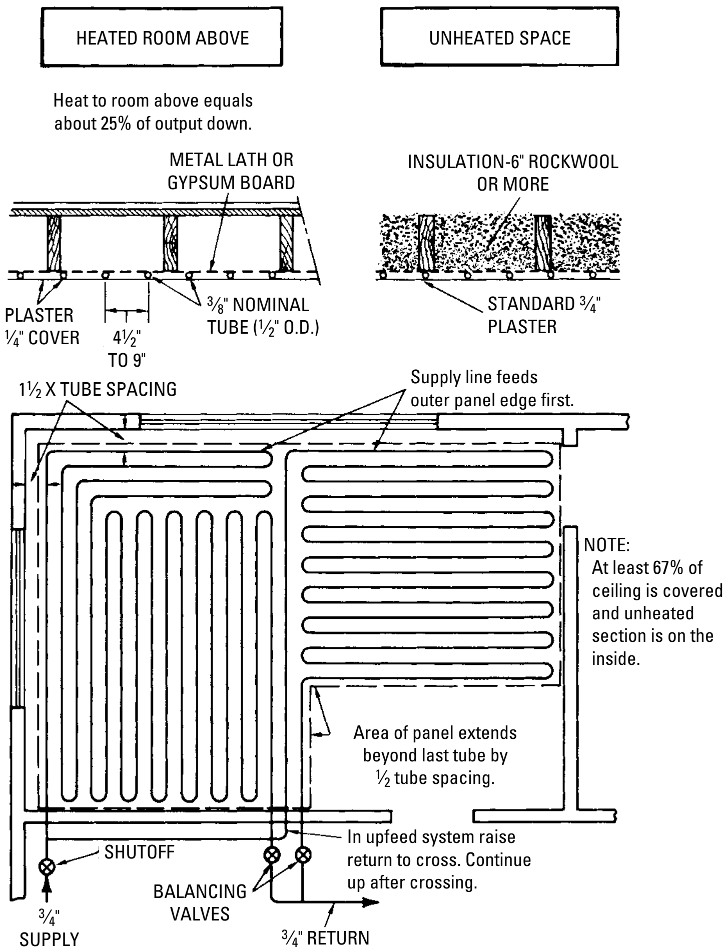


Figure 1-2 Diagram of a typical radiant ceiling heating panel.

Apartment buildings and many office and commercial structures should find the ceiling panel method of radiant heating most desirable. In offices and stores, the highly variable and changeable furnishings, fixtures, and equipment favor the construction of ceiling panels, to say nothing of the advantage of being able to make as many partition alterations as desired without affecting the efficiency of the heating system.

Wall Panel Systems

Walls are not often used for radiant heating because large sections of the wall area are often interrupted by windows and doors. Furthermore, the heat radiation from heating coils placed in the lower sections of a wall will probably be blocked by furniture. As a result, a radiant wall installation is generally used to supplement ceiling or floor systems, not as a sole source of heat.

Wall heating coils are commonly used as supplementary heating in bathrooms and in rooms in which there are a number of large picture windows. In the latter case, the heating coils are installed in the walls opposite the windows. Wall heating coils will probably not be necessary if the room has good southern exposure. A typical wall installation is shown in Figure 1-3.

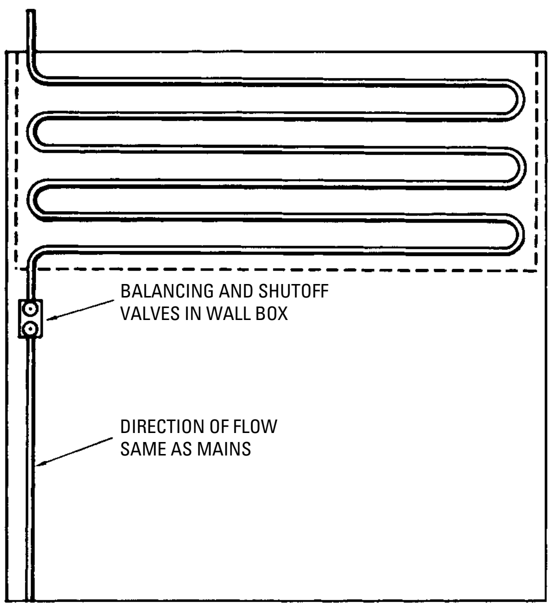


Figure 1-3 Typical wall installation. Panel is installed on wall as high as possible.

Hydronic Radiant Floor Heating

Hydronic radiant floor systems heat water in a boiler, heat pump, or water heater and force it through tubing arranged in a pattern of loops located beneath the floor surface. These systems can be classified as being either wet installations or dry installations depending on how the tubing is installed.

In wet installations, the tubing is commonly embedded in a concrete foundation slab or attached to a subfloor and covered with a lightweight concrete slab. Dry installations are so called because the tubing is not embedded in concrete.

System Components

The principal components of a typical hydronic radiant floor heating system can be divided into the following categories:

1. Boilers, water heaters, and heat pumps
2. Tubing and fittings
3. Valves and related controls
4. Circulator
5. Expansion tank
6. Air separator
7. Heat exchanger
8. Thermostat

Boilers, Water Heaters, and Heat Pumps

The boilers used in hot-water radiant heating systems are the same types of heating appliances as those used in hydronic heating systems. Information about the installation, maintenance, service, and repair of hydronic boilers is contained in Chapter 15 of Volume 1.

Gas-fired boilers are the most widely used heat source in hydronic radiant heating systems. Oil-fired boilers are second in popularity and are used most commonly in the northern United States and Canada. Coal-fired boilers are still found in some hydronic radiant heating systems, but their use has steadily declined over the years.

Note

Hydronic radiant floor heating systems operate in an 85–140°F (29–60°C) temperature range. This is much lower than the 130–160°F (54–71°C) temperature operating range required in other hydronic systems. As a result, the boilers used in floor systems operate at lower boiler temperatures, which results in a much longer service life for the appliance.

The electric boilers used in hydronic radiant floor systems are competitive with other fuels in those areas where electricity costs are low. Their principal advantage is that they are compact appliances that can be installed where space is limited.

Radiant floor systems can also be heated with a geothermal heat pump. In climates where the heating and cooling loads are equal or almost equal in size, a geothermal heat pump will be very cost effective.

Most standard water heaters produce a maximum of 40,000 to 50,000 Btu/h. This is sufficient Btu input to heat a small house or to separately heat a room addition, but it cannot provide the heat required for medium to large houses. As a result, some HVAC manufacturers have developed high-Btu-output dedicated water heaters for radiant heating systems. These water heaters are designed specifically as single heat sources for both the domestic hot water and the space-heating requirements. As is the case with boilers used in hydronic radiant heating systems, they operate in conjunction with a circulating pump and an expansion tank. See Chapter 4 ("Water Heaters") for additional information about combination water heaters.

Tubing and Fittings

The tubing in a radiant heating system is divided into the supply and return lines. The *supply line* extends from the discharge opening of a boiler to the manifold. It carries the heated fluid to the loops (circuits) in the floors, walls, or ceilings. A *return line* extends from the return side of a manifold to the boiler. It carries the water from the heating panels back to the boiler where it is reheated.

Hydronic radiant floor heating systems use copper, plastic (PEX or polybutylene tubing), or synthetic-rubber tubing to form the loops. Because of space limitations, only the two most commonly used types are described in this chapter: copper tubing and PEX (plastic) tubing. Information about the other types of tubing used in hydronic heating systems can be found in Chapter 8 ("Pipes, Pipe Fittings, and Piping Details") of Volume 2.

Loops or Circuits

The words *loop* and *circuit* are synonyms for the length of tubing within a zone. Sometimes both are used in the same technical publication. At other times, one or the other is used exclusively. Many loops or circuits of the same length will form a zone. Circuits also refer to the electrical circuit required to operate the heating system.

Copper Tubing

In most modern radiant floor heating systems, the water is circulated through copper or cross-linked polyethylene (PEX) tubing (see Figure 1-4). The metal coils used in hydronic radiant heating systems commonly are made of copper tubing (both the hard and soft varieties). Steel and wrought-iron pipe also have been used in hydronic floor heating systems, but it is rare to find them in modern residential radiant floor heating systems.

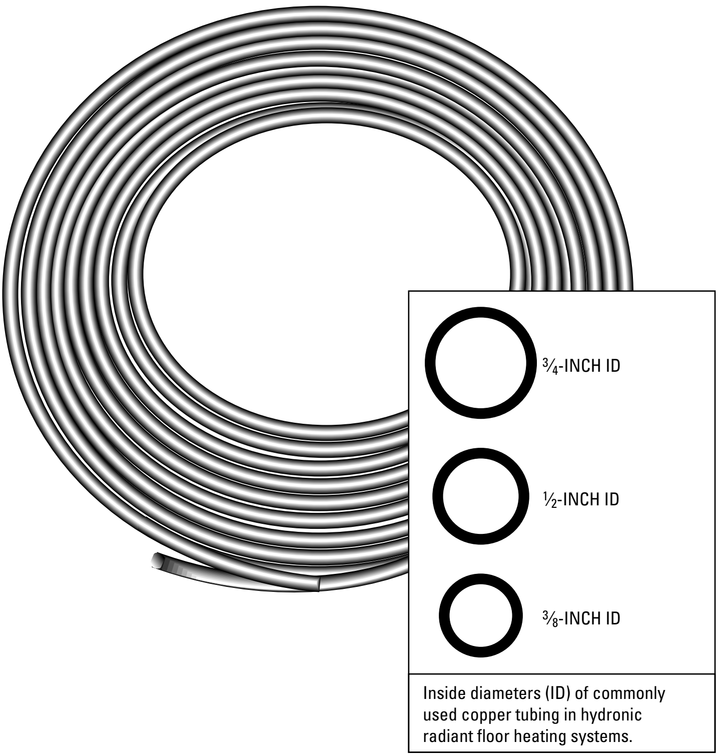


Figure 1-4 Copper tubing.

The soft tempered Type L copper tubing is recommended for hydronic radiant heating panels. Because of the relative ease with which soft copper tubes can be bent and shaped, they are especially well adapted for making connections around furnaces, boilers, oil-burning equipment, and other obstructions. This high workability characteristic of copper tubing also results in reduced installation time and lower installation costs. Copper tubing is produced in diameters ranging from ⅛ inch to 10 inches and in a variety of different wall thicknesses. Both copper and brass fittings are available. Hydronic heating systems use small tube sizes joined by soldering.

The size of the pipes or tubing used in these systems depends on the flow rate of the water and the friction loss in the tubing. The *flow rate* of the water is measured in gallons per minute (gpm), and constant *friction loss* is expressed in thousandths of an inch for each foot of pipe length. For a description of the various types of tubing used in hydronic heating systems, see the appropriate sections of Chapter 8 ("Pipes, Pipe Fittings, and Piping Details") in Volume 2.

Most of the fittings used in hydronic radiant heating systems are typical plumbing fittings. They include couplings (standard, slip, and reducing couplings), elbows (both 45° and 90° elbows), male and female adapters, unions, and tees (full size and reducing tees) (see Figure 1-5).

Three special fittings used in hydronic radiant heating systems are the brass adapters, the brass couplings, and the repair couplings. A *brass adapter* is a fitting used to join the end of a length of ¾-inch diameter copper tubing to the end of a length of plastic polyethylene tubing. A *brass coupling*, on the other hand, is a fitting used to join two pieces of plastic heat exchanger tubing. A *repair coupling* is a brass fitting enclosed in clear vinyl protective sheath to prevent concrete from corroding the metal fitting. The fitting is strengthened by double-clamping it with stainless steel hose clamps.

A decoiler bending device or jig should be used to bend metal tubing into the desired coil pattern. Only soft copper tubing can be easily bent by hand. It is recommended that a tube bender of this type be made for each of the different center-to-center spacing needed for the various panel coils in the installation.

Soft copper tubing is commonly available in coil lengths of 40 feet, 60 feet, and 100 feet. When the tubing is uncoiled, it should be straightened in the trough of a straightener jig. For convenience of handling, the straightener should not be more than 10 feet long.

Note

> Most copper tubing leaks will occur at bends or U-turns in the floor loops. These leaks are caused by water or fluids under high pressure flowing through the weakened sections of tubing. The weakened metal is commonly caused by improper bending techniques.

Whenever possible, continuous lengths of tubing should be used with as few fitting connections as possible. Coils of 60 feet or 100 feet

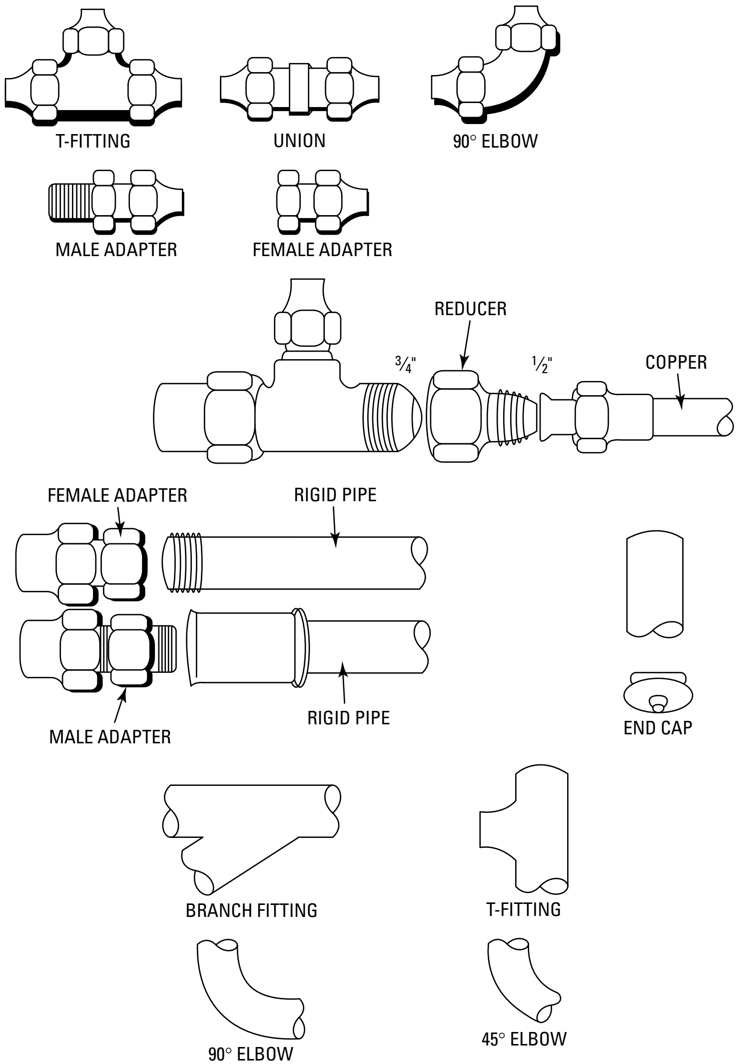


Figure 1-5 Some examples of copper tubing fittings.

are best for this purpose and are generally preferred for floor panels. The spacing between the tubing should be uniform and restricted to 12 inches or less. Use soldered joints to make connections between sections of tubing or pipe.

Cross-Linked Polyethylene (PEX) Tubing

Cross-linked polyethylene (PEX) tubing is commonly used indoors in hydronic radiant heating panels or outdoors embedded beneath the surface of driveways, sidewalks, and patios to melt snow and ice. It is made of a high-density polyethylene plastic that has been subjected to a cross-linking process (see Figures 1-6, 1-7, and 1-8). It is flexible, durable, and easy to install. There are two types of PEX tubing:

- Oxygen barrier tubing
- Nonbarrier tubing

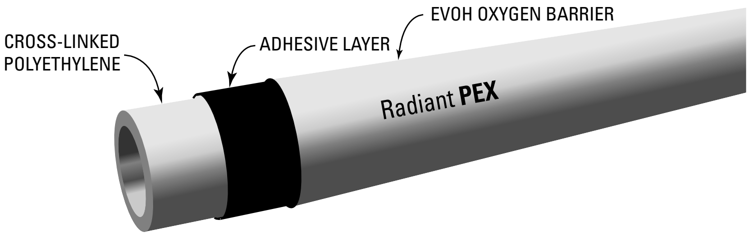


Figure 1-6 PEX tubing. *(Courtesy Watts Radiant, Inc.)*

Oxygen barrier tubing (BPEX) is treated with an oxygen barrier coating to prevent oxygen from passing through the tubing wall and contaminating the water in the system. It is designed specifically to prevent corrosion to any ferrous fittings or valves in the piping system. BPEX tubing is recommended for use in a hydronic radiant heating system.

Nonbarrier tubing should be used in a hydronic radiant heating system only if it can be isolated from the ferrous components by a corrosion-resistant heat exchanger, or if only corrosion-resistant system components (boiler, valves, and fittings) are used.

PEX tubing is easy to install. Its flexibility allows the installer to bend it around obstructions and into narrow spaces. A rigid plastic cutter tool, or a copper tubing cutter equipped with a plastic cutting wheel, should be used to cut and install PEX tubing. Both tools produce a square cut without burrs.

PEX tubing can be returned to its original shape after accidental crimping or kinking by heating it to about 250–275°F. This attribute of PEX tubing makes it possible to perform field repairs without removing the damaged tubing section. This is not the case with polybutylene tubing, which is not cross-linked. Synthetic rubber tubing

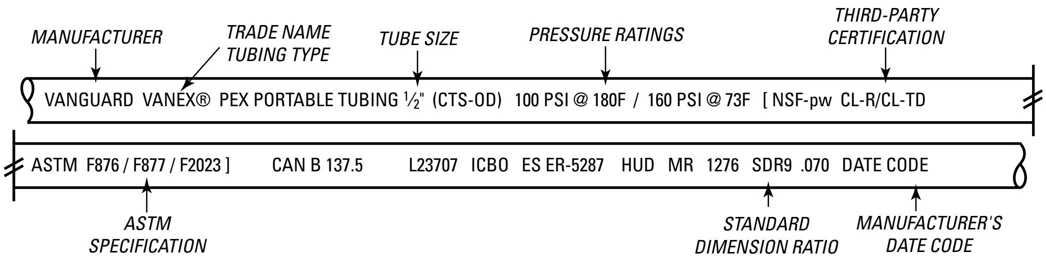
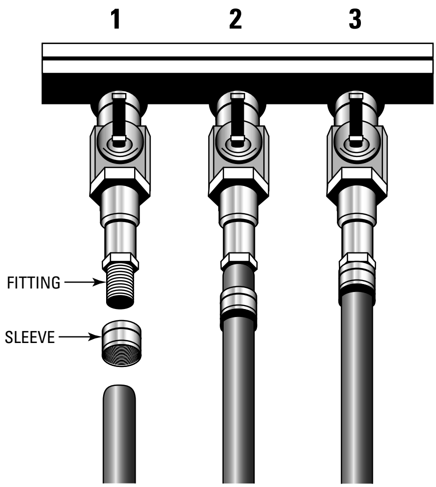


Figure 1-7 PEX tubing markings. *(Courtesy Vanguard Piping Systems, Inc.)*

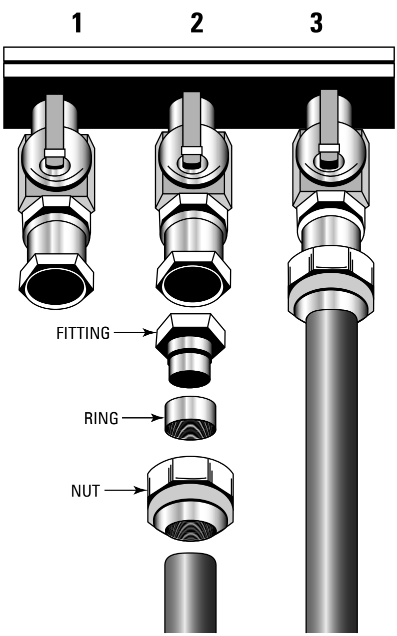


Crimping Fittings

1. Expand the end of the PEX tubing with the expansion tool provided by the PEX tube manufacturer.

2. Insert the brass fitting into the end of the expanded PEX tube.

3. Use the expansion tool to pull the brass sleeve back over the PEX tube and fitting for a tight connection.



Compression Fitting

1. Slide the locking nut and split compression ring up the tubing.

2. Insert the tubing onto the compression fitting.

3. Tighten the nut onto the compression fitting snugly.

4. Re-tighten the fittings after the heat has been turned on and the hot water has circulated through the tubing.

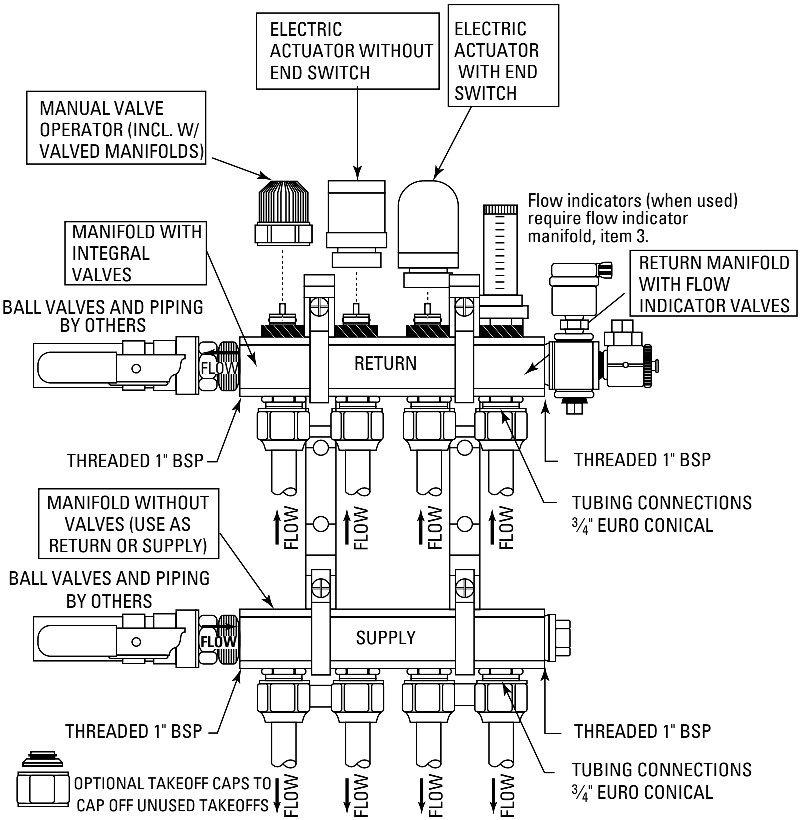
Figure 1-8 PEX tubing fittings.

(Courtesy Watts Radiant, Inc.)

is also not cross-linked, but its material composition and its flexibility make it very resistant to crimping or kinking damage.

Manifolds

A *manifold* is a device used to connect multiple tubing lines to a single supply or return line in a hydronic radiant floor heating system (see Figures 1-9 and 1-10). Each heating system has at least two



Manifolds with integral valves should be used as return manifolds unless flow indicators are desired. If both flow indication and electric valve actuators are needed, use manifold with flow indicator valves on their turn and manifold with integral valves on the supply. Apply any desired combination of 2-wire and 4-wire electric actuators.

Figure 1-9 Weil-McLain hydronic radiant heating manifold.

(Courtesy Weil-McLain)

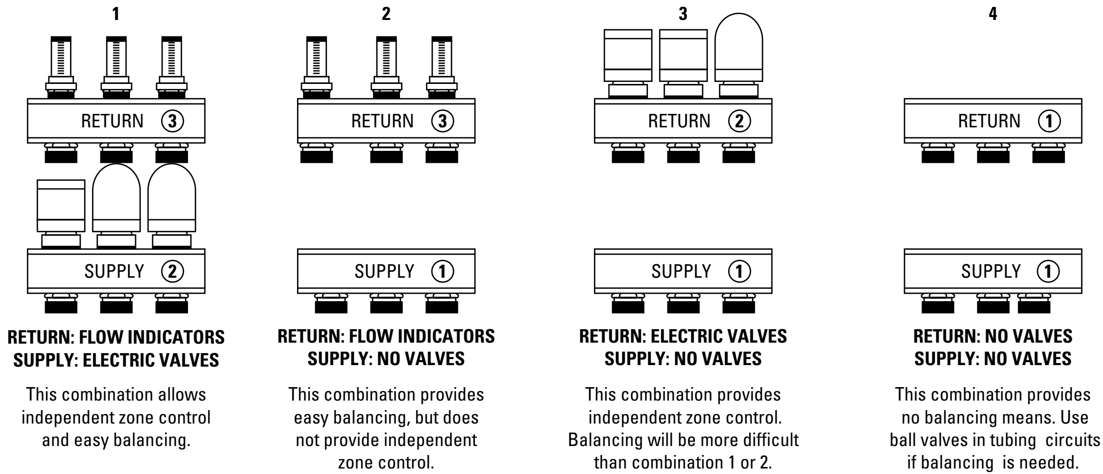


Figure 1-10 Manifold combinations. *(Courtesy Weil-McLain)*

types of manifolds: a supply manifold and a return manifold. A supply manifold receives water from the heating appliance (that is, the boiler, water heater, or heat pump) through a single supply pipe and then distributes it through a number of different tubing lines to the room or space being heated (see Figure 1-11). A return manifold provides the opposite function. It receives the return water from the room or space through as many tubing lines and sends it back to the boiler by a single return pipe. A supply manifold and a return manifold are sometimes referred to jointly as a *manifold station*.

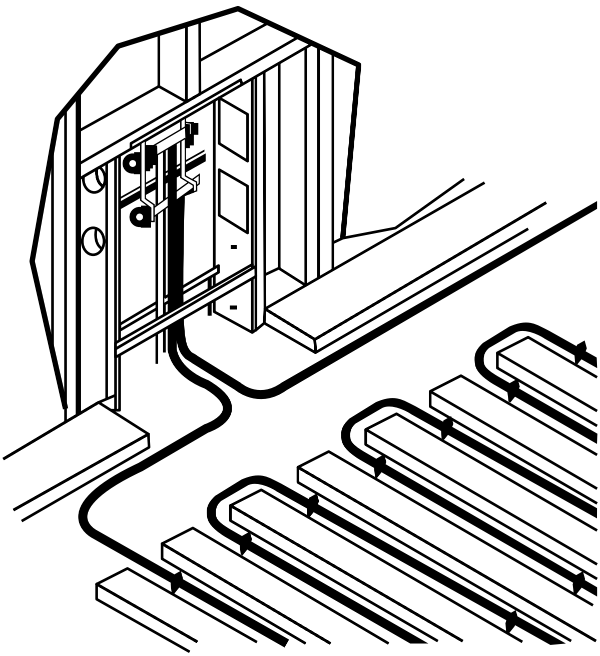


Figure 1-11 Typical manifold location.

Preassembled manifolds are available from manufacturers for installation in most types of heating systems. Customized manifolds can also be ordered, but they are more expensive than the standard, preassembled types.

A *supply manifold*, when operating in conjunction with zone valves, can be used to control the hot water flow to the distribution lines in the radiant heating system. The zone valves, which are usually ball valves, can be manually adjusted or automatically opened and closed with a zone valve actuator. Some zone valves are designed as fully open or fully closed valves. Others are operated by a modulating actuator that can adjust the opening to the heat required by the zoned space.

A supply manifold with zoning capabilities is sometimes called a *zone manifold* or *distribution manifold*. In addition to zone valves, these manifolds also can be ordered to include supply and return water sensors, the circulator, and a control panel with indoor and outdoor sensors.

Depending on the heating system requirements, a manifold may also include inline thermometers or a temperature gauge to measure the temperature of the water flowing through the tubing; check valves or isolation valves to isolate the manifold so that it can be serviced or repaired; drain valves to remove water from the manifold; an air vent to purge air from the system; and pump flanges (for the circulator) plus all the required plumbing connections and hardware.

Manifold balancing valves regulate each zone (loop) to ensure efficient heat distribution and eliminate those annoying cold and hot spots on the floor. These valves can be adjusted to deliver the design flow rate of water in gallons per minute (gpm). Some manifolds are designed to electronically read the flow and temperature of the water in individual tubing loops. This function results in rapid and accurate data feedback for balancing. It also makes troubleshooting problems easier.

Manifolds are available for mounting on walls or installation in concrete slabs. The latter type, sometimes called a *slab manifold*, is made of copper and is available with up to six supply and six return loop connections. Slab manifolds also should be equipped with a pressure-testing feature so that they can be tested for leaks before the slab is poured.

Slab manifolds are installed with a box or form that shields the device from the concrete when it is poured. All connections remain below the level of the floor except for the tops of the supply and return tubing.

Valves and Related Control Devices

Valves and similar control devices are used for a variety of different purposes in a hydronic radiant floor heating system. Some are used as high-limit controls to prevent excessively hot water from flowing through the floor loops. Some are used to isolate system components, such as the circulating pump, so that it can be serviced or removed without having to shut down the entire system. Others are used to regulate the pressure or temperature of the water, to reduce the pressure of the water before it enters the boiler, or to regulate the flow of water.

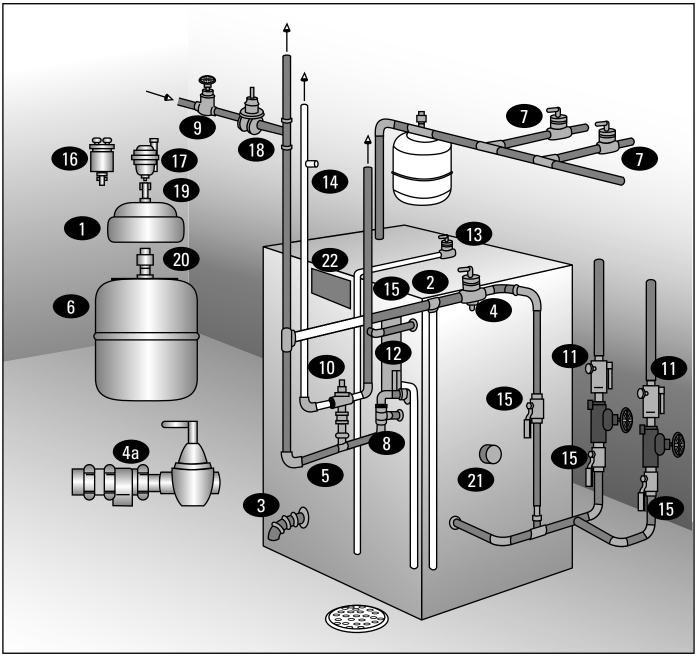
Many of the different types of valves and control devices used in hydraulic radiant floor heating systems are listed in the sidebar. A brief description of the more commonly used ones is provided in this section. For a fuller, more detailed description of their operation, maintenance, service, and repair, read the appropriate sections of Chapter 9 ("Valves and Valve Installation") of Volume 2. Not all the valves listed in the sidebar or the ones described in this chapter will necessarily be used in the same heating system. The valves chosen will fit the requirements of a specific application (see Figures 1-12, 1-13, and 1-14).

Hydraulic Heating System Valves and Related Control Devices

- Air vent
- Aquastat
- Backflow preventers
- Ball valves
- Boiler drain valve
- Check valves
- Feed water pressure regulator
- Flow control valve
- Gate valve
- Globe valve
- Isolation valve
- Mixing valve
- Motorized zone valve
- Pressure-reducing valve
- Pressure relief valve
- Purge and balancing valves
- Solenoid valve

Air Vent

An air vent is a device used to manually or automatically expel air from a closed hydronic heating system. An automatic air vent valve provides automatic and continuous venting of air from the system. The function of both types is to prevent air from collecting in the piping loops.



1. Air scoop.
2. Backflow preventer.
3. Boiler drain valve.
4. Boiler fill valve.
4a. Combination backflow preventer and boiler fill valve.
5. Bronze check valve.
6. Expansion tank.
7. Flow check valves.
8. Flow control valve.
9. Gate or globe valve.
10. Mixing valve.
11. Purge valve.
12. Pressure relief valve.
13. Hot water safety relief valve.
14. Test plug.
15. Ball valve.
16. Automatic float vent valve.
17. Float vent.
18. Water pressure reducing valve.
19. Service check valve.
20. Combination temperature and pressure gauge.
21. Boiler energy saver.

Figure 1-12 Typical locations of valves and related control devices in a hydronic heating system. *(Courtesy Watts Regulator Co.)*

Aquastat

An *aquastat* is a control device consisting of a sensing bulb, a diaphragm, and a switch (see Figure 1-14). As the temperature surrounding the sensing bulb increases, the gas inside the bulb expands and flows into the diaphragm. This action causes the diaphragm to expand and activate the switch controlling the connected device. When temperatures exceed the high-limit setting on

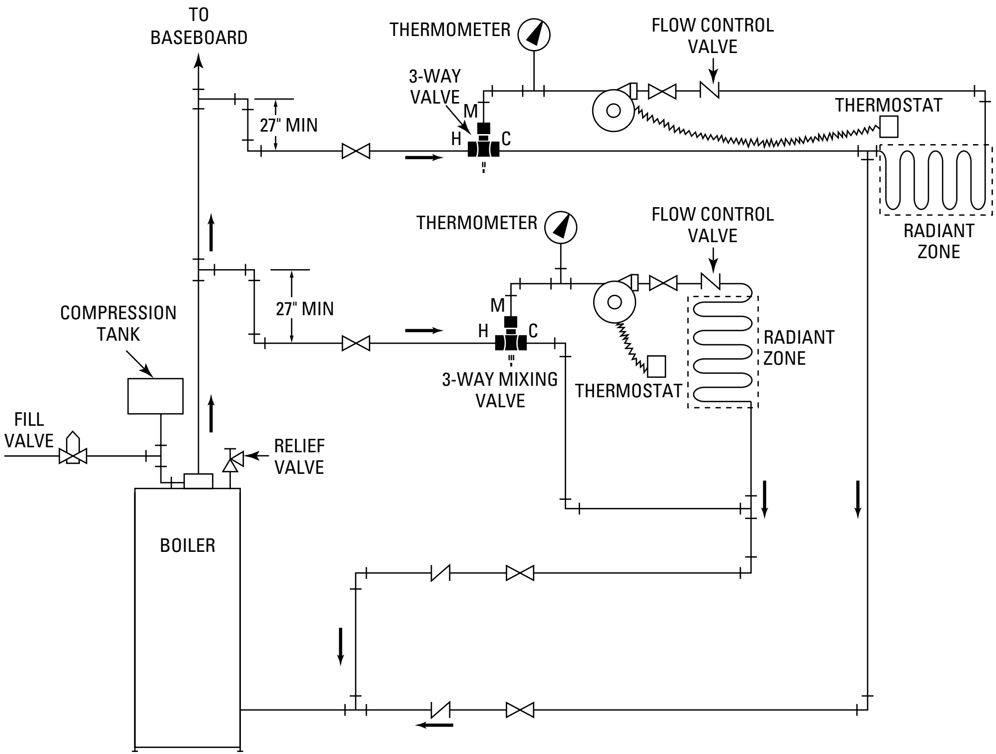
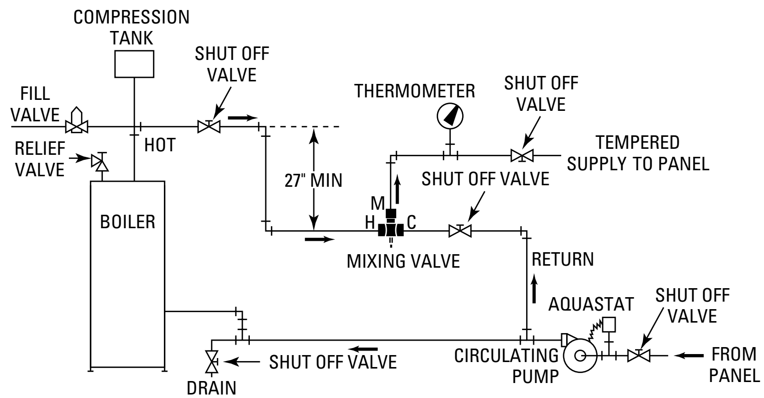


Figure 1-13 Piping diagram of a zoned radiant heating system supplying hot water to both floor panels and baseboards.



Note: Circulating pumps, illustrated in the above applications, circulate tempered water through the system. The aquastat shuts the circulating pump off if the tempered water exceeds the temperature set point, which is normally ± 5°F (± 2°C) of the tempering valve discharge.

Figure 1-14 Piping diagram of a radiant heating system with circulator controlled by aquastat.

the aquastat, it shuts off the circulator or circulators until the problem can be corrected.

The switching contacts of some aquastats can be manually adjusted for temperature settings. In other systems, the switching contacts of an aquastat may be preset at a predetermined temperature setting.

Backflow Preventer

A *backflow preventer* is a valve used to prevent the mixing of boiler hot water with domestic (potable) water (see Figure 1-15). Most systems use an inline backflow preventer. It must be installed with the arrow on the side of the valve facing the direction of water flow. Sometimes a backflow preventer and boiler fill valve are combined in the same unit.

Ball Valve, Gate, and Globe Valves

A *ball valve* can be used to isolate components or lines, or to regulate flow. A *gate valve* is often used to isolate components for service, repair, or replacement. They are not designed to regulate the flow of water. A *globe valve* is used to regulate the flow of water in a radiant heating system.

Note

> Use a fully closing ball or gate valve on the supply and return line so that the manifold can be isolated and serviced without interrupting the pressure in the rest of the system.

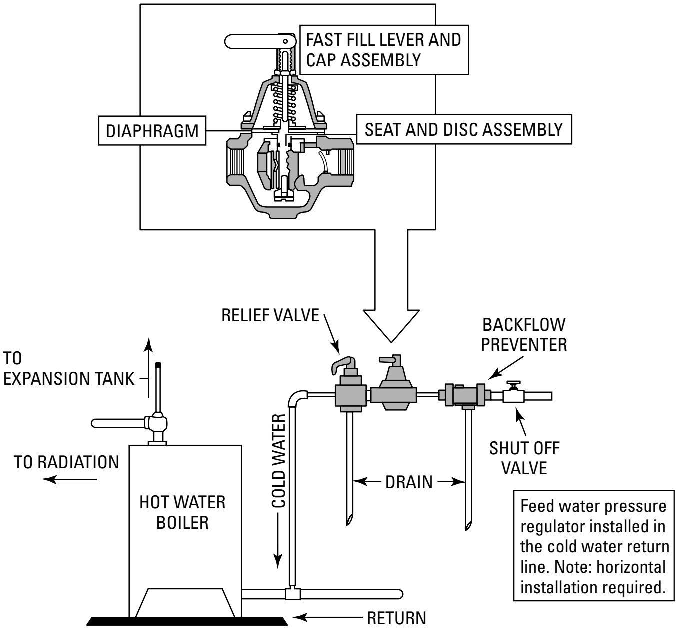


Figure 1-15 Feed water pressure regulator. *(Courtesy Watts Regulator Co.)*

Boiler Drain Valve

A *boiler drain valve* is a quarter-turn ball valve used to drain water from a boiler. As shown in Figure 1-12, it is located near the bottom of the boiler close to a floor drain.

Check Valves

A *check valve* (also called a shutoff valve) is used to ensure that water is flowing in the correct direction by providing positive shutoff to the flow. Typical locations of check (shutoff) valves are shown in Figures 1-12, 1-13, and 1-14.

A *swing check valve* is designed to prevent the backflow of water. A *flow-control valve* is a check valve used to prevent circulation of the hot water through the heating system when the thermostat has not called for circulation. The flow-control check valve must be used when the radiant panels are located below the boiler.

Note

> Flow-control valves should not be used when the radiant floor panel is below the level of the boiler.

Another type of check valve used in a radiant floor heating system is the *isolation valve* (also sometimes called a *service valve*).

The isolation valve is used to isolate a hydronic system component for servicing and/or removal so that it can be repaired or replaced. Isolating the component eliminates the need to drain and refill the system with water.

Caution

Reduce the system pressure to a safe level before attempting to remove system components.

Caution

An isolation valve is not designed to isolate a pressure (safety) relief valve or other safety or flow-sensitive components.

Feed Water Pressure Regulators

A feed water pressure regulator is used to fill both the boiler and system piping (including the floor panel loops) with water. A typical location of a feed water pressure regulator in the cold-water return line is illustrated in Figure 1-15. These valves also maintain the water pressure at the required level in the system at all times. If a leak should occur in the system, the feed water pressure regulator is designed to provide the required amount of makeup water. Using the feed water pressure regulator speeds filling and purging of air from the piping during the initial fill procedure.

Disconnect Switch

Two principal types of on-off switches are used to open or close an electrical circuit: the disconnect switch and the thermostat (see *Thermostat* in this section).

The *disconnect switch* is a manually operated on-off switch used to shut down the entire heating system when a problem is beginning to develop. When the switch is in the off position, the circuit opens and the electricity operating the boiler, heat pump, or water heater is shut off. When it is in the on position, the circuit closes (that is, completes itself) and electricity bypasses the boiler, heat pump, or space-heating water heater.

Inline Thermometer

An *inline thermometer* is a device that is used to monitor the water temperature as it circulates through the system. Two inline thermometers are installed in the heating system. One monitors the temperature of the water as it enters the supply line. The other monitors the temperature of the water as it leaves. The difference between these two measurements provides clues to the operating efficiency of the system.

Mixing Valve

A *thermostatic mixing valve* is used in a radiant heating system to recirculate a variable portion of the return water and at the same time add a sufficient quantity of hot boiler water to maintain the required water temperature in the loops. These valves are also called *thermostatic mixing valves*, *water blending valves*, *water blenders*, *water tempering valves*, or *tempering valves*. Typical locations of mixing valves are shown in Figures 1-12, 1-13, and 1-14.

Both manual and automatic modulating mixing valves are used in hydronic heating systems. The manual mixing valve is often used to control the water temperature in a high-mass concrete slab. It is not as accurate as an automatic valve (for example, a thermostatic valve), but the high-mass concrete slab stores it and releases it slowly over a long period of time, making exact temperature control unnecessary.

The three-way and four-way thermostatic mixing valves provide automatic control of the mixed water temperatures. The valve varies the flow of hot water between its hot port and its cold port so that it can deliver through its mixed port a steady flow of water at a constant temperature.

Mixing valves are often used with high-temperature boilers designed to provide water at temperatures of more than 160°F.

Motorized Zone Valve

A *motorized zone valve* is used to control the flow of water through a single zone (see Figure 1-16). It consists of a valve body combined with an electric actuator. A radiant panel heating system will often use a number of motorized zoning valves to maintain a uniform temperature throughout the rooms and spaces in the structure. As shown in Figure 1-17, a motorized zone valve is used to control each zone. Motorized zone valves are controlled by an aquastat, individual thermostats at each loop, or a room thermostat.

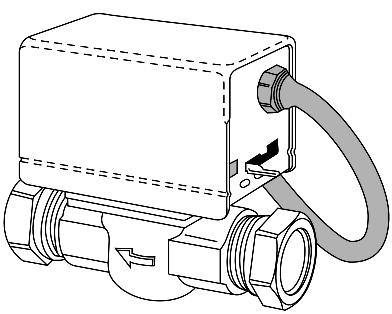


Figure 1-16 Honeywell V4043 motorized zone valve.

(Courtesy Honeywell, Inc.)

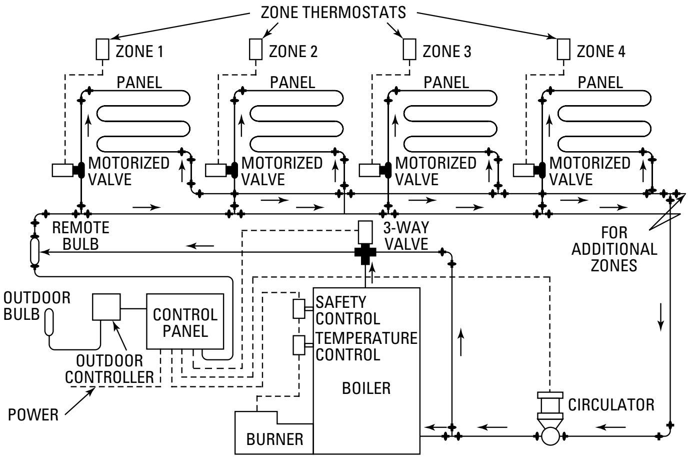


Figure 1-17 A typical control system for a multiple-zone radiant heating system. *(Courtesy Honeywell Tradeline)*

Note

A zone valve simplifies the piping required for a hydronic heating system because it eliminates the need for a flow check valve and relays.

Pressure-Reducing Valve

A *pressure-reducing valve* is designed to reduce the pressure of the water entering the system and to maintain the pressure at a specific minimum setting (usually about 12 lbs). A typical location of a pressure relief valve is shown in Figure 1-12.

Pressure Relief Valve

A *pressure relief valve* (also sometimes called a *safety relief valve*) is used to prevent excessive and dangerous pressure from entering the system. It is located on top of the boiler or very close to it (see Figures 1-12, 1-13, and 1-14).

Purge and Balancing Valves

Purge and balancing valves are used on either the supply or return side of the manifold in systems where multiple manifolds are served by only one circulator. Among its varied functions is (1) to allow adjustments of proper water flow for each loop; (2) to function as a shutoff valve and a drain valve for each zone or loop; (3) to control (balance) water flow through the circulation loop; and (4) to provide a means of expelling air from heating zones during initial loop fill (valve is located on the boiler return piping). If the heating system contains individual loops of unequal length, each should be equipped with a balancing valve.

Circulator

The *circulator* (circulating pump) provides the motive force to circulate the water through the radiant heating system. Sometimes a variable-speed pump is used to maintain a supply water temperature between 90°F and 150°F.

In some zoned systems, a circulator operates in conjunction with a zone thermostat instead of a zoning valve to maintain a uniform floor temperature in each room or space of the structure. The zone thermostat controls the temperature in the zone by turning the circulator on and off. The size of the circulating pump selected for a radiant panel heating system will depend on the pressure drop in the system and the rate at which water must circulate. The circulation rate of the water is determined by the heating load and the *design* temperature drop of the system and is expressed in gallons per minute (gpm). This can be calculated by using the following formula:

$$\text{gpm} \times \frac{\text{Total Heating Load}}{T \times 60 \times 8}$$

The *total heating load* is calculated for the structure and is expressed in Btu per hour. A value of 20°F is generally used for the design temperature drop (T) in most hot-water radiant panel heating systems. The other two values in the formula are the minutes per hour (60) and the weight (in pounds) of a gallon of water (8).

By way of example, the rate of water circulation for a structure with a total heating load of 30,000 Btu per hour may be calculated as follows:

$$\begin{aligned} \text{gpm} &= \frac{30{,}000 \text{ Btu/hr}}{20 \times 60 \times 8} \\ &= \frac{30{,}000}{9600} = 3.13 \end{aligned}$$

Expansion Tank

An *expansion tank* (also called a *compression tank*) is required for use in all closed hydronic radiant heating systems (see Figure 1-18). Water and other fluids expand when they are heated. The expansion tank provides space to store the increased volume to prevent stress on the system.

Air Separator

An *air separator* (also called an *air scoop* or an *air eliminator*) is a device used in a closed radiant heating system to capture and remove air trapped in the water (see Figure 1-18). Some of these devices are

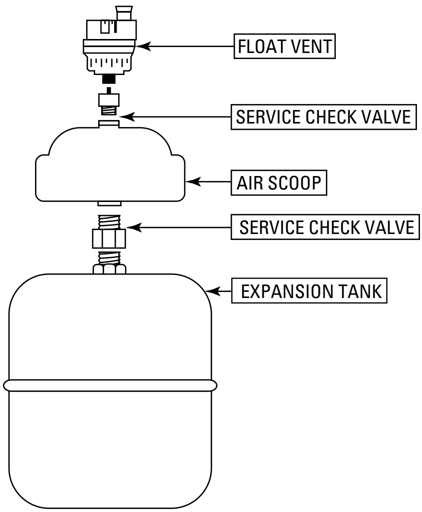


Figure 1-18 Air separator and expansion tank.

equipped with tappings for the installation of an expansion tank and air vent.

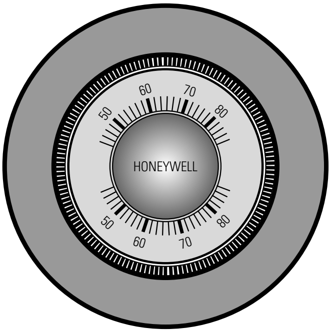
Heat Exchanger

A *heat exchanger* is a device used in some radiant heating systems to separate dissimilar fluids such as water mixed with antifreeze (in snow- and ice-melting applications) and water (for radiant floor heating tubing and domestic hot water). Its function is to allow the transfer of heat between the fluids without allowing them to mix and thereby contaminate one another.

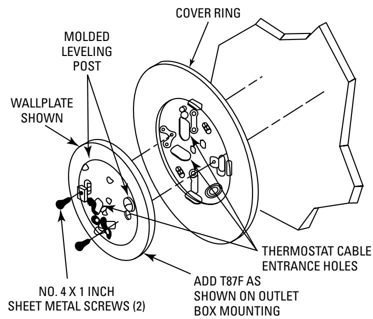
Automatic Controls

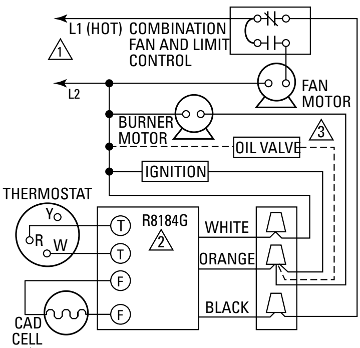
While any thermostatic method of control will function with a radiant floor heating system, the most desirable method is one based on continuously circulating hot water. The temperature of the water should be automatically adjusted to meet outdoor conditions, but the circulation itself is controlled by interior limiting thermostats instead of the simple off-on method of circulating hot water at a fixed temperature (see Figure 1-19).

Some radiant floor heating systems are designed with a thermostat for each zone (see Figure 1-17). A more common method is to group several rooms or spaces together and control them by a single thermostat. In this approach, the kitchen and dining room may be included in one thermostat-controlled loop, the bedrooms in another, the bathrooms in still another, and so on.



Honeywell **T87F thermostat for zone control in hydronic and radiant heating systems.**



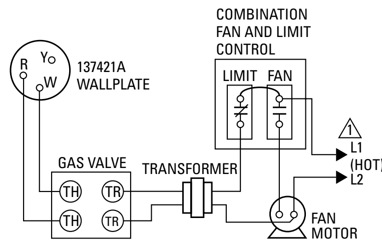


1 Power supply, provide disconnect means and overload protection as required.

2 R8184 protectorelay oil primary contains internal transformer.

3 Connect oil valve, if applicable.

T87F used for 2-wire, spst control of heating only in a typical oil system. Low voltage power for the control circuit is supplied by a transformer in the oil primary control. (*Courtesy Honeywell, Inc.*)



1 Power supply, provide disconnect means and overload protection as required.

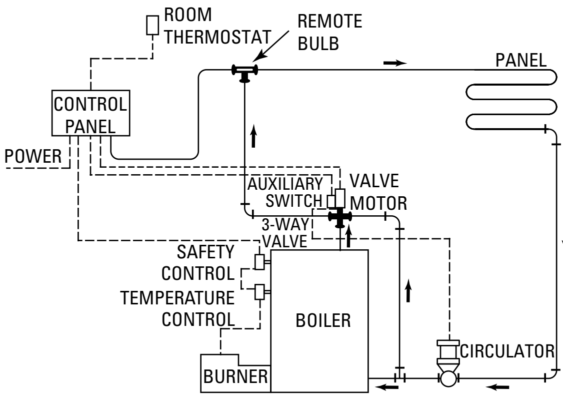
T87F used for 2-wire, spst control of heating only in a typical gas system. (*Courtesy Honeywell, Inc.*)

Figure 1-19 Examples of thermostat controls used in hydronic radiant heating systems.

Many HVAC control manufacturers are now producing control consoles such as the one shown in Figure 1-20.

Designing a Hydronic Radiant Floor Heating System

Design of a hydronic radiant floor heating system should be attempted only by those with the qualifications, training, and experience to do it right. It is *very* important that the design of a radiant panel heating system be correct at the outset. The fact that the coils or cables are permanently embedded in concrete, or located beneath



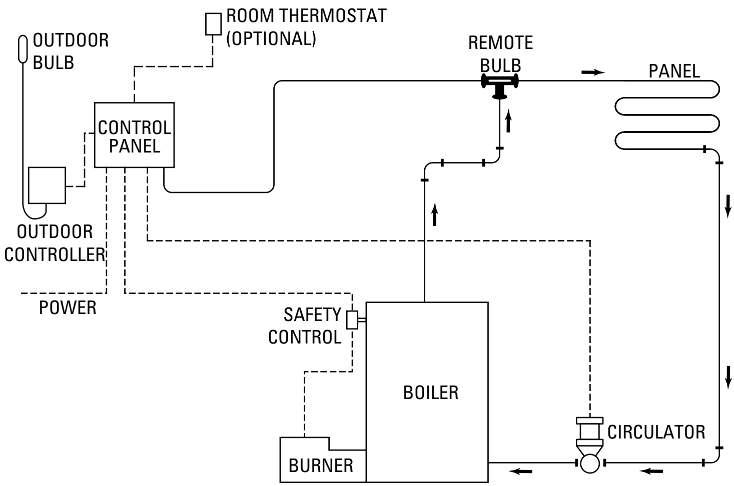
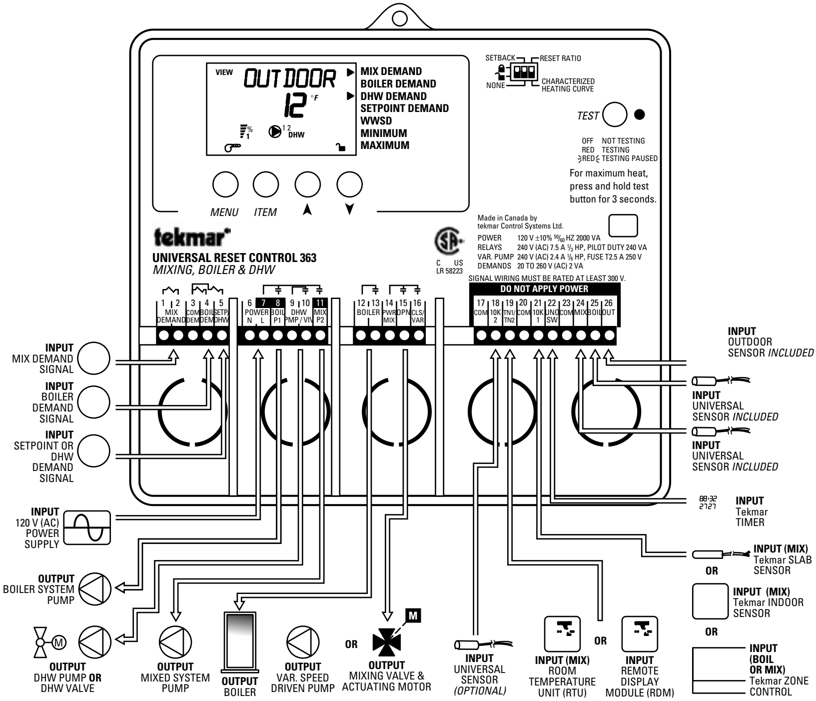


Figure 1-19 *(Continued)*

other materials, makes corrections or adjustments very difficult and expensive.

Many manufacturers of radiant panel heating system equipment have devised simplified and dependable methods for designing this type of heating system. In most cases, the manufacturer will provide any available materials to assist in calculating the requirements of a particular radiant floor heating system. Various design manuals, manufacturer-specific installation guides, and software tools are available for use in designing and sizing radiant floor heating systems.



***Tekmar* Universal reset Control 363. (*Courtesy Tekmar Control Systems, Inc.*)**

The control panel operates in conjunction with both indoor and outdoor sensors to control space and heating temperatures (multiple zones or single-zone), domestic hot water supply, slab heat, and snow–melting applications. The control panel uses an outdoor reset to adjust the boiler and mixed loop water temperatures delivered to the heating system. A variable speed driven wet-rotor circulator or a floating action driven mixing valve is used as a mixing device.

Figure 1-19 *(Continued)*

A radiant floor heating system in which there is a constant (uninterrupted) circulation of water is the preferred design. The benefits of constant water circulation through the circuits are as follows:

- It maintains an even floor temperature.
- It prevents hot spots from forming when there is no call for heat.
- It prevents air from entering the system.
- It reduces the risk of the water freezing in systems where antifreeze cannot be used (that is, systems in which the water

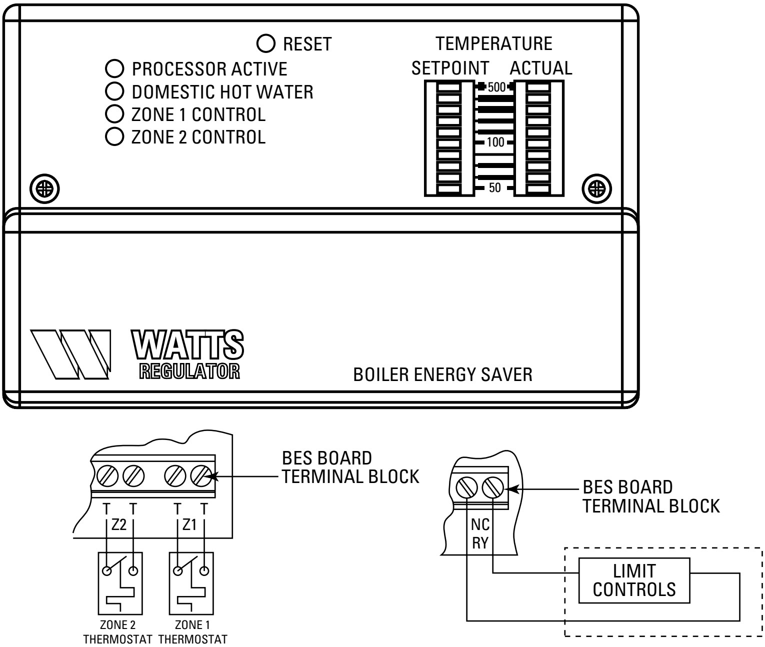


Figure 1-20 Watts Boiler Energy Saver and wiring diagrams.

(Courtesy Watts Regulator Company)

heater heats both the water for space heating and the water for cooking and bathing purposes).

The flow of water in some radiant heating systems is controlled by the circulator (pump). When the room thermostat calls for heat, the pump starts and rapidly circulates heated water through the radiant panels until the heat requirement is satisfied. The pump is then shut off by the thermostat. In some systems, a flow-control valve is forced open by the flow of water through the pipes as long as the pump is running, permitting free circulation of heated water through the system. When the pump stops, the control valve closes, preventing circulation by gravity, which might cause overheating. The principal disadvantage of a system with this off-on control is that it results in temperature lag and causes the panels to intermittently heat and cool.

The continuous circulation of water through radiant heating panels is made possible by means of an outdoor-indoor control.

In this arrangement, hot water from the boiler is admitted to the system in modulated quantities when the temperature of the circulating water drops below the heat requirement of the panels. This modulated bleeding of water into the panel is accomplished through a bypass valve. When no additional heat is required, the valve is closed. When more heat is required, the valve is gradually opened by the combined action of the outdoor temperature bulb and a temperature bulb in the supply main. This system gives control by the method of varying the temperature of the water.

Air Venting Requirements

A common defect encountered in hot-water system design is improper venting. The flow of water should be automatically kept free of air binding throughout the system. Air in the pipes or pipe coils almost always results in a reduction of heat.

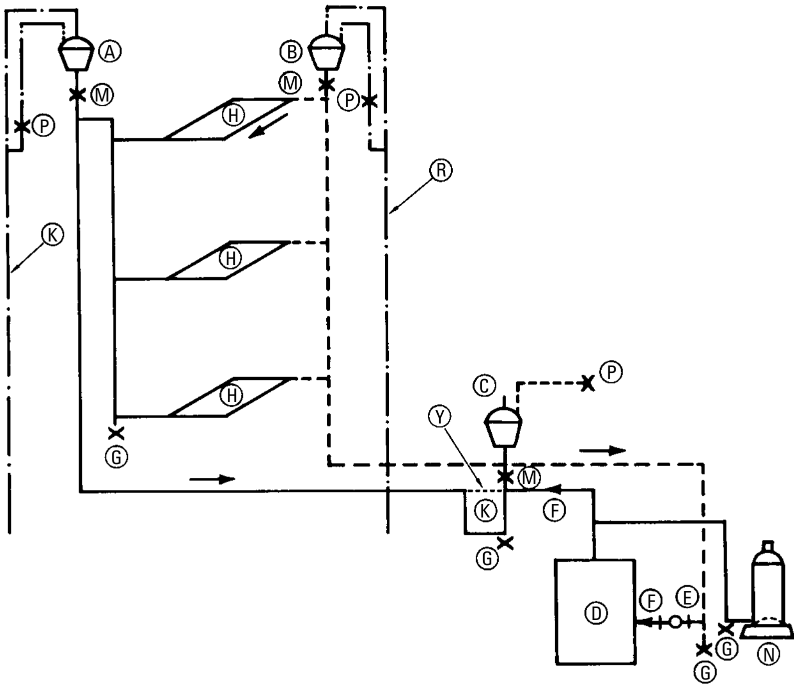
A practical method of venting is shown in Figure 1-21. The key to this method is the use of automatic air vents. Each air vent should be located in an area readily accessible for repair. The air trap test cock should be placed where it can be easily operated. Both the air trap and the air trap test cock must be located where they are not subject to freeze-up, as both are noncirculating except during venting operation (automatic or manual).

Sizing Calculations

The successful operation of any hot-water heating system requires the incorporation of design provisions that ensure an even and balanced flow of water through the pipes or coils of the installation.

The procedure for designing a hydronic radiant floor heating system may be outlined as follows:

1. Determine the total rate of heat loss per room in the structure.
2. Determine the available area for panels (loops) in each room.
3. Determine the output required by each panel to replace the heat loss.
4. Determine the required surface temperature for each panel.
5. Determine the required heat input to the panel (should equal heat output).
6. Determine the most efficient and economical means of supplying heat to the panel.
7. Install adequate insulation on the reverse side and edges of the panel to prevent undesirable heat loss.
8. Install the panels opposite room areas where the greater heat loss occurs.



Symbols: → Indicates downward grade of tubing. (A) automatic air trap at top of main flow riser; (B) automatic air trap at top of main return riser; (C) automatic air trap at top of special loop (K) required by possible obstruction and when small size vent by-pass is also not permissible at (Y); (D) heater; (E) pump; (F) check valve; (G) drain valve; (H) heating panel coil; (K) loop in main flow (See (C)); (M) trap shut-off valve (for repair); (N) expansion tank; (P) manual test cock (air trap); (R) open and automatic vent tube (½ in. copper).

Note—By reversing direction of grade at (H) air trap (B) can be eliminated. Same riser vent layout should be used for up-feed systems. Test cocks (P) should be located accessible for occasional use. Open ends of vent tubes (R) (normally dry) can discharge visibly into nearest drain or sink.

Figure 1-21 An automatic vent radiant heating system.

Note

Always keep floor temperatures at or slightly below recommended high limits.

Radiant Floor Construction Details

Radiant floor construction can be divided into two broad categories based on the installation method used: (1) wet installation and (2) dry installation. The *wet installation method* involves completely embedding the tubing in a concrete slab or covering it with a thin layer of concrete (commonly a gypsum-based lightweight pour).

The *dry installation method* is so-called because the tubing is installed without embedding it in concrete.

The examples of radiant floor construction described in this section represent the most commonly used forms. They are offered here only as examples, not as planning guides for contractors. The actual construction plans will depend on the design of the hydronic radiant floor heating system, the impact of local building codes and regulations, and other variables.

Slab-on-grade construction

In slab-on-grade construction, the tubing is attached to a wire mesh or special holding fixtures to keep it in place until the concrete is poured around it. The tubing loops are embedded in the middle of the concrete slab and are located approximately 2 inches below the slab surface (see Figure 1-22). A brief summary of the steps involved in slab-on-grade construction is as follows:

1. Compact the soil base to prevent uneven settling of the slab.
2. Cover the compacted soil with a lapped 6-mil vapor barrier.
3. Cover the vapor barrier with 2-inch-thick extruded polystyrene insulation.
4. Install rigid polystyrene insulation vertically on the inside surface of the exterior foundation walls to prevent edgewise (horizontal) heat loss.
5. Lay concrete reinforcing mesh over the insulation.
6. Position the tubing on top of the reinforcement mesh according to the tubing layout plan.
7. Tie the tubing to the reinforcement mesh with tie straps or wire.
8. Cover the tubing with a minimum of 9 inches of concrete.

Thin-Slab Construction

In this type of wet installation, a layer of lightweight concrete or lightweight gypsum is poured over the tubing to form a thin slab (see Figure 1-23). Thin-slab construction is used over a wood subfloor supported by wood framing.

A summary of the steps involved in forming a thin-slab floor system using poured concrete to form the slab may be outlined as follows:

1. Apply a lapped 6-mil polyethylene vapor barrier to the wood subfloor.
2. Position the tubing on the subfloor according to the tubing layout plan.

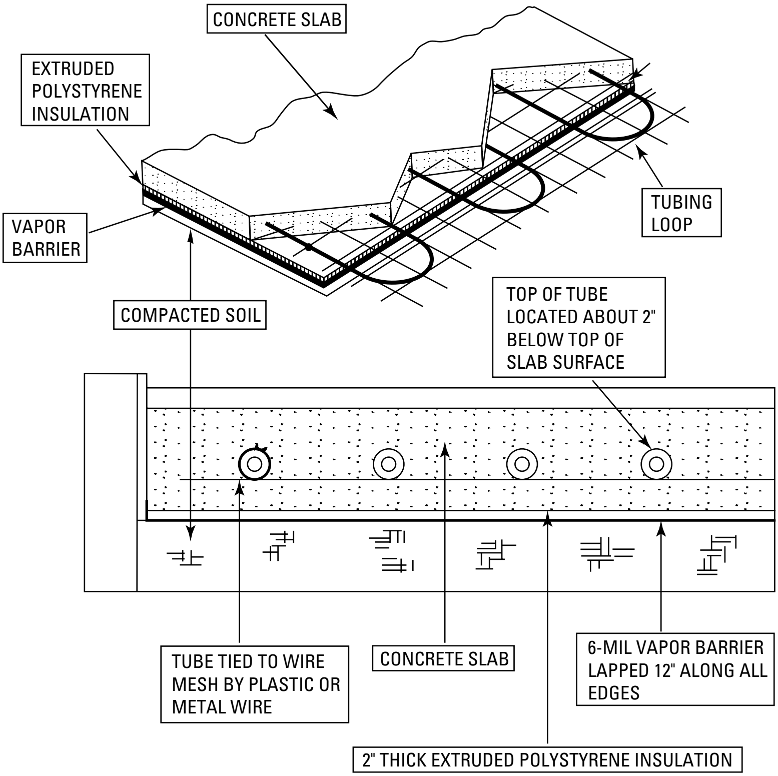


Figure 1-22 Slab-on-grade construction.

3. Fasten the tubing to the wood subfloor with plastic clips or metal staples.
4. Pour concrete over the tubing and subfloor.
5. Install batt insulation in the joist cavities beneath the subfloor. If lightweight gypsum cement instead of concrete is used to form the slab, pour the gypsum in two stages. The first pour should be no higher than the tops of the tubes. When this first layer dries, it will shrink slightly and pull back from the tubing. Apply a second layer of gypsum to completely cover the first layer and the tops of the tubing.

Sandwich Floor Construction

Sandwich floor construction is available in a number of different configurations (see Figure 1-24). This construction method involves

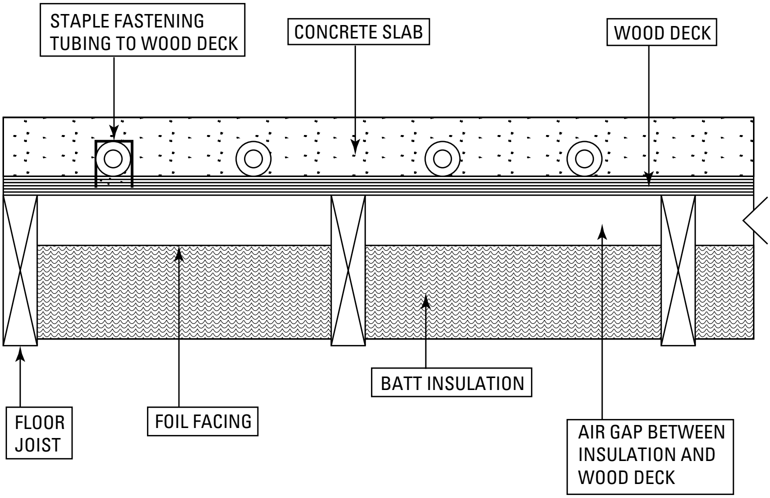


Figure 1-23 Thin-slab construction details.

locating the tubing between the subfloor and additional flooring layers. In some cases, aluminum plates are added for heat dispersion. The two layers of a sandwich floor have wood sleepers installed between them for adding the tubing and subsequent flooring layers. These systems all contain less thermal mass than slab systems, and some allow for more rapid temperature responsiveness.

Staple-Up Method

In the staple-up method, the tubing is located below the subfloor. This method of installing tubing is very common in both new construction and remodeling work. Its use is recommended when retrofitting because it avoids the problem and expense of having to remove the existing floor covering.

Note

> The staple-up construction method will require drilling holes for the tubing in some of the supporting joists.

The staple-up construction method illustrated in Figure 1-25 is used without heat transfer plates. The tubing is fastened to the bottom of the subfloor in the joist cavities. Install either 3½-inch batts or 2-inch polystyrene rigid insulation in the joist cavities below the tubing with a 1½- to 4-inch air gap between the subfloor and the insulation.

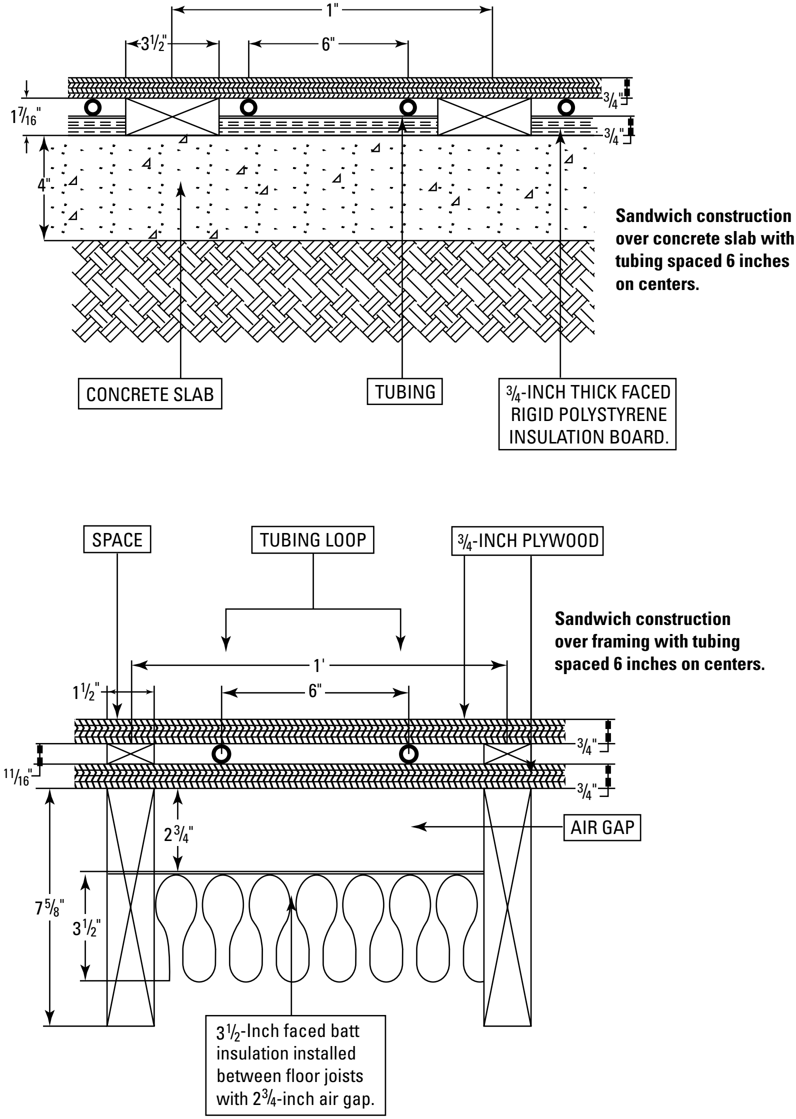


Figure 1-24 Examples of sandwich floor construction.

(Courtesy Watts Radiant, Inc.)

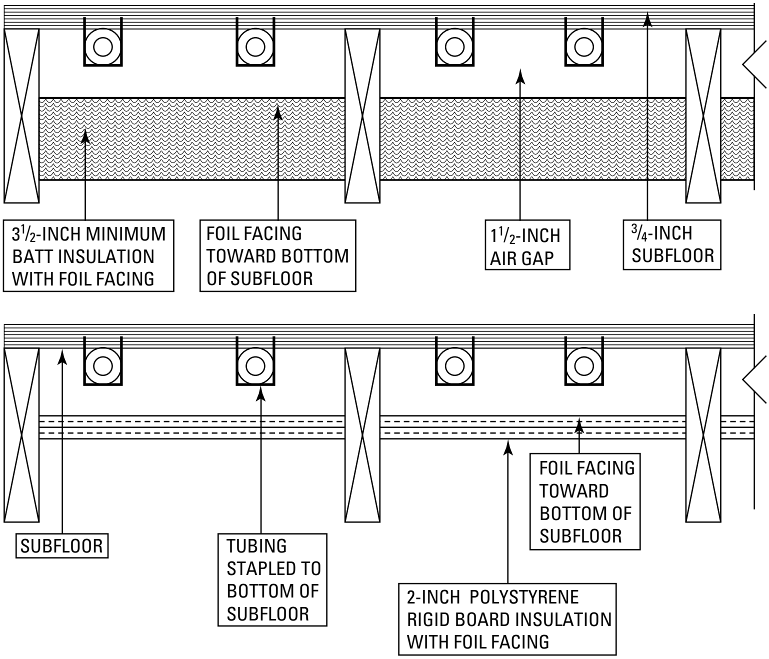


Figure 1-25 Staple-up method.

The heating efficiency of the staple-up construction method can be greatly improved by adding preformed, grooved aluminum heat transfer plates beneath the subfloor (see Figure 1-26). The plates are stapled to the bottom of the subfloor in the joist cavities, and the tubing is inserted in the preformed plate grooves. Insulation is installed beneath the tubing with a 2- to 4-inch air space between the top of the insulation and the bottom of the subfloor. The heat from the tubing spreads horizontally across the plate surface and then flows upward into the room or space above the floor. Without these plates, a percentage of the heat from the tubing is lost because it flows down into the spaces below the room being heated. To compensate for the heat loss, the heating system must operate at higher temperatures. This results in higher heating costs.

A variation of the staple-up construction method is to hang the tubing several inches below the subfloor in the joist cavities. Aluminum heat-transfer plates are fastened to the bottoms of the floor joists leaving an air gap between the plates and the bottom of the subfloor.

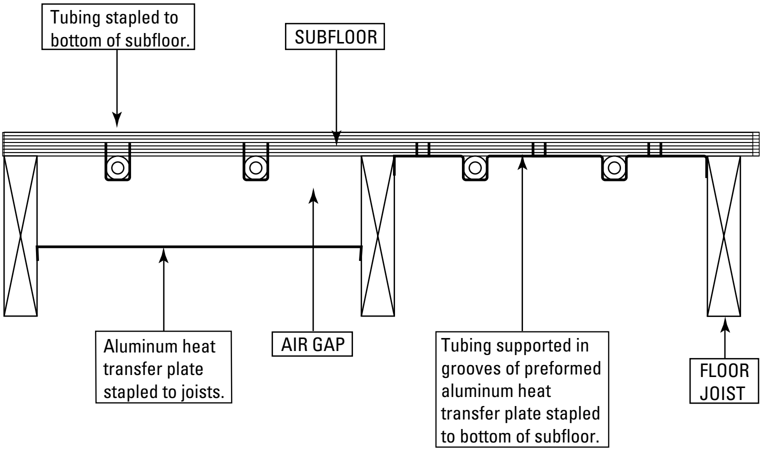


Figure 1-26 Staple-up method with heat transfer plates.

Tubing Installed Above the Subfloor

Figure 1-27 illustrates a common dry installation method of installing the tubing above the subfloor. It consists of wood sleepers nailed to the top surface of the wood subfloor with the tubing located in the spaces between the sleepers. Plywood is nailed to the tops of the sleepers to support the floor covering material.

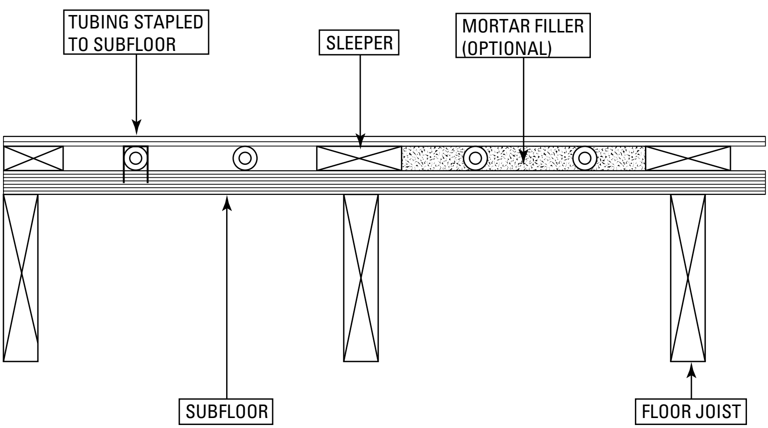


Figure 1-27 Tubing installed above the subfloor between sleepers.

Note

> A loose, noninsulating masonry filler poured around the tubing will increase the thermal mass of the floor. Do not use loose fill insulation, such as perlite or vermiculite. These are insulating materials that will interfere with the heat radiation from the tubing. Masonry filler is not an insulating material.

An alternative method is to install heat-transfer plates between the sleepers and use the plates to support (cradle) the tubing. In both cases, a suitable insulation must be installed between the floor joists (see Figure 1-28).

Still another method is to install factory-made, grooved wood panels beneath the finished floor. The dimensions of the panels may vary, depending on the manufacturer. The tubing is inserted in the panel grooves and set flush with the panel surface.

Floor Coverings

Floor covering materials reduce the amount of heat radiation rising into the room or space above the floor. The insulating properties of floor coverings must be considered when designing a hydronic or electric radiant floor heating system. Plush carpets and polyurethane carpet pads should not be installed over a radiant floor heating system. The same holds true for thick wood floors or multiple layers of plywood subfloors. Both have a high thermal resistance.

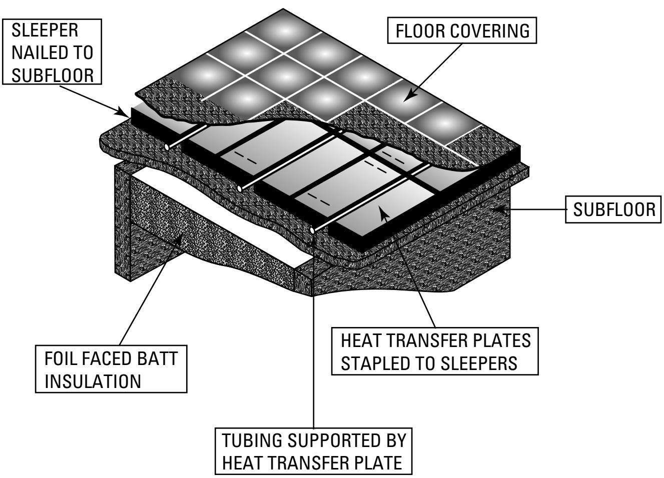


Figure 1-28 Tubing installed above the subfloor between sleepers with heat-transfer plates. *(Courtesy Weil-McLain)*

Carpets are commonly installed over a carpet pad. The combined carpet and cushion R-value (that is, its insulating value) should not exceed a maximum of R-4.0. Use either a foam rubber or waffle rubber pad. To reduce the resistance even further, consider eliminating the carpet pad.

Sheet final and tile floor coverings radiate the heat much faster than carpet, thereby reducing the lag time between when the hot water flows through the circuit and the heat is actually delivered to the room or space above.

Coils and Coil Patterns

Hydronic radiant floor heating panels are available as prefabricated units, or they can be constructed at the site. The principal coil patterns used in radiant floor heating systems are the following:

1. Coil pattern for uniform heat distribution.
2. Coil pattern for perimeter heat distribution along two walls.
3. Coil pattern for perimeter heat distribution along one wall.

Counterflow Spiral Tube Layout Pattern

The tube layout illustrated in Figure 1-29 provides the most even and uniform heat distribution for a room in a radiant floor heating system. It accomplishes this by running the supply and return lines parallel to one another. As a result, an average temperature is created between the tubes.

Double Serpentine Layout Pattern

In some rooms, there will be a significant amount of heat loss through two adjacent exterior walls. As shown in Figure 1-30, the supply tubing runs along the perimeter of the walls where the hot water can provide maximum heat transfer. It then turns inward in a series of serpentine-like loops to the center of the room (the area of lowest heat loss) before returning to the manifold.

Single Serpentine Layout Pattern

If a major heat loss occurs along a single exterior wall, the supply tubing runs along the perimeter of that wall before returning in a series of serpentine loops to the return manifold (see Figure 1-31).

In a well-designed hydronic radiant floor heating system, the linear travel from the heating unit and pump should be the same for each of the panels (see Figure 1-32). This will result in the flow through each panel being in natural balance.

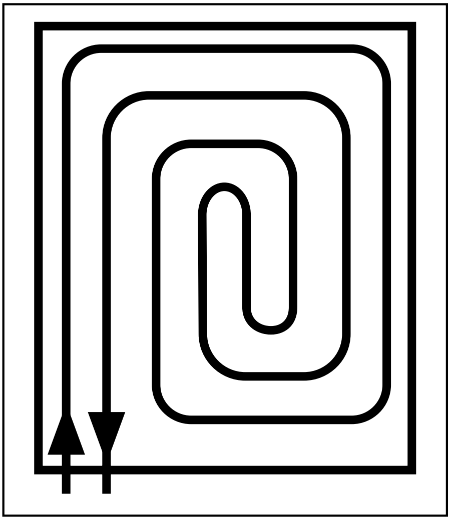


Figure 1-29 Counterflow spiral tube layout pattern.

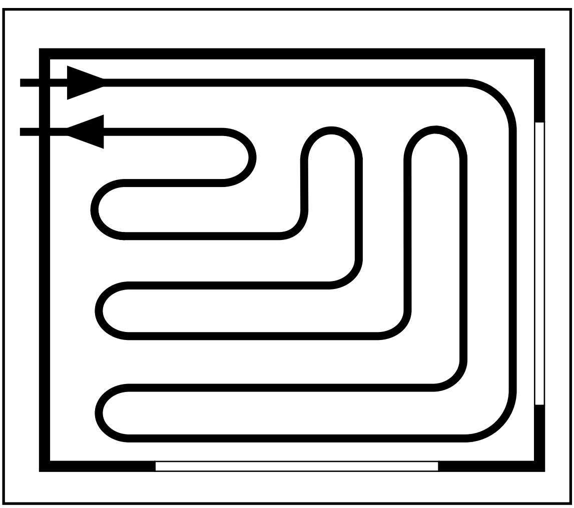


Figure 1-30 Double serpentine layout pattern.

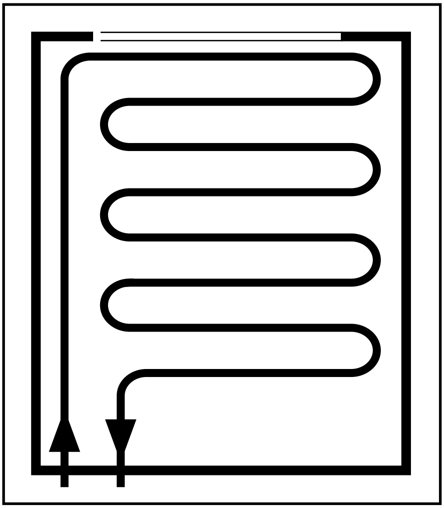


Figure 1-31 Single serpentine layout pattern.

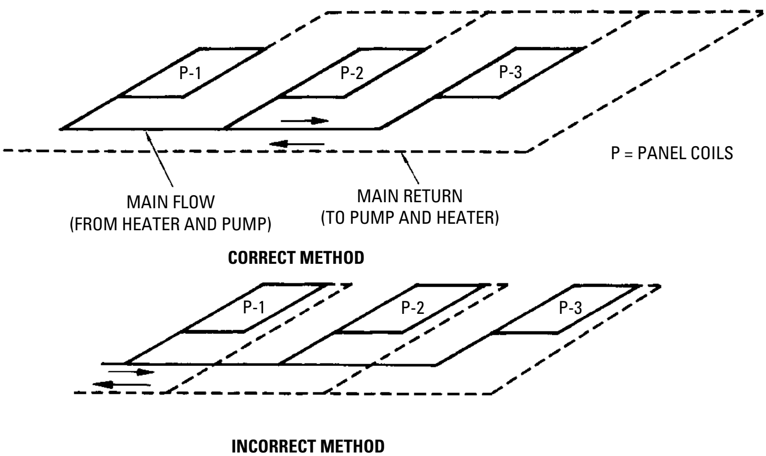


Figure 1-32 Correct and incorrect method of laying out a forced hot-water distribution system. The travel from pump and heater should be the same through P_1, P_2, and P_3 as shown in the correct method.

Installing a Hydronic Radiant Floor Heating System (PEX Tubing)

These installation recommendations are provided for general information only. The architect or HVAC contractor is responsible for all design details and installation procedures for the specific radiant floor heating system. The architect or contractor is also responsible for maintaining the work in compliance with all applicable building codes, local and national.

Note

> Install all the components of a hydronic radiant floor heating system in accordance with the equipment manufacturer's instructions and all applicable codes. Failure to do so could result in severe personal injury, death, or substantial property damage.

Installation Recommendations

The following installation recommendations are provided as a general reference. Each manufacturer will provide instructions specific to its product.

System Inspection

After the PEX tubing has been embedded or concealed, it becomes a relatively permanent part of the structure. Because of the difficulty of servicing embedded or concealed loops, it is essential that a final inspection be performed to make sure the tubing or piping has not been damaged during construction and that all tubing or piping loops have been installed in compliance with local codes and ordinances. Check the following:

- Check to make sure the tubing or piping loops have been installed according to the layout (coil patterns) in the building plan.
- Inspect the tubing or piping for kinks, scrapes, slits, or crush damage.
- Inspect the tubing or piping for correct spacing.
- Make sure all manifolds are correctly located and provide easy access.
- Check to make sure the tubing or piping connections to the manifold are tight.
- Make sure the tubing or piping is properly fastened and there is a correct spacing maintained between the fasteners.

Tubing Length and Diameter

It is important to know the length and inside diameter (ID) of the tubing when creating a circuit (loop). Excessive circuit lengths will result in a significant temperature drop in the circuit. The temperature drop is the difference between the supply (hotter) water entering the circuit and the return (cooler) water leaving the circuit. In residential heating systems, the temperature drop is normally 15–20°F. If the temperature drop is greater than 15–20°F, it will result in insufficient heat and/or uneven heat being delivered to the room or space.

Long loops also result in increased friction in the tubing, which slows the flow rate of the water. This pressure drop must be overcome by the circulator (pump) in order to maintain a uniform flow rate for the water in the tubing.

A typical residential hydronic radiant heating system uses ½-inch-ID tubing. The maximum recommended length for this diameter is 300 feet. Most circuits (loops) in residential heating systems are shorter (about 100 to 250 feet long). Tubing with an ID of ⅝-inch or ¾–inch, on the other hand, can be used in circuits up to a maximum of 450 feet in length.

In addition to the tubing ID, the length of the tubing required per square foot of floor will also be affected by such variables as the type of slab used, the heat load for the structure, the type of appliance (boiler, water heater, or heat pump), the type of controls used, and even the climate.

Tubing Spacing

Another important factor to consider when designing and installing a hydronic radiant floor heating system is the spacing of the tubing in the loops. Most residential heating systems are based on the use of 1 to 1½ linear feet of ½-inch-ID tubing per square foot of floor area with the tubing spaced 9 to 12 inches apart. That is only a general rule, however, because there are situations where the tubing must be spaced closer to increase the heat output (for example, under windows, along cold exterior walls, and so on). A 3-inch to 6-inch spacing of the tubing will require 2 to 4 linear feet of tubing per square foot of heated floor area.

Loop Continuity

The tubing loop extending from the manifold supply port to the manifold return port must be one continuous length. Never splice together two lengths of tubing to form a loop. Doing so will weaken the loop.

Insulation

Install insulation beneath the tubing to prevent the downward loss of a portion of the heat. In uninsulated slab-on-grade construction, for example, a portion of the heat will be lost to the ground. The ground becomes a heat sink if there is no insulation installed. Use 1- to 2-inch-thick rigid polystyrene to insulate a slab-on-grade radiant heating system. Batt and blanket insulation are also in other types of radiant heating systems. See "Radiant System Construction Details" for examples of the use of the different types of insulation.

Vapor Barrier

A vapor barrier of 6-mil polyethylene sheeting should be installed between a thin slab and the wood sheathing to limit the transfer of moisture from the slab to the wood. Check the local building code for the use of a vapor barrier. Not all codes require it.

Panel Testing Procedures

Radiant heating coils should be tested for leaks after they have been secured in position but before they are covered with concrete or some other covering material. Both a compressed-air test and a hydraulic pressure test are used for this purpose.

The compressed-air test requires a compressor, a pressure gauge, and a shutoff valve. The idea is to inject air under pressure into the radiant heating system and watch for a pressure drop on the gauge. A continually dropping pressure is an indication of a leak somewhere in the system.

The pressure gauge is attached to one of the radiant heating coils, and the shutoff valve is placed on the *inlet* side of the gauge in a valve-open position. The air compressor is then connected, and compressed air is introduced into the system under approximately 100 psi. After the introduction of the air, the shutoff valve is closed and the compressor is disconnected. The system is now a closed one. If there are no leaks, the air pressure reading on the gauge will remain at approximately 100 psi. A steady drop in the air pressure reading means a leak exists somewhere in the system. A leak can be located by listening for the sound of escaping air. Another method is to use a solution of soap and water and watch for air bubbles.

The hydraulic pressure test requires that the coils be filled with water and the pressure in the coils be increased to approximately 275 to 300 psi. Care must be taken that *all* air is removed from the coils before the system is closed. The system is then closed, and the gauge is watched for any change in pressure. A leak in the system will be indicated by a steady drop in pressure on the gauge. The source of the leak can be located by watching for the escaping water. If a leak is discovered, the coil should be repaired or replaced and a new test run on the system.

Installation Guidelines

Guidelines

- Run the tubing parallel to the wall or walls with the greatest heat loss.

(*continues*)

Guidelines (*continued*)

- Maintain a 12-inch gap between the outermost tubing and an exterior wall.
- Space tubing 6 inches o.c. between the first two loops along the wall or walls with the greatest heat loss.
- Tie tubing every 3 feet or less with plastic tie wraps. Note: Never tie tubing anywhere within the end of a loop.
- Always use a vapor barrier under the slab. Note: Place the vapor barrier between the ground and insulation, if the latter is used under the slab.
- Place a vapor barrier between the soil and any insulation installed under the slab.
- Insulate under the slab if groundwater comes within 3 feet.
- Always install edge insulation along the foundation walls to prevent edgewise (horizontal) heat loss.

Whenever possible, follow the radiant heating system manufacturer's installation guidelines. The procedure described here for installing a hydronic radiant floor heating system (using PEX tubing) is offered as a general guideline. It may be outlined as follows:

1. Attach the manifold wall brackets to the wall.
2. Assemble the manifold (if it is not a factory-assembled unit) and clamp it into position on the wall brackets.
3. Mount a pipe bend support directly below the manifold to hold the supply pipe.
4. Connect the supply pipe to the manifold and lay out the pipe loop by following the layout plan.
5. Mount a pipe bend support below the manifold to hold the return pipe.
6. Create coil pattern.
7. Cut the return pipe and connect it to the manifold.
8. Mark or number the first loop for identification.
9. Check the length of the first loop against the layout plan by using the length markings on the outside of the pipe. A significant deviation in overall length between the layout plan and the installed pipe loop will require an adjustment of the loop balance settings.
10. Repeat steps 1 through 8 for the remaining loops in the system.

11. Close the supply, return, and shutoff valves on the first manifold.
12. Connect hoses to the end caps on the manifold.
13. Connect the end of one of the hoses to the main and the end of the other hose to a drain.
14. Open the end cap valves for filling and draining the system.
15. Open the supply and return valves on the manifold for the first loop.
16. Turn on the water and allow it to flow through the loop until all the air has been expelled. Purging the air from the system is a very important step. Air trapped in the loops will cause the system to operate inefficiently.

Note

If the water will not flow through the loop, the pipe may be buckled or crimped or there may be a blockage at the manifold connection. Check and repair before proceeding to the next step.

17. Repeat steps 10 through 15 until each loop in the heating system has been filled with water and any air trapped in the piping has been removed.
18. Open all the system valves and perform a pressure test (at 3 to 4 bar pressure). The pressure will drop during the first few hours and then remain stable if there are no leaks and the ambient temperature remains constant.
19. Install the floor covering (cement, carpet, tiles, and so on).
20. Close all the loop valves and open the shutoff valves.
21. Fill the boiler and the supply pipes with water, and purge the air. Open every valve and fixture (faucets and so on) in the system and continue purging until all the air trapped in the pipes has been pushed out of the lines and the water flows freely from the fixtures. Purge the air from the end caps at each end of the manifolds. In a structure with several floors, purge the air from the manifold located at the lowest level first.

Note

There must be shutoff valves on the manifolds to properly purge air from the loops.

22. Open all the loops in the heating system and check to make sure the air has been removed. If there is still air in the tubing, repeat steps 20 and 21 until all air has been removed.
23. Place the system under pressure by starting the boiler and circulator.

Servicing and Maintaining Hydronic Radiant Floor Heating Systems

Hydronic radiant floor heating systems require very little service and maintenance, but this does not mean they should be ignored. The following recommendations apply to all floor heating systems:

- Check the system pressure on a regular basis. An incorrect pressure reading may indicate air trapped in the system. An air pocket or bubble will block the flow of water and cause pressure readings outside the norm.
- Check the system for leakage. If the tubing is attached under the floor to the stud bottoms, access to the tubing or tubing connections to make repairs is relatively easy. If the tubing is embedded in cement above the subfloor, however, locating a leak is more difficult and expensive.
- Check to make sure there is enough water in the system. If not, it may need refilling.

If purging air, repairing leaks, and/or refilling the system with water does not result in maintaining the required pressure in the system, ask for a service call from a certified HVAC technician with experience in hydronic floor radiant heating systems.

Troubleshooting Hydronic Floor Radiant Heating Systems

Problems with hydronic floor radiant heating systems (see Table 1-1) will occur in the following areas:

1. Heating appliance (boiler, heat pump, or water heater)
2. Circulator (circulating pump)
3. Automatic controls
4. Tubing

Most of the troubleshooting and repair procedures for the various components of a hydronic floor radiant heating system have been described in considerable detail in other chapters. Use the volume index to locate those sources of information.

The first step when troubleshooting a radiant floor system is to check the controls. Turn the room thermostat on or off and wait for a few minutes for the system to respond. If the system responds by turning on or off within 2 or 3 minutes, the controls are not the problem.

Table 1-1 Troubleshooting Hydronic Floor Radiant Heating Systems

Symptom and Possible Cause	*Suggested Remedy*
Insufficient heat.	
(a) Slow initial response time.	(a) Normal for hydronic floor heating system.
(b) Insufficient heat generally occurring on design temperature day.	(b) Improper system design; add auxiliary heat.
(c) Boiler or other heat source problem.	(c) Check heat source for problem and correct.
(d) Defective floor sensor.	(d) Replace.
No heat.	
(a) Defective room thermostat and/or floor sensor.	(a) Replace thermostat and/or floor sensor.
(b) Boiler or other heat source problem.	(b) Check heat source for problem and correct.
(c) Defective circulator.	(c) Test; repair or replace.
Floor temperature too hot or too cold.	
(a) Defective mixing valve.	(a) Replace defective valve.
(b) Incorrect mixing valve setting.	(b) Adjust valve setting; change valve setting number according to specifications in manufacturer's installation manual.
(c) Defective outdoor air sensor.	(c) Test and replace.
Floor temperature too cold.	
(a) Boiler or other heat source problem.	(a) Check heat source for problem and correct.
(b) Circulator working against large system temperature drop; not moving enough water.	(b) Check temperature drop when system is warm; circulator is undersized if drop is found to be too large; correct as necessary.

Table 1-1 *(continued)*

Symptom and Possible Cause	***Suggested Remedy***
(c) Circulator working against small system temperature drop; water and floor temperatures almost equal, resulting in little heat transfer.	(c) Check temperature drop when system is warm; circulator is oversized if temperatures almost equal; increase floor temperature if less than 85°F to be too large.
Hot spot in floor.	
(a) Excessive high and concentrated temperatures in floor caused by tubing or tubing connection break.	(a) Locate break and repair.

Check the boiler, heat pump, or water heater for a problem. These appliances and their troubleshooting methods are described in Chapter 15 ("Steam and Hydronic Boilers") in Volume 1, Chapter 10 ("Heat Pumps") in Volume 2, and Chapter 4 ("Water Heaters") in Volume 2, respectively.

Note

Some heating systems have a thermometer installed in the circulation loop. The thermometer displays the temperature of the circulating water. A low fluid temperature displayed *while the circulator is operating* will indicate a problem with the boiler, heat pump, or water pump.

The troubleshooting and repair of circulators (water-circulating pumps) is covered in Chapter 10 ("Steam and Hydronic Line Controls") in Volume 2.

Problems requiring repairs or replacements of the manifolds or loops, especially embedded loops in wet installations, require the expertise of HVAC technicians experienced in the installation and maintenance of floor radiant heating systems.

Hydronic Radiant Heating Snow- and Ice-Melting Systems

Radiant systems used to melt snow and ice on driveways, sidewalks, and other outdoor surfaces are inexpensive to operate because they are used only when required. They begin to operate at a reduced output mode when the outdoor temperatures drop below a certain preset point and then switch to full operation when rain or snow reaches the surface.

The simplest form of control for snow-melting and ice-melting installations is a remote, manually operated on-off switch. The switch is commonly located inside the garage and operated only when required. Some snow- and ice-melting installations are operated by an automatic control system connected to a thermostat and a heating boiler, heat pump, or water heater.

Because the tubes carrying the heated water are located outdoors beneath the driveway surface, an antifreeze solution such as propylene glycol should be added to protect the system from freezing.

Electric Radiant Floor Heating

A number of manufacturers produce electric radiant floor heating systems for use in residential and light commercial construction. They are safe, relatively easy to install, and extremely energy efficient.

Note

> Electric radiant heating produces electromagnetic fields, and these EMFs may cause health problems. The potential health risk from EMFs can be minimized or even eliminated by (1) following the wiring and grounding methods recommended by the *National Electrical Code*; (2) purchasing and installing a radiant heating system that produces very low EMFs (some manufacturers claim zero EMFs for their systems); and (3) avoiding systems that produce EMFs higher than 2 mG at 2 feet.

Most of these electric radiant floor heating systems consist of a thin electric mat or roll applied to the subfloor where it is embedded in a thinset or self-leveling cement. Watts Radiant manufactures heating mats (HeatWeave UnderFloor mats) for installation between the floor joists under the subfloor.

System Components

An electric floor heating system in which electric heating mats or rolls are used will include some or all of the following components, depending on the system design:

1. Heating mats or rolls
2. Thermostat
3. Floor sensor
4. Ground fault circuit interrupter
5. Relay contactor
6. Timer
7. Dimmer switch

Heating Mats or Rolls

The electric mats or rolls used in electric floor radiant heating systems are made of coils of heat resistance wire joined to a supporting material. They are only ⅛ inch thick, which means they can be installed over the subfloor and under the floor covering without significantly raising the floor level (see Figure 1-33). The heating element of a constant-wattage electric heating cable or wire operates on 120 volts or 240 volts.

Electric heating mats or rolls are produced in a wide variety of sizes to fit different floor dimensions. Custom sizes can also be ordered from manufacturers to fit areas with curves, angles, and other nonstandard shapes.

An entire electric radiant floor heating system can be ordered from any one of the manufacturers listed in the sidebar. When ordering the materials for one of these heating systems, send them an installation layout plan listing the exact dimensions of the rooms or spaces to be heated. The plan may be for an entire house, an addition to a house, or a single room or space.

Note

> The manufacturer will cut the mats or rolls to the sizes listed in the installation plan. Once the mats or rolls are cut, they cannot be returned if a mistake is discovered unless it can be shown that the manufacturer was at fault.

The recommended heating capacity for electric resistance heating is specified by the building codes on a watt-per-square-foot-of-living-area basis. The electric heating mats or rolls are designed to draw 8 to 15 watts per square foot. Their operation is very similar to that of an electric blanket.

Manufacturers of Electric Radiant Heating Mats or Rolls

Flextherm, Inc.
2400, de la Province Street
Longueuil, Quebec J4G 1G1
Canada
450-442-9990
800-353-9843
www.flextherm.com

Heatway, Inc. (Watts Heatway, Inc.)
3131 W. Chestnut Express Way
Springfield, MO 65802
800-255-1996
www.heatway.com

(*continues*)

Manufacturers of Electric Radiant Heating Mats or Rolls (*continued*)

NuHeat Industries Ltd.
1689 Cliveden Ave.
Delta, BC V3M 6V5
Canada
800-778-9276
604-529-4400
www.nuheat.com

SunTouch Electric Floor Warming
A Division of Watts Radiant, Inc.
3131 W. Chestnut Expressway
Springfield, MO 65802
417-522-6128
www.suntouch.net

WarmlyYours, Inc.
1400 E. Lake Cook Road, Suite 140
Buffalo Grove, Illinois 60089
800-875-5285
www.WarmlyYours.com

Warmzone, Inc.
Salt Lake City, Utah
888-488-9276
801-994-8450
www.warmzone.com

Watts Radiant, Inc.
A Division of Watts Water Technologies, Inc.
31341 West Chestnut Expressway
Springfield, Missouri 65802
800-276-2419
978-688-1811
www.wattsradiant.com

Automatic Controls

The automatic controls of a typical electric radiant floor heating system consist of a thermostat, a GFCI safety breaker, and an optional timer. If a floor-heating thermostat is used instead of a room thermostat, the former is wired to a floor sensor that detects the actual floor temperature. A GFCI and a timer are integral components of a floor-warming thermostat.

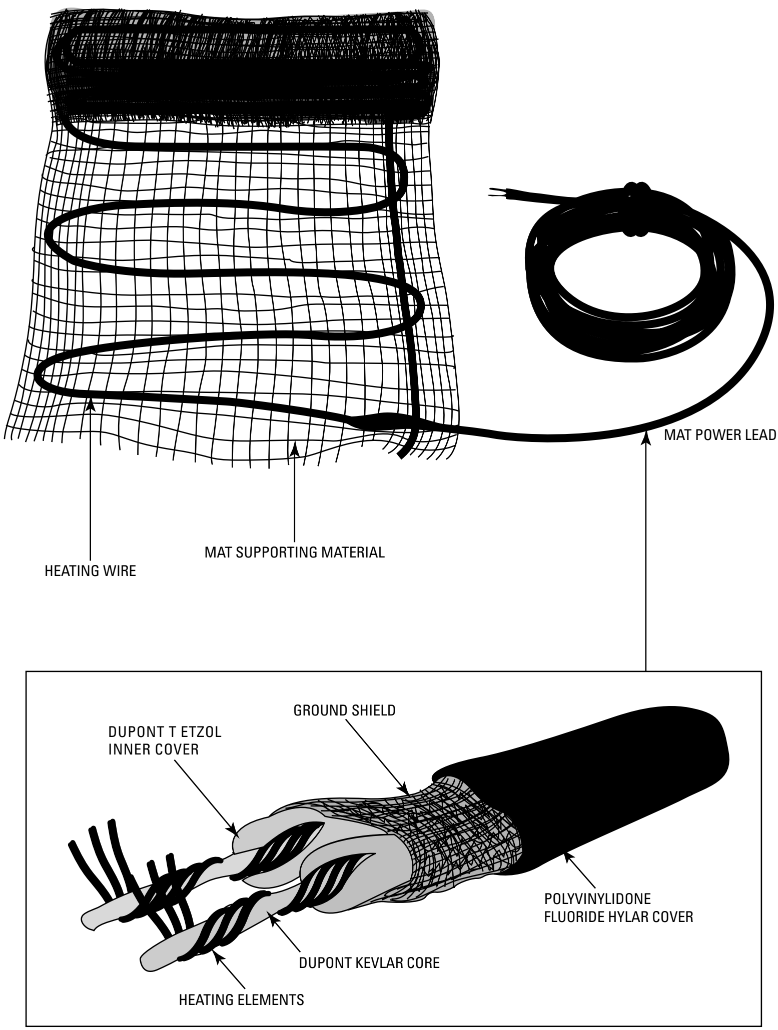


Figure 1-33 Construction details of a typical electric heating mat or roll. *(Courtesy Watts Radiant, Inc.)*

Thermostat

The *thermostat* is the controlling device for an electric radiant floor heating system. Most modern systems use a *programmable thermostat*, which contains an integral ground fault circuit interrupter (GFCI) and a manual high-low temperature setback switch (see Figure 1-34). A programmable thermostat is connected to an embedded floor sensor that monitors the floor temperature and transmits it to a digital display on the thermostat. A programmable thermostat can be programmed for four setting changes each day of the week.

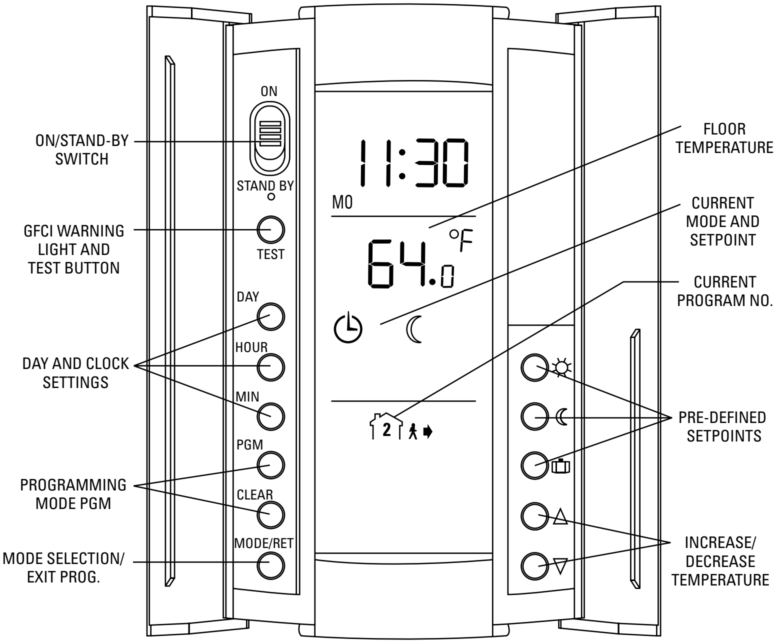


Figure 1-34 Programmable thermostat with digital display for an electric radiant floor heating system. *(Courtesy Watts Radiant, Inc.)*

Nonprogrammable thermostats are used commonly for small spot-warming areas. They are also equipped with a GFCI device.

Note

> Never exceed the maximum capacity of the thermostat to heat the floor. If additional power is required, zone with additional programmable thermostats or use a relay contactor.

Floor Sensor

A floor sensor is a temperature-monitoring device embedded in the floor and connected to a programmable thermostat. It should be installed in such a way as to give the truest floor temperature. Its installation will also be governed by the type of floor covering.

Many manufacturers will recommend the location of the floor sensor for the different types of floor coverings used with their floor sensor (see Figure 1-35).

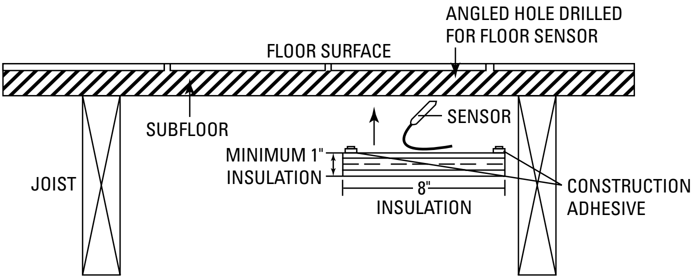


Figure 1-35 Floor sensor installed in angled hole drilled in the bottom of the subfloor. *(Courtesy Watts Radiant, Inc.)*

Ground Fault Circuit Interrupter

A *ground fault circuit interrupter* (GFCI) is used to monitor the flow of electricity through the heat resistance wire in the mat or roll for any loss of current. If a loss of current is detected, the GFCI immediately cuts off the electricity to the heating system. This is done to prevent damage to the heat resistance wire in the heating mat or roll. The GFCI is an integral part of a programmable thermostat.

An indicating-type GFCI circuit breaker may be installed to serve as a local disconnect. It should be installed near the end of the line close to the thermostat.

Relay Contactor

A *relay contactor* is a device used in conjunction with a single controller to operate the heating in large rooms or spaces. Both single- and double-relay contactors are used in heating systems.

Timer

A *timer* is an optional device used to control when the heating system is turned on and off. It can be used to program 14 events, or two on-off cycles per day for a 2-day or 5-day period. It also can be used in conjunction with a dimmer switch to regulate floor temperature. It cannot moderate the floor temperature.

Dimmer Switch

A *dimmer switch* is a device with an on-off button and a sliding manual control used in some systems to increase or decrease the floor temperature. It can be used in conjunction with a 7-day programmable timer to program a weekly period repetitively.

Installing Electric Heating Mats or Rolls

Electric heating mats or rolls must be installed in accordance with the manufacturer's instructions and any local codes or ordinances.

Before installing the heating mats or rolls, check the shipment to make sure the manufacturer has included everything. If the order is complete, remove the mats or rolls from their boxes and test the ohm resistance of each to make sure it has not been damaged during shipment.

Note

> This will be the first of three resistance tests. The second resistance test is performed after the mats have been secured to the subfloor, and the third after the floor covering has been applied over the mats.

To perform a resistance test, set a digital multimeter to the 200-ohms setting and connect the mat lead wires to the multimeter probes. Make sure the resistance reading is within the range of plus 10 percent to minus 5 percent of the resistance rating listed on the mat tag.

An insulation test should be performed to make sure there is no short or ground in the mat or roll. To conduct an insulation test, set the digital multimeter to the megohms setting and connect the silver braid (ground) and black lead to the multimeter probes. The multimeter should read "open" or "OL." Check the instructions with the multimeter to confirm which code represents the "open line." Repeat this test between the silver braid (ground) and the white lead wire.

Caution

> The installation of electrical heating systems involves some risk of fire and/or electrical shock that can result in injury or even death. With that in mind, only a qualified, certified electrician or someone with similar training and experience should connect the electric heating mats or rolls to the thermostat and the electrical circuit. Connections should be made in accordance with local codes and ordinances and the provisions in the latest edition of the *National Electrical Code*. The heating mats or rolls must be installed by a qualified contractor or homeowner before the connections to the electrical circuits and control device are made.

Installing Electric Mats or Rolls over Subfloors

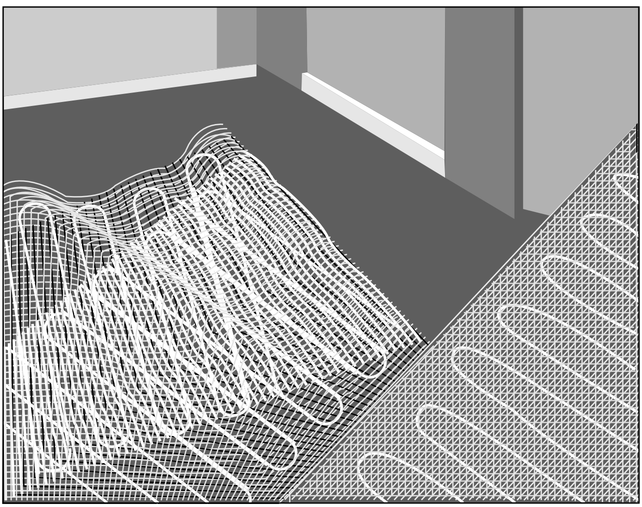
Keep a permanent record of the location of the mats or rolls and the floor sensor, if one is installed.

Note

> Do not install solid-based furniture, built-in cabinets, bookcases, room dividers, or plumbing fixtures over heating mats or rolls.

The procedure for installing electric heating mats or rolls over a subfloor may be outlined as follows:

1. Use the installation plan provided by the manufacturer to lay the mats or rolls out in the room. This dry run is done to make sure the mats or rolls cover the floor properly (see Figure 1-36).
2. Cut the supporting material (but *not* the heat resistance wire) and turn the mat or roll to fit the dimensions of the room (see Figure 1-37).



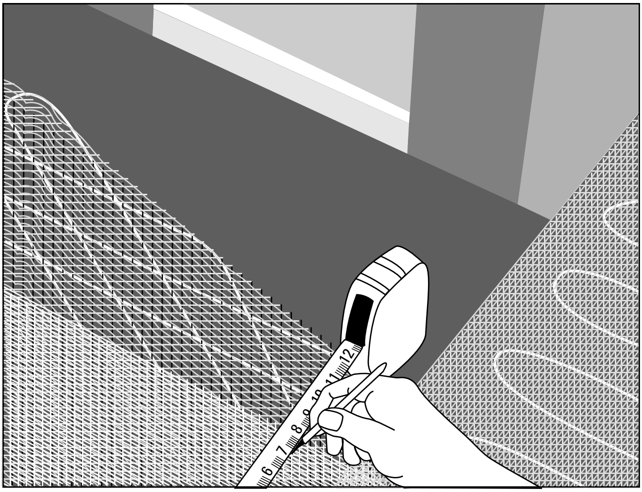
Step 1: Laying the mats on the floor.

Lay the mats out on the floor and "dry" fit them to the dimensions of the room according to the installation plan and the floor markings.

- **Do not walk on the heating elements (wires)**
- **Do not drop tools on the heating element (wire) or strike it with a hammer or tool.**
- **Place cardboard or carpet sections over the mat and the heating element to protect the latter from damage.**

Figure 1-36 Laying the mats or rolls out on the floor.

(Courtesy WarmlyYours.com, Inc.)



Step 2: Fitting the mats on the floor.

Fit the heating mats (rolls) one panel at a time. Cut and turn the mats according to the installation plan and the floor markings, and then modify the roll into successive and interconnected panels shaped to cover the planned area.

Figure 1-36 *(Continued)*

3. Glue the mat to the subfloor to prevent it from moving out of position.
4. Test the ohm resistance of each heating roll after it has been secured to the subfloor to make sure it wasn't damaged during installation. *This is the second resistance test.*
5. Cover the roll with a layer of thinset cement. Allow the thinset cement sufficient time to cure. Do *not* turn on the radiant heating system until the thinset cement has cured according to the recommended time on the packaging.
6. Consult the installation plan and mark the approximate location of the heating elements on the cement surface with chalk.
7. Cover the layer of thinset cement with the floor covering (tile, carpet, and so on). Note: Do not nail, screw, or staple near the heating elements and cold lead wires when installing the floor covering. Use the chalk lines as a guide.
8. Test the ohm resistance of the heating rolls to verify that they were not damaged when the floor covering was applied. *This is the third resistance test.*

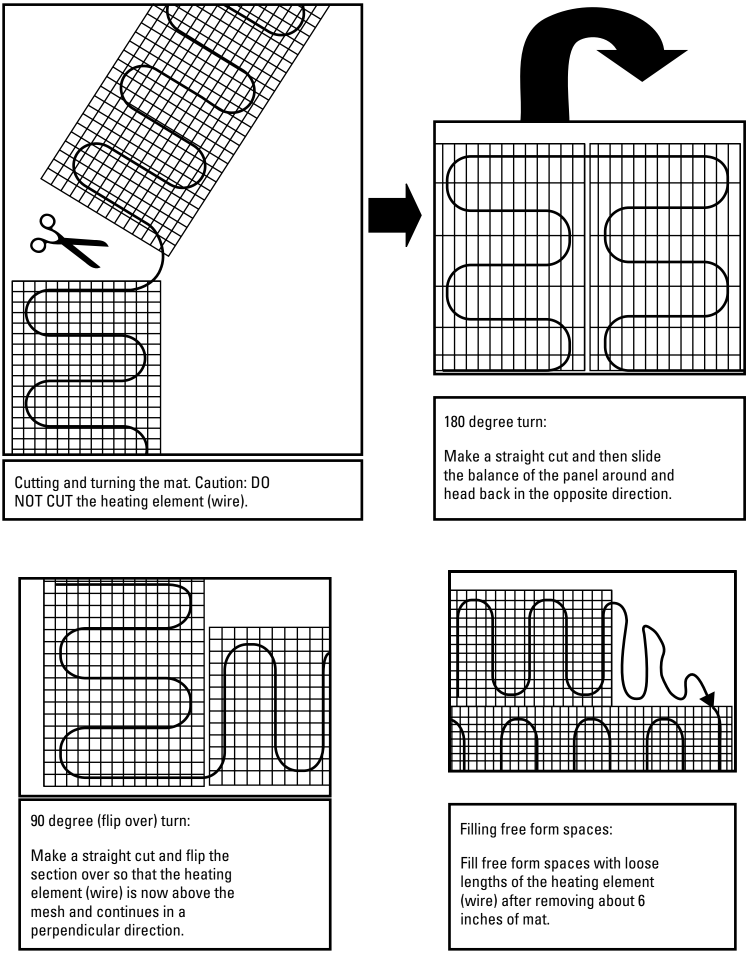


Figure 1-37 Turning the mat or roll to fit the dimensions of the room. *(Courtesy WarmlyYours.com, Inc.)*

9. Hardwire the electric mat or roll to the thermostat. This step should be done only by an electrician or an individual with the required experience of working with electrical systems.

Installing Electric Heating Mats or Rolls in Joist Cavities under Subfloors

Electric heating mats or rolls are also available for use in joist cavities beneath wood subfloors in residential and light commercial construction. The joists are spaced 16 inches on centers.

These mats or rolls may be jointed to fill larger spaces, but they must be wired in parallel (not in series) when joined together. The mats are rated either 120 VAC or 240 VAC. They are wide enough to fit into joist cavities with joists separated 16 inches on center.

The following installation steps are offered only as a guideline. Specific instructions can be obtained from the manufacturer and should be carefully followed.

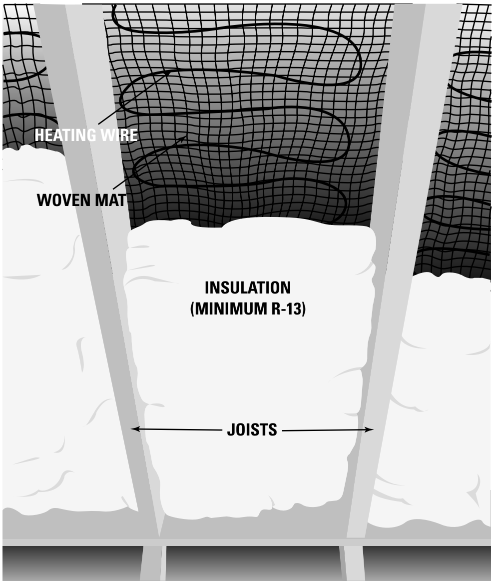
The procedure for applying electric radiant heating mats or rolls in joist cavities under subfloors may be outlined as follows:

1. Install the floor sensor.
2. Push a length of mat into the joist cavity so that it touches the bottom of the subfloor. The heating wires must be between the supporting mesh and the bottom of the subfloor.
3. Staple one edge of the supporting mesh to the side of the joist. Place the staples a minimum of ½ inch from the heating wire and ¾ inch down from the subfloor on the joist.
4. Push the other edge of the mat against the subfloor and nail the mesh to the joist surface. Use the same staple locations. Pull the mat snug against the subfloor as you staple the opposite edge to the joist. There will be a slight droop when you are finished. A gap of not more than 1 inch between the mat and the subfloor is acceptable (see Figure 1-38).
5. Cut the supporting mesh of the mat when it reaches the end of the joist cavity or some other blockage. Do *not* cut the heating wire. Pull the heating wire (without the mesh) down and across a notch cut into the bottom of the floor joist (see Figure 1-39). The notch must not exceed ¼ inch in depth and must be covered by a steel nailing plate. Avoid nicking or damaging the heating wire when nailing the plate to the bottom of the joist.

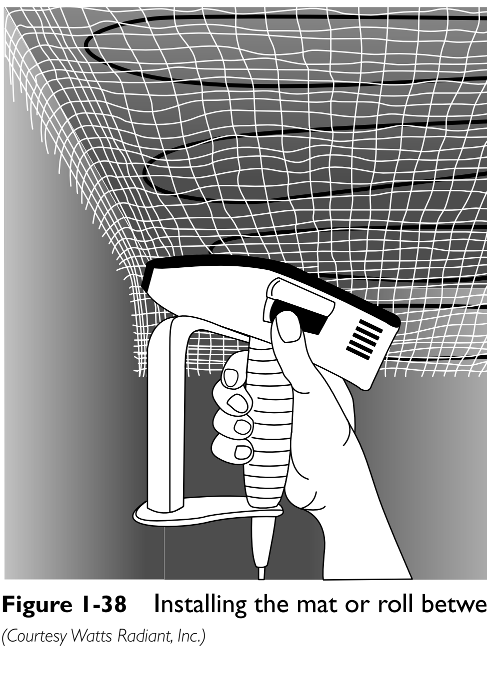
Note

Check the local building codes to see if notching the bottom of the joist for routing the heating wire is permitted. Some codes prohibit notching the joist. Notching the joist is allowed by the BOCA National Building Code (Section 2308.8.2 of the 2000 edition) in each of the one-third ends of a joist span (never in the middle one-third of the span).

6. If notching the joist is not permitted, drill a 2-inch diameter hole through the side of the joist and pull the heating wire *with its supporting mesh* through the hole. Cut away the mesh next to the hole after it has been pulled through.



Installation details



Stapling mat to side of floor joist

Figure 1-38 Installing the mat or roll between the joists.

(Courtesy Watts Radiant, Inc.)

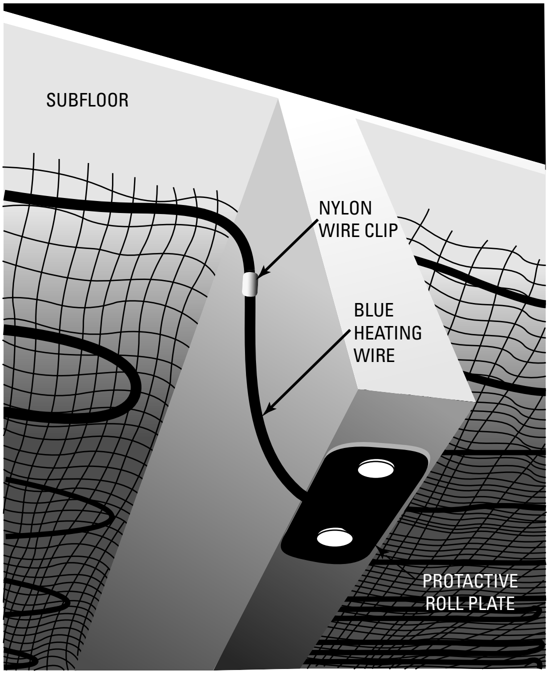


Figure 1-39 Extending a heating wire down and around a floor joist. *(Courtesy Watts Radiant, Inc.)*

7. If a second mat is required to finish out a room area, start the second mat flush with the end of the first mat and wire them in parallel (not series). Do not overlap the mats.
8. Connect the mat leads to the junction box in accordance with the provisions of the local building code or the latest edition of the *National Electrical Code*, if there is no applicable local code. Use additional electrical boxes where required. Connect the floor sensor and power supply.

Caution

Use an experienced and qualified electrician to make these electrical connections. There is always the possibility of severe shock injury, death, and/or property damage if the electrical work is done by inexperienced and unqualified workers.

9. After all the controls have been installed, energize the heating system briefly to see if it is operational.

10. If the system is operating properly, turn off the power and push foil-faced blanket or batt insulation (minimum R-13 rating) into the joist cavities. Leave a clearance of ½ inch to 1 inch between the mat or roll and the insulation (see Figure 1-40).
11. Seal the ends of the joist cavities by installing the last of the insulation vertically. Push the insulation up tight against the subfloor and staple it there so that no heat can escape through the band joists, rim joists, or the open end of a joist cavity.

Installing Electric Cable

Not all electric radiant floor heating systems use mats or rolls to produce the heat. Before mats or rolls became popular, floor systems consisted of coiled electric heating cables. The procedure for installing electric heating cables may be outlined as follows:

1. Make sure the power supply is shut off before beginning any work.
2. Begin the electrical rough-in work by installing the electrical box for the thermostat on the wall.
3. Pull the power supply cable into the thermostat electrical box.
4. Punch out the conduit holes on the box. The heating cable and thermostat sensor leads will be pulled through these electrical box holes later.
5. Lay the cable out on the floor according to the specified coil pattern.
6. Staple the electric cable to the floor through plastic strapping to prevent the coils from moving out of position.
7. Pull the cable and thermostat sensor leads through the punched out conduit holes in the electrical box.
8. Cover the cable with a thin coat of mortar.
9. Allow the mortar a day to dry and then apply the floor covering (for example, carpet, wood flooring).
10. Install the thermostat in the thermostat electrical box.
11. Connect to the power supply.

Note

Only a qualified HVAC technician or someone with an equivalent amount of work experience should be allowed to install an electrical radiant floor heating system. Electricity in inexperienced hands can cause serious injury and even death.

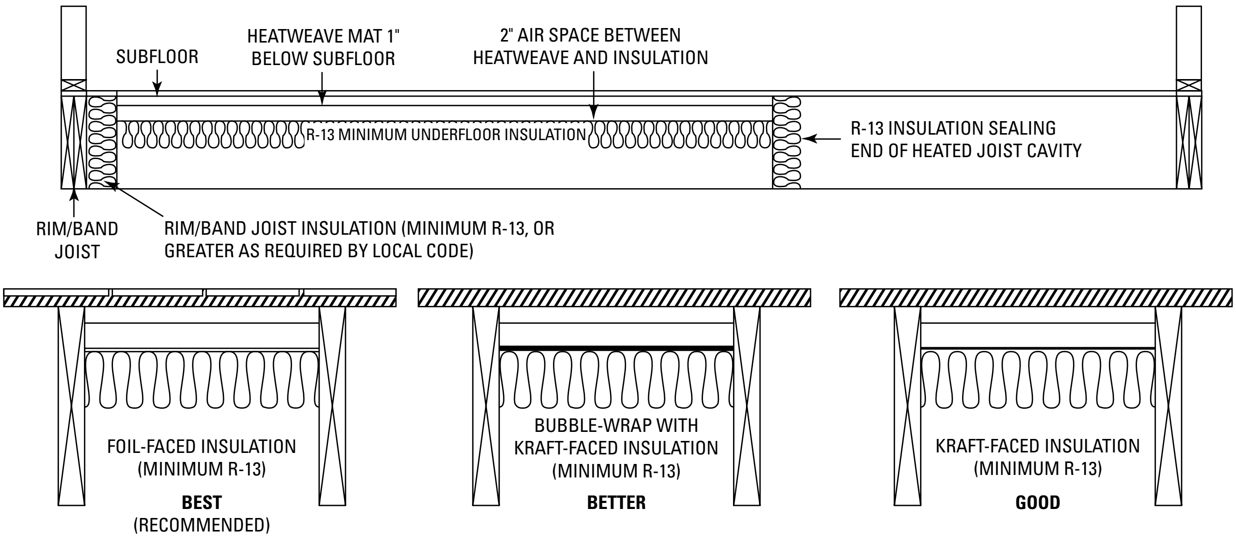


Figure 1-40 Installing insulation. *(Courtesy Watts Radiant, Inc.)*

Servicing and Maintaining an Electric Radiant Floor Heating System

There are no valves, fittings, or moving parts to service or repair in an electric radiant floor heating system. Consequently, there is no need for a maintenance schedule.

Note

Manufacturers provide repair kits with accompanying instructions for repairing mats or rolls damaged at the job site. They do not, however, warranty the repair or ensure proper function of the product following the repair because they have no means of controlling the repair work. Only a qualified electrician should make repairs to mats or rolls.

Caution

Before troubleshooting or repairing an electric heating system, make sure the power is turned off and the mat or roll is disconnected from the power source. Do not cut the heating wire with the mat or roll still connected to the power source.

Note

On rare occasions, a cable in a heating mat may break. When this occurs, it can be easily detected by using an instrument that functions as an underground fault detector. Repairing the break is simply a matter of locating it, removing the small section of floor above it, splicing the cable, and then replacing the flooring. As was already mentioned, the ground fault circuit interrupter is used to monitor electricity flow to determine if there has been any loss of current. If there has been a loss, the thermostat will cut off power to the heating system until the problem is located and corrected. The GFCI on a programmable thermostat should be tested immediately after installing the thermostat, and once a month after the initial test to make sure the GFCI is continuing to operate properly. Testing instructions are provided by the manufacturer of the programmable thermostat.

Troubleshooting Electric Radiant Floor Heating Systems

Caution

Never attempt to service or repair the electric controls inside an electric furnace cabinet unless you have the qualifications and experience to work with electricity. Potentially deadly high-voltage conditions exist inside these furnace cabinets. Refer to Table 1-2.

Table 1-2 Troubleshooting Electric Radiant Floor Heating Systems

Symptom and Possible Cause	***Suggested Remedy***
No heat.	
(a) Power may be off. Check fuse or circuit breaker panel for blown fuses or tripped breakers.	(a) Replace fuses or reset breakers. If the problem repeats itself, call an electrician or an HVAC technician.
(b) Check thermostat (programmable type) for dead batteries.	(b) Replace batteries and reset thermostat.
Not enough heat.	
(a) Thermostat set too low.	(a) Adjust setting. *Note:* Thermostats in electric heating systems must be set several degrees higher than the desired room temperature.
(b) Cables require time to heat.	(b) Allow the cables enough time to warm up before changing thermostat setting to a higher one.

Cooling for Hydronic Radiant Floor Systems

Hydronic radiant floor heating systems are capable of providing both heating and cooling independently of air movement. For the heating cycle, hot water is circulated through the pipe coils. For the cooling cycle, cold water (*above* the dew point) is circulated, and the heating cycle is reversed. By keeping the water temperature above 65°F, harmful moisture condensation is avoided.

Radiant panel cooling results only in the removal of sensible heat, and there is sometimes an uncomfortable feeling of dampness. As a result, a separate means of dehumidification is often necessary. Often this can be quite expensive because it may require the installation of a separate dehumidification unit and round flexible air ducts to the various rooms and spaces in the structure.

A common and effective method of cooling a structure equipped with a hydronic radiant floor heating system is to add forced-air cooling. There are several very efficient add-on cooling systems available

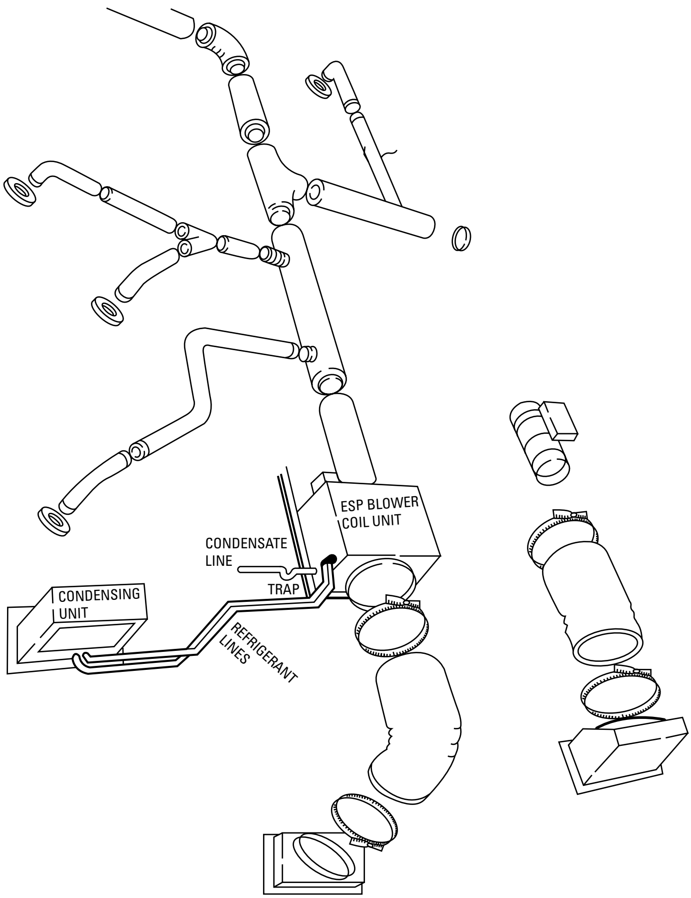


Figure 1-41 Space-Pak air distribution system.
(Courtesy Dunham-Bush, Inc.)

for use with radiant heating. One of the more commonly used ones is the Unico air-conditioning system (see Figure 1-41). It consists of one or more chillers to move the chilled water throughout the house. Air handlers transfer the cold air to the interior rooms and spaces. The cool air travels from the air handler to the rooms and spaces inside the structure through small, round, flexible ducts.

Chapter 2

Radiators, Convectors, and Unit Heaters

The two basic methods by which heat-emitting units transfer heat to their surroundings are (1) radiation and (2) convection. *Radiation* is the transmission of thermal energy by means of electromagnetic rays. In other words, an object is warmed by heat waves radiating from a hot surface. *Convection* is the transfer of heat by natural or forced movement (circulation) of the air across a hot surface. In actual practice, heat-emitting units will transfer heat partially by radiation (up to 30 percent) and partially by convection (70 to 90 percent).

The output of heat-emitting units is expressed in terms of Btu per hour (Btu/h), in square feet of equivalent direct radiation (EDR), or in 1000 Btu per hour (MB/h). The required radiation of an installation is determined on the basis of the Btu-per-hour capacity of each heat-emitting unit. See *Determining Required Radiation* in this chapter.

The selection of a heat-emitting unit will depend on the type of heating system, the cost, the required capacity, and the application. For example, electric unit heaters should be used only where the cost of electricity is especially low. These heaters are generally associated with high operating costs. On the other hand, they are relatively inexpensive, and their installation cost is low because no separate piping or boiler is required. Each type of heat-emitting unit will have similar advantages and disadvantages that you must carefully consider before choosing the type most suited for the installation.

The principal types of heat-emitting units used in heating systems are:

1. Radiators
2. Convectors
3. Baseboard heaters
4. Kickspace heaters
5. Floor and window recessed heaters
6. Unit heaters

Radiators

A *cast-iron radiator* is a heat-emitting unit that transmits a portion of its heat by radiation and the remainder by convection. An *exposed* radiator (or freestanding radiator) transmits approximately half of its heat by radiation, the exact amount depending on the size and number of the sections. The balance of the emission is by conduction to the air in contact with the heating surface, and the resulting circulation of the air warms by convection.

Cast-iron radiators have been manufactured in both column and tubular types (see Figures 2-1 and 2-2). Column and large-tube radiators (with 2½-inch spacing per section) have been discontinued. The small-tube radiator with spacings of 1¾ inches per section is now the prevailing type. Ratings for various cast-iron radiators are given in Tables 2-1, 2-2, and 2-3, courtesy of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

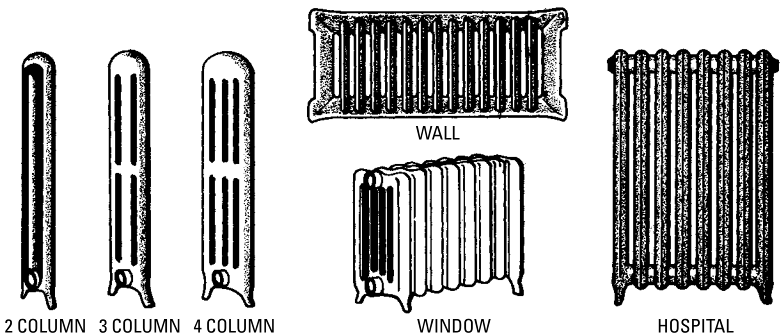


Figure 2-1 Various types of column cast-iron radiators.

As shown in Figure 2-1, each radiator section has 1¼-inch-diameter openings *located* at the top and bottom on each side. These openings (called *waterways* in hot-water radiators) are the passages through which the steam or hot water flows between the radiator sections. Round metal fittings are installed in these openings to join the sections together when forming a larger radiator module.

The radiators used in modern steam and hot-water heating systems are designed with nipples located in both the upper and lower portions of each radiator section, but this was not always the case with steam radiators. The earliest cast-iron steam radiators used in the old one-pipe steam heating systems were produced

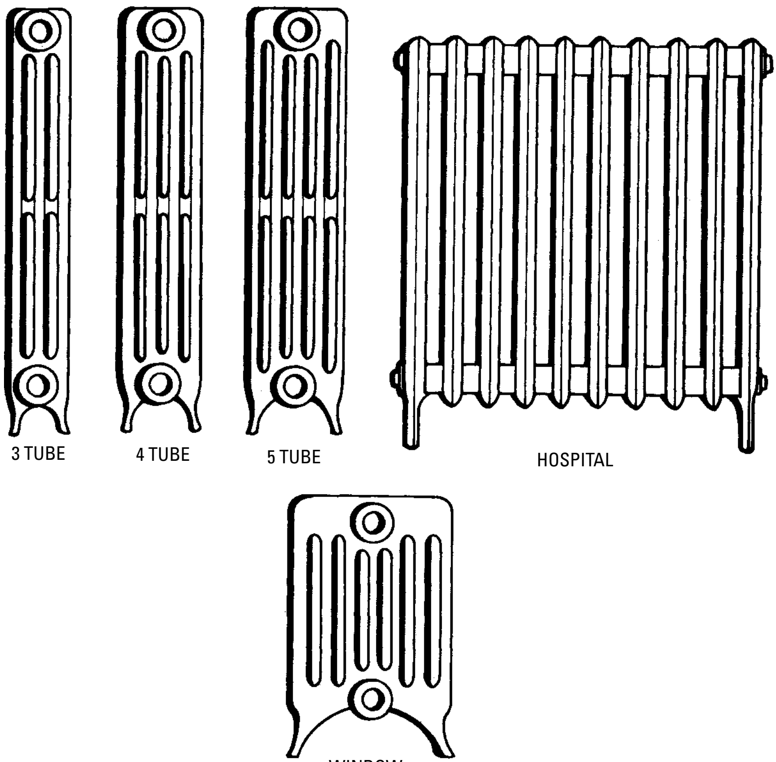


Figure 2-2 Various types of tubular cast-iron radiators.

with nipples located only in the bottom portion of each section. This was done because steam is light and rises quickly in the radiator, pushing air ahead of it. The air is expelled through an air vent located near the top of the radiator; the steam returns to the bottom of the same radiator section and then moves through the nipple to the adjoining section. Hot-water cast-iron radiators, on the other hand, require nipples at both the top and bottom of each section to improve water circulation. Hot water is heavier than steam and will not move as quickly without the assistance of two sets of nipples.

Wall and window radiators are cast-iron units designed for specific applications. Wall radiators are hung on the wall and are especially useful in installations where the floor must remain clear for cleaning or other purposes. They may consist of one or more

Table 2-1 Column-Type Cast-Iron Radiators

	*Generally Accepted Rating per Section**					
	One-Column		*Two-Column*		*Three-Column*	
Height (in)	*ft²*	*Btu/h*	*ft²*	*Btu/h*	*ft²*	*Btu/h*
15			1½	360		
18					2¼	540
20	1½	360	2	480		
22			2¼	540	3	720
23	1⅔	400	2⅓	560		
26	2	480	2⅔	640	3¾	900
32	2½	600	3⅓	800	4½	1080
38	3	720	4	960	5	1200
45			5	1200	6	1440
	Four-Column		*Five-Column*		*Six-Column*	
Height (in)	*ft²*	*Btu/h*	*ft²*	*Btu/h*	*ft²*	*Btu/h*
13					3	720
16					3¾	900
18	3	720	4⅔	1120	4½	1080
20					5	1200
22	4	960				
26	5	1200	7	1680		
32	6½	1560				
38	8	1920	10	2400		
45	10	2400				

**These ratings are based on steam at 215°F and air at 70°F. They apply only to installed radiators exposed in a normal manner, not to radiators installed behind enclosures, behind grilles, or under shelves.*
(Courtesy 1960 ASHRAE Guide)

flat wall radiator sections. Window radiators are located beneath a window on an exterior wall. The heat radiating from the surface of the unit provides a very effective barrier against drafts.

Radiator Efficiency

Radiator efficiency is an important operating characteristic of the heating system. The following recommendations are offered as a guide for obtaining higher radiator operating efficiency:

Table 2-2 Large-Tube Cast-Iron Radiators (sectional, cast-iron, tubular-type radiators of the large-tube pattern, that is, having tubes approximately 1⅜ inches in diameter, 2½ inches on centers)

Number of Tubes per Section	Catalog Rating per Section*		Height	Width	Section Center Spacing†	Leg Height‡ to Tapping
	ft^2	Btu/h	in	in	in	in
3	1¾	420	20	4⅝	2½	4½
	2	480	23		2½	4½
	2⅓	560	26		2½	4½
	3	720	32		2½	4½
	3½	840	38		2½	4½
4	2¼	540	20			
	2½	600	23		2½	4½
	2¾	660	26	6¼–6 13/15	2½	4½
	3½	840	32		2½	4½
	4¼	1020	38		2½	4½
5	2⅔	640	20		2½§	4½
	3	720	23		2½§	4½
	3½	840	26	9–8 9/18	2½§	4½
	4⅓	1040	32		2½§	4½
	5	1200	38		2½§	4½
6	3	720	20		2½	4½
	3½	840	23		2½	4½
	4	960	26	9–10⅜	2½	4½
	5	1200	32		2½	4½
	6	1440	38		2½	4½
7	2½	600	14		2½	3
	3	720	17	11⅜–12 13/16	2½	3
	3⅔	880	20		2½	3 or 4½

*These ratings are based on steam at 215°F and air at 70°F. They apply only to installed radiators exposed in a normal manner, not to radiators installed behind enclosures, behind grilles, or under shelves.

†Maximum assembly 60 sections. Length equals number of sections times 2½ in.

‡Where greater than standard leg heights are required, this dimension shall be 6 in, except for 7-tube sections, in heights from 13 to 20 in, inclusive, for which this dimension shall be 4½ in. Radiators may be furnished without legs.

§For five-tube hospital-type radiation, this dimension is 3 in.

(Courtesy 1960 ASHRAE Guide)

Table 2-3 Small-Tube Cast-Iron Radiators

Number of Tubes per Section	*Section Dimensions*						
	*Catalog Rating per Section**		*A Height‡*	*B Width*		*C Spacing†*	*D Leg Height‡*
				Min	*Max*		
	ft²	*Btu/h*	*in*	*in*	*in*	*in*	*in*
3§	1.6	384	25	3¼	3½	1¾	2½
4§	1.6	384	19	4 7/16	4 13/16	1¾	2½
	1.8	432	22	4 7/16	4 13/16	1¾	2½
	2.0	480	25	4 7/16	4 13/16	1¾	2½
5§	2.1	504	22	5⅝	6 5/16	1¾	2½
	2.4	576	25	5⅝	6 5/16	1¾	2½
6§	2.3	552	19	6 13/16	8	1¾	2½
	3.0	720	25	6 13/16	8	1¾	2½
	3.7	888	32	6 13/16	8	1¾	2½

**These ratings are based on steam at 215°F and air at 70°F. They apply only to installed radiators exposed in a normal manner, not to radiators installed behind enclosures, behind grilles, or under shelves.*

†Length equals number of sections times 1¾ in.

‡Overall height and leg height, as produced by some manufacturers, are 1 inch greater than shown in columns A and D. Radiators may be furnished without legs. Where greater than standard leg heights are required, this dimension shall be 4½ in.

§Or equal.

(Courtesy 1960 ASHRAE Guide)

1. A radiator *must* be level for efficient operation. Check it with a carpenter's level. Use wedges or shims to restore it to a level position.
2. Make sure the radiators have adequate air openings in the enclosure or cover. The openings must cover at least 40 percent of the total surface of the unit.
3. Unpainted radiators give off more heat than painted ones. If the radiator is painted, strip the paint from the front, top, and sides. The radiator will produce 10 to 15 percent more heat at a lower cost.
4. Check the radiator air valve. If it is clogged, the amount of heat given off by the radiator will be reduced. Instructions for cleaning air valves are given in *Troubleshooting Radiators* in this chapter.
5. Radiators must be properly vented. This is particularly true of radiators located at the end of long supply mains. Instructions

for venting radiators are given in *Vents and Venting* in this chapter.

6. Never block a radiator with furniture or drapes. Nothing should block or impede the flow of heat from the radiator.
7. Placing sheet metal or aluminum foil against the wall behind the radiator will reflect heat into the room.

Radiator Heat Output

The heat output of a cast-iron radiator is determined by the following factors:

- Ambient temperature (that is, the temperature of the air surrounding the radiator). The ambient temperature is assumed to be 70°F for purposes of sizing estimates.
- Temperature of the radiator surface. The surface temperature will depend on the temperature of the steam or hot water circulating through the radiator sections. Steam is always hotter than hot water.
- Surface area of the radiator. Repeated tests have shown that the amount of heat given off by ordinary cast-iron radiators per degree difference in temperature between the steam (or water) in the radiator and the surrounding air is about 1.6 Btu per square foot of heating surface per hour.

A relative radiating surface of a radiator is measured in terms of the square feet of equivalent direct radiation (EDR). A cast-iron radiator will give off heat at the rate of 240 Btu per hour when supplied with steam at 2½ lbs of pressure (220°F) with a surrounding air temperature of 70°F. It is determined as follows:

$(220 - 70) \times 1.6 = 240$ Btu

One square foot of steam radiation equals 1.6 square feet of hot-water radiation or 1.4 square inches of warm-air pipe area. Tables 2-1, 2-2, and 2-3 list the heating surfaces for various column and tubular cast-iron radiators.

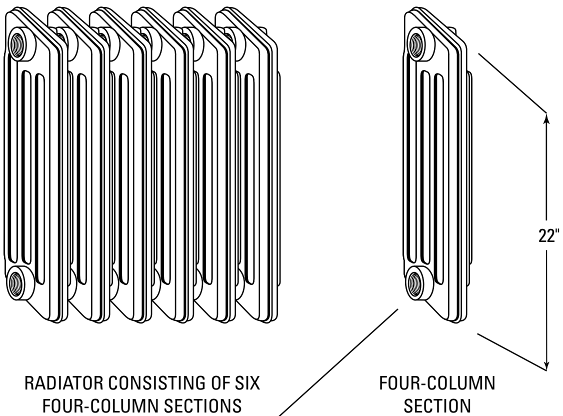
The cast-iron radiators in hot-water heating systems deliver water at a temperature of no more than 180°F. As a rule, a square-foot EDR for a hot-water cast-iron radiator will emit 170 Btu per hour.

There is no IBR code covering recessed radiation. As a result, manufacturers of recessed heat-emitting units must rate and certify their own product. The Weil-McLain Company is typical of these manufacturers. Its certified ratings are determined from a series of tests conducted in accordance with the IBR Testing and Rating Code for

Baseboard Type Radiation whenever the provisions of the code should be applied. The Weil-McLain ratings include a 15 percent addition for heating effect and barometric pressure correction factor allowed by the IBR code. Other manufacturers use similar rating methods.

Sizing Radiators

To size a column-type or tube-type cast-iron radiator, first measure its height in inches and then count the number of sections and the number of tubes or columns in each section (see Figure 2-3). The



			18"	20"	22"	23"	26"	30"	32"	36"	38"	45"
3 Tubes				1.72		2.00	2.33	3.00		3.50	3.50	
4 Tubes				2.25		2.50	2.75		3.50	4.25		
5 Tubes				2.67		3.00	3.50	4.33	4.33	5.00	6.00	
6 Tubes				3.00		3.50	4.00		5.00			
7 Tubes	2.60	3.50		4.20			4.75					
1 Column				1.50		1.67	2.00		2.50		3.00	
2 Cols.				2.00		2.33	2.67		3.33		4.00	5.00
3 Cols.			2.25		3.00		3.75		4.50		5.00	6.00
4 Cols.			3.00		4.00		5.00		6.50		8.00	10.0
5 Cols.	3.00	3.75	4.50	5.00		6.30	7.00		8.50		10.0	

1. Find the Sq. Ft. EDR per section above (4.00).
2. Multiply by the number of sections altogether in that radiator to get Sq. Ft. EDR for the entire radiator ($4.00 \times 6 = 24$ Sq. Ft. EDR).
3. Multiply by 240 BTUs per hour to get the steam design output or Multiple by 170 BTUs per hour to get the hot water design output.

Figure 2-3 Sizing cast-iron radiators. *(Courtesy John D. Howell [hydronics.com])* sections are the divisions or separations of a cast-iron radiator as seen when standing directly in front of it. When you look at the radiator from its narrow end, you can see that each section consists of one or more vertical columns or pipes.

Note

These vertical columns or pipes (they are called *columns* in the traditional cast-iron radiators) are 2½ inches wide. In newer radiators, they are called *tubes* and are only 1½ inches wide.

Find the square-foot EDR (equivalent direct radiation) of one section of the radiator. Multiply that figure by the number of sections in the radiator module to arrive at the square-foot EDR rating of that radiator. Multiply the square-foot EDR rating by 240 Btu per hour to obtain the heating capacity of that radiator in a steam heating system or by 170 Btu per hour for its heating capacity in a hot-water heating system.

Installing Radiators

A cast-iron radiator is constructed by joining together a number of individual sections (see Figure 2-4). The number of sections used depends on the heating requirements for the room or space. For purposes of on-site handling, these radiators are supplied up to a

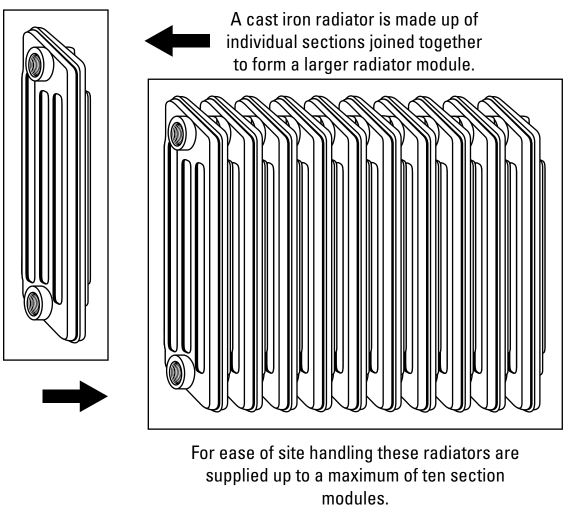


Figure 2-4 Joining together radiator sections.

(Courtesy John D. Howell [hydronics.com])

maximum of 10 section modules. Additional sections can be joined together on site to form longer radiators (see Figure 2-5). The procedure used to join the sections will depend on whether the nipples are threaded or smooth and beveled.

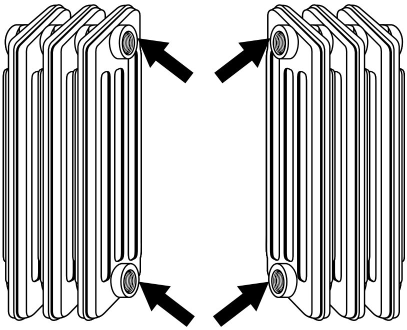


Figure 2-5 Forming longer radiators on-site.

(Courtesy John D. Howell [hydronics.com])

Joining Threaded Radiator Sections

In older cast-iron radiators, each section has a pair of 1¼-inch-diameter threaded openings. One pair of openings has left-handed threads, and the opposite pair on the facing section has right-handed threads (see Figure 2-6).

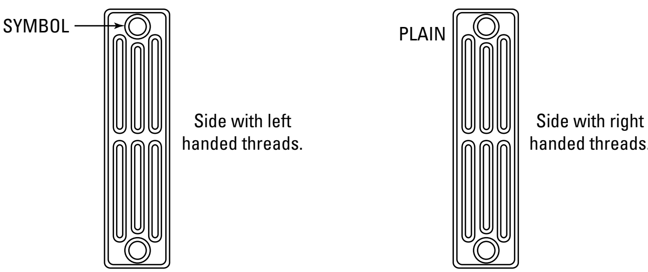


Figure 2-6 Left-handed and right-handed threaded waterways.

(Courtesy John D. Howell [hydronics.com]).

To join the radiator sections together, connect the openings threads with left- and right-handed threaded nipples and joining gaskets. Proceed as follows:

1. Clean the gasket seating areas of the four waterway openings with abrasive cloth (*not* a file) to ensure that they are free of paint, dirt, and any other contaminants that would interfere with the joining of the two radiator section surfaces (see Figure 2-7).

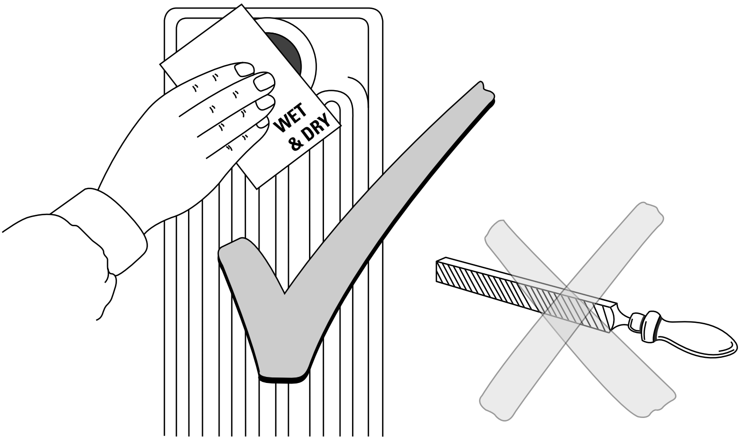


Figure 2-7 Cleaning gasket seating area around waterway opening on radiator section. *(Courtesy John D. Howell [hydronics.com])*

2. Align the sections accurately. Make sure that the end sections being joined together have opposite threads—in other words, left-handed threads on one section facing right-handed threads on the other.

Note

Sections with an **O** symbol positioned on the top left-hand side are left-handed threads. Sections with no symbol have right-handed threads. This holds true for all models except 6/58, which is the reverse. The side with a symbol on it has right-handed threads, and the plain side has left-handed threads.

3. Make sure the top and bottom seams on the cast-iron radiator sections match. The top seams are commonly smoother than the bottom ones.
4. Screw the nipples into the first pair of threads by turning only one turn each (see Figure 2-8).
5. Place a jointing gasket over each nipple.

Warning

Do not use jointing compound or PFT tape when jointing gaskets and nipples. Doing so will invalidate the radiator manufacturer's guarantee.

6. Using the largest radiator section as a base unit, add smaller sections to it by carefully aligning and mating the opposing waterways and protruding nipples (see Figure 2-9).

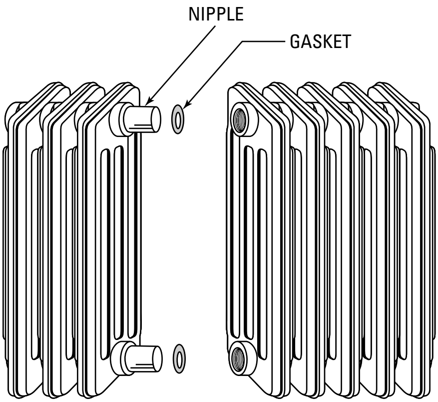


Figure 2-8 Installing nipples and gaskets.

(Courtesy John D. Howell [hydronics.com])

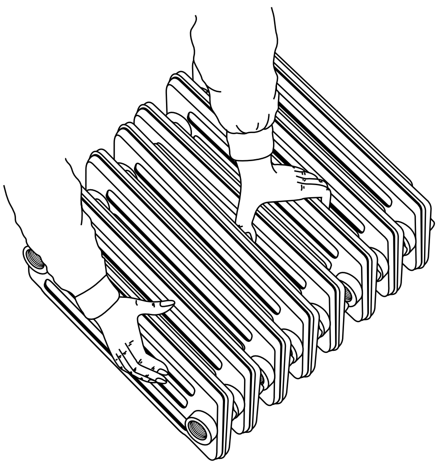


Figure 2-9 Adding smaller sections to a larger base unit.

(Courtesy John D. Howell [hydronics.com])

7. Determine the insertion depth of the joining key by measuring it along the top of the radiator from the position of the new joint to the point where it will project from the base unit waterway. Mark this point on the joining key shaft (see Figure 2-10).
8. Insert the joining key through one of the waterways of the second section (see Figure 2-11). Applying slight pressure, pull the two sections together with one hand and begin to turn the joining key with the other hand until they begin to join together. Stop when both are engaged.

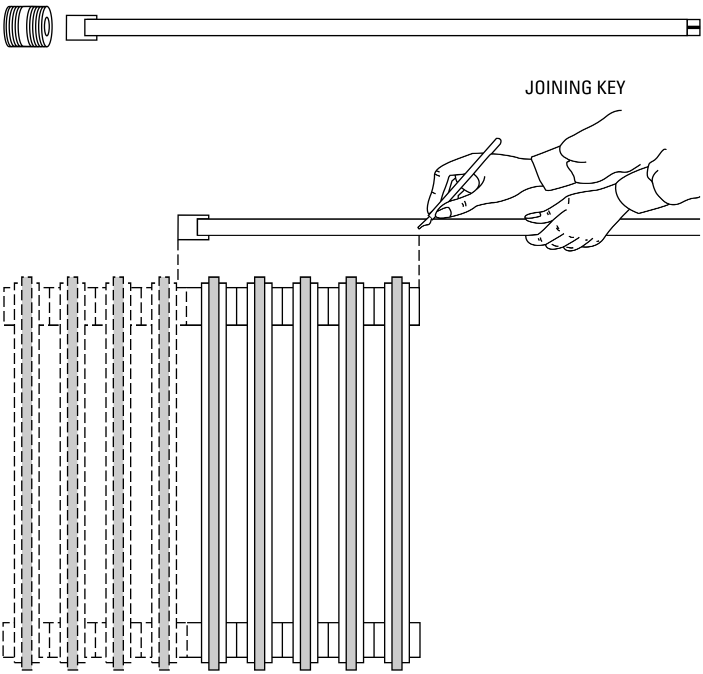


Figure 2-10 Measuring the insertion depth with the joining key.
(Courtesy John D. Howell [hydronics.com])

Note

Use a wood block under the joining key to keep it in line. Doing so will ensure that the waterway threads are not damaged by the key shaft.

9. Repeat step 8 by inserting the joining key through the second waterway (each radiator section has a waterway at the top and bottom). Alternate between both waterways a few turns at a time until the end sections meet and the nipples are hand-tight. Do *not* fully tighten yet.
10. Make a final check to ensure that both radiator sections are uniformly aligned, and then fully tighten them to a recommended torque of 140–150 lbs/ft (see Figure 2-12). Do *not* over-tighten or you may strip the threads.
11. Add additional radiator sections by following the same procedures previously described. When the required number of sections

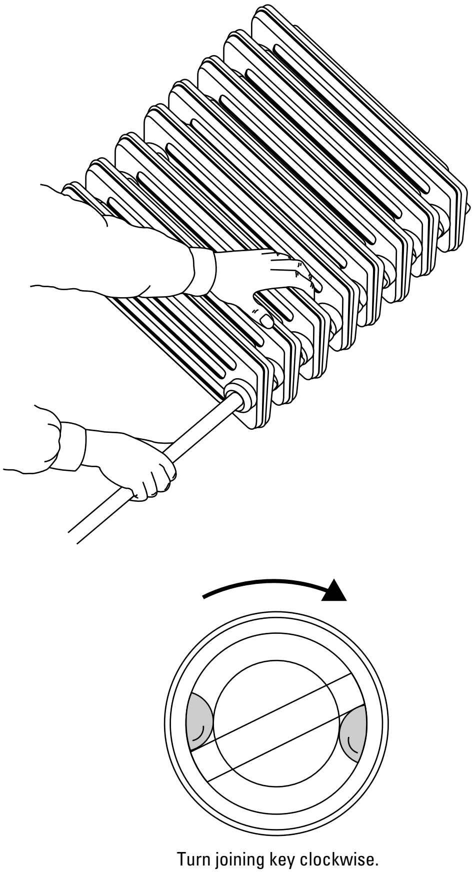


Figure 2-11 Inserting the joining key. *(Courtesy John D. Howell [hydronics.com])*

have been added, lift and carry the completed radiator in the upright position to the installation point. Do not carry it on its side because doing so will place stress on the joints.

Note

Site assembly following the aforementioned procedures should produce a radiator capable of reaching a test pressure of 140 psi.

Remove radiator sections by reversing the aforementioned installation steps. Before attempting to unscrew the nipples with the joining key, look through the waterways for the rough or smooth side of the

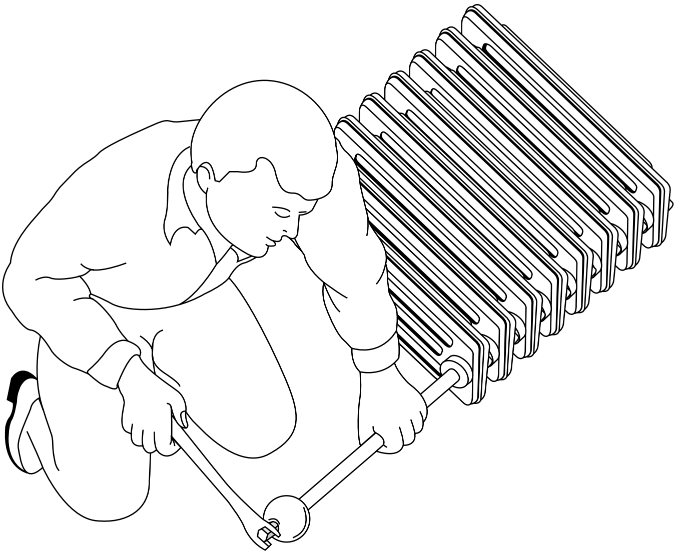


Figure 2-12 Tightening the sections to the required torque.
(Courtesy John D. Howell [hydronics.com])

nipples. If the rough side is visible, turn the joining key counterclockwise. If the smooth side is visible, turn it clockwise (see Figure 2-13).

Joining Radiator Sections with Smooth Beveled Nipples

Modern radiators have threadless push nipples instead of threaded ones. A push nipple is a short, smooth, beveled pipe. The bevel creates a bulge in the middle of the nipple. When the nipple is pushed into the opening in the radiator section, the bulge creates a tight

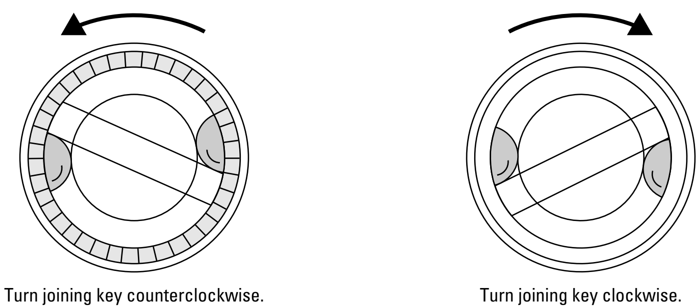


Figure 2-13 Turning the joining key counterclockwise or clockwise as required. *(Courtesy John D. Howell [hydronics.com])*

seal. Push nipples have replaced threaded nipples in radiators because the latter are almost impossible to remove after years of use. Corrosion on the threads causes a weld-like seal to form, making it very difficult to disassemble the radiator.

Radiator Valves

Various valves are required for the efficient operation of radiators. These valves (or *vents*) are used to bleed air from the radiator when the heating system first starts. The choice of valve will depend on the requirements of the particular system.

The four principal functions provided by valves operating in conjunction with radiators are as follows:

1. Admission and throttling of the steam or hot-water supply.
2. Expulsion of the air liberated on condensation.
3. Expulsion of air from spaces being filled by steam or hot water.
4. Expulsion of the condensation.

Radiator valves (packed or packless), manual or automatic air valves, and thermostatic expulsion valves (traps) are used to perform the aforementioned functions.

The packed-type radiator valve is an ordinary low-pressure steam valve that has a stuffing box and a fibrous packing to prevent leakage around the stem (see Figure 2-14). The objection to this type of valve is the frequent need for adjustment and renewal of the packing to keep the joint tight. These valves also require many turns of the stem to fully open.

The packless radiator valve is one that has no packing of any kind. Sealing is obtained by means of a diaphragm (see Figure 2-15) or a bellows (see Figure 2-16). On each valve, there is no connection between the actuating element (stem and screw) and the valve being sealed hermetically; hence, there can be no leakage. With the diaphragm arrangement, a spring is used to open the valve. With bellows construction, there is no spring; a shoulder on the end of the stem works in a bearing on the valve inside the bellows.

Some so-called packless radiator valves actually employ spring discs to secure a tight joint. Although called packless, the spring discs form a metallic equivalent of packing.

Both manual and automatic air valves are used to remove air from radiators. The manual valves are not well adapted for this function because they usually receive only irregular attention. Air is

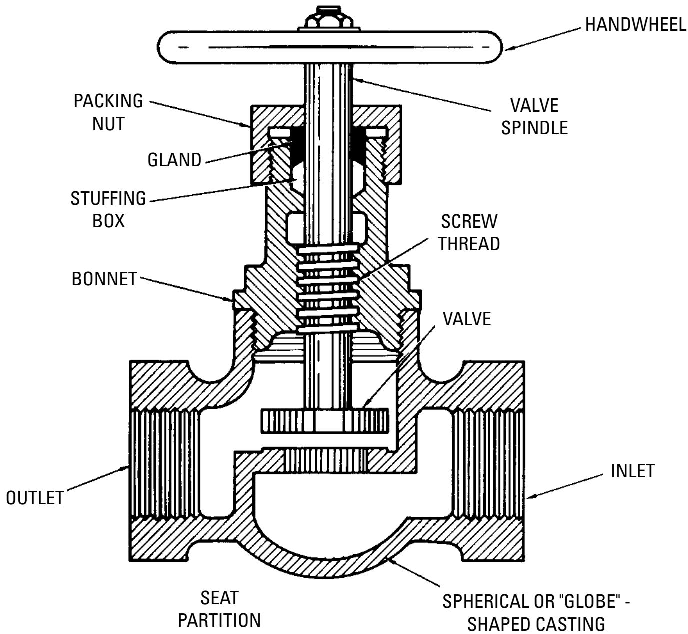


Figure 2-14 Typical packed radiator valve.

constantly forming in the radiator and should be removed as it forms. After the air valve remains closed for some time, the radiator gradually fills with air (or becomes air bound), as shown in Figure 2-17, with the air at the bottom and the steam at the top. On opening the valve (see Figure 2-18), the air is pushed out by the incoming steam. The radiator is gradually filled with steam until it begins to come out of the air valve (see Figure 2-19). At this point, the air valve should be closed.

An *automatic air valve* is one form of the thermostatic valve (see Figure 2-20). Automatic operation is made possible by a bimetallic element contained in the valve. The principles generally employed to secure automatic action are as follows:

1. Expansion and contraction of metals.
2. Expansion and contraction of liquids.
3. Buoyancy of flotation.
4. Air expansion.

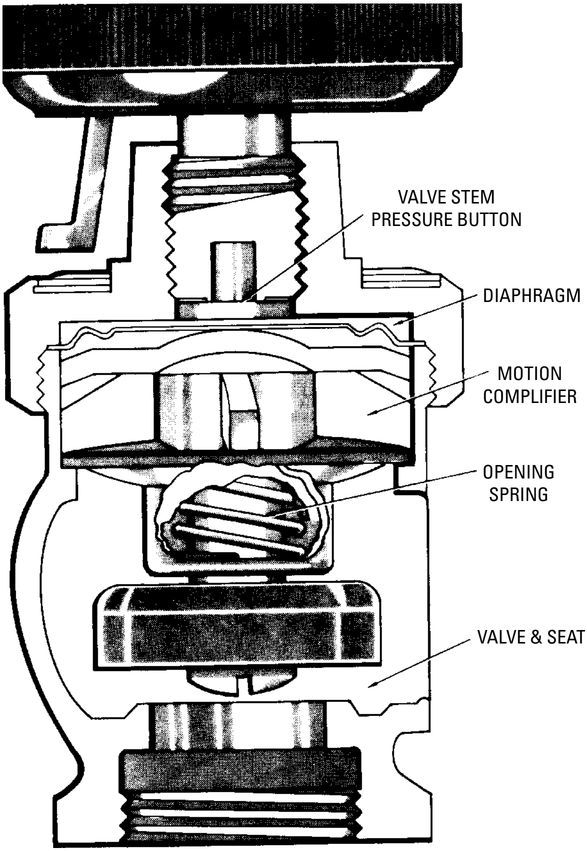


Figure 2-15 Diaphragm-type packless radiator valve. *(Courtesy Trane Co.)*

When the relatively cold air passes through the valve, the metal strips lie in contracted position (with legs close together and the valve open), allowing air to escape (see Figure 2-21). The steam then enters the valve, and its higher temperature causes the metal strips in the bimetallic element to expand. The brass strip expands more than the iron strip, which causes the end containing the valve spindle to rise and close (see Figure 2-22). When the strips are fully expanded, the

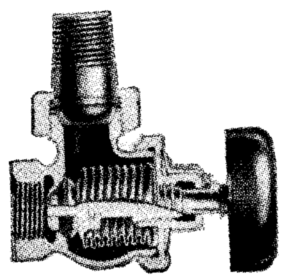


Figure 2-16 Bellows-type packless radiator valve. *(Courtesy Sarco Co.)*

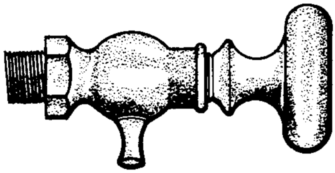


Figure 2-17 Air-bound radiator.

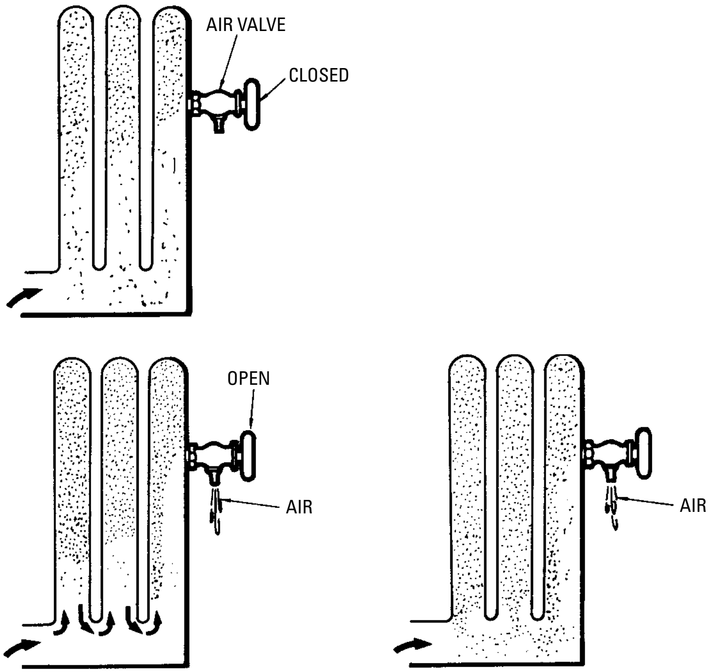


Figure 2-18 Air is pushed out by incoming steam.

valve is closed, shutting off the escape of steam (see Figure 2-23). In case the radiator becomes flooded with water, the additional water entering will cause the float to push up the valve and prevent the escape of water (see Figure 2-24).

Because an automatic air valve is used only for expelling air from a radiator, it should be distinguished from a thermostatic expulsion valve. A *thermostatic expulsion valve* opens to air and condensation and closes to steam. The low temperature of the air and condensation causes the bimetallic element to contract and

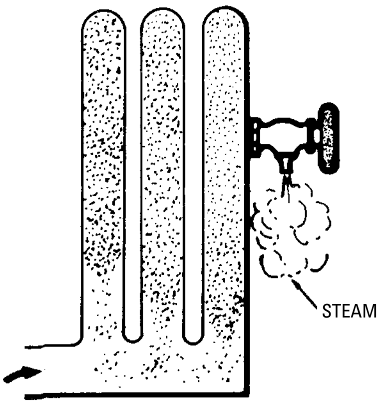


Figure 2-19 Steam escaping from air valve.

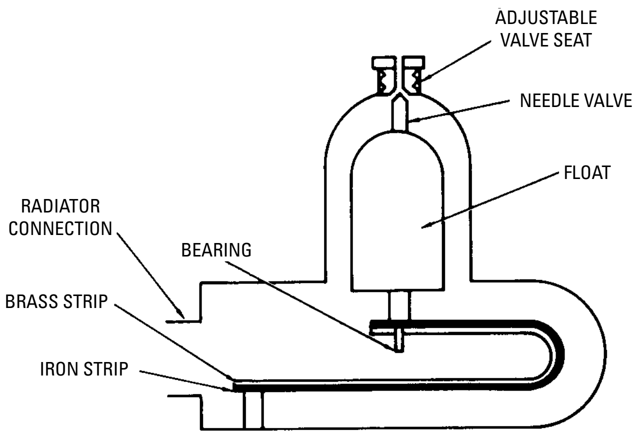


Figure 2-20 Working components of an automatic air valve.

open the valve, whereas the relatively high temperature of the steam causes the element to expand and close the valve.

Although a thermostatic expulsion valve is sometimes referred to as a trap, this term is more correctly used to indicate a larger unit not connected to a radiator and having the capacity to drain condensation from large mains. As distinguished from the thermostatic valve, a trap handles only condensation and not air.

A bellows charged with a liquid is used on some of the thermostatic valves as an actuating element instead of the bimetallic device.

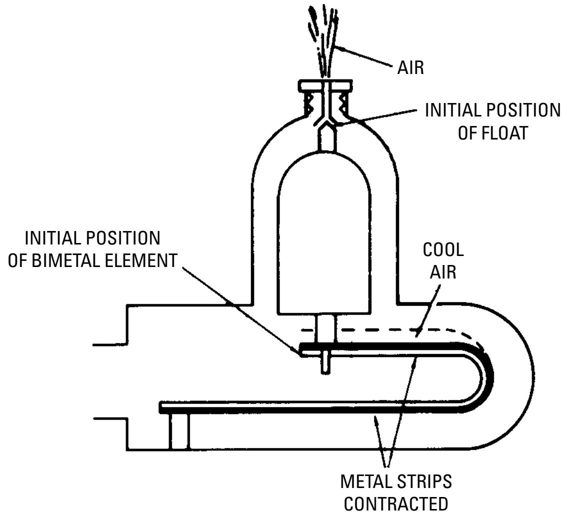


Figure 2-21 Bimetal strips contracted and valve open.

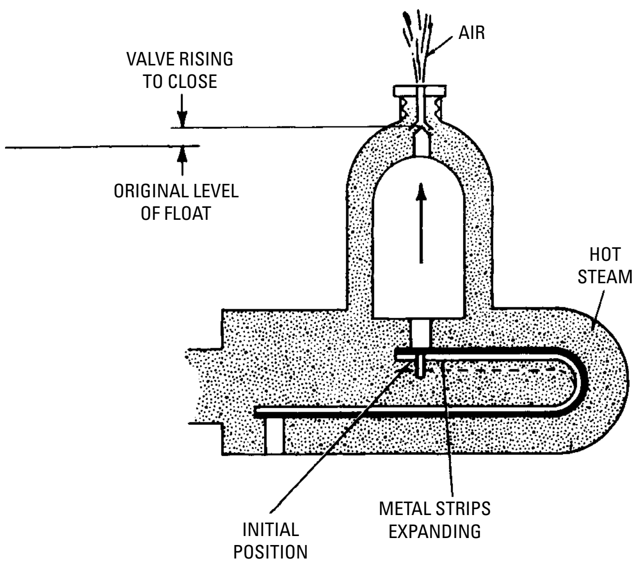


Figure 2-22 Bimetal strips expanding.

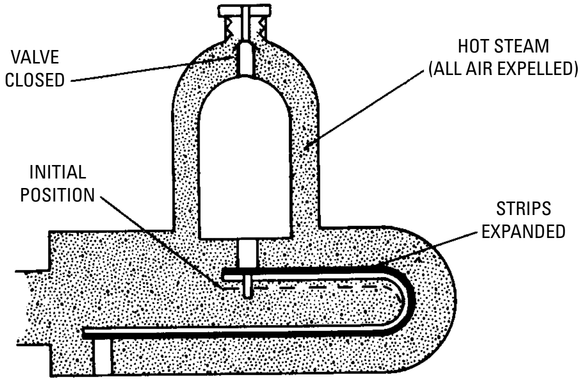


Figure 2-23 Bimetal strips fully expanded and valve closed.

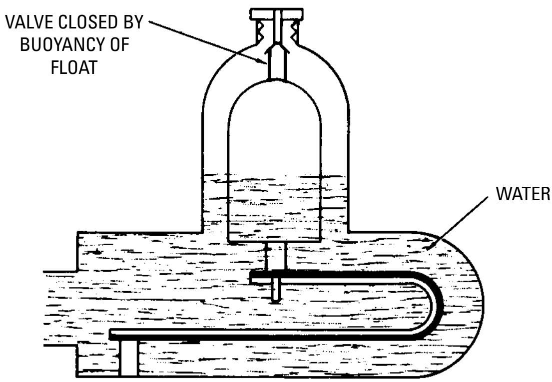


Figure 2-24 Valve closed by buoyancy of float.

The operating principle of a Trane bellows-type thermostatic valve is illustrated in Figures 2-25, 2-26, 2-27, and 2-28.

Additional information about valves and valve operating principles is contained in Chapter 9 of Volume 2 ("Valves and Valve Installation").

Radiator Piping Connections

Some typical radiator piping connections are shown in Figures 2-29, 2-30, 2-31, 2-32, and 2-33. The important thing to remember when connecting a radiator is to allow for movement of the risers

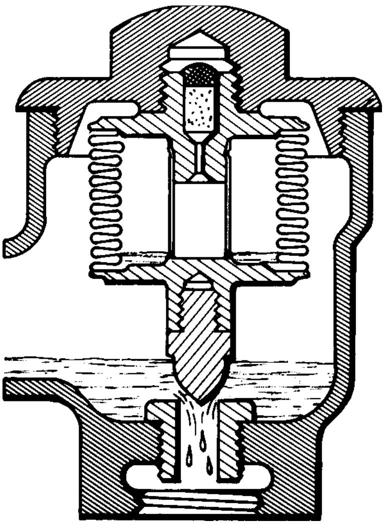


Figure 2-25 Condensate being discharged from heating unit.

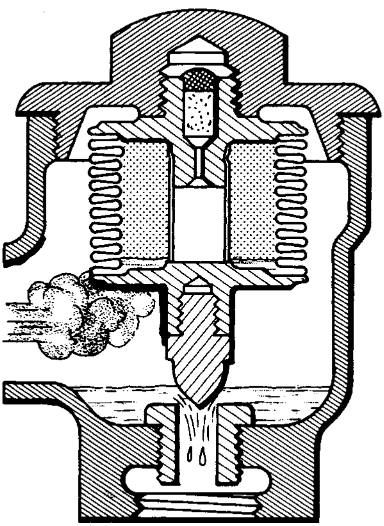


Figure 2-26 Steam enters trap. Pressure within the bellows increases and causes it to expand.

and runouts. This movement is caused by the expansion and contraction resulting from temperature changes in the piping.

Vents and Venting

Each volume of water contains a small percentage of air at atmospheric pressure mechanically mixed with it. This air is liberated

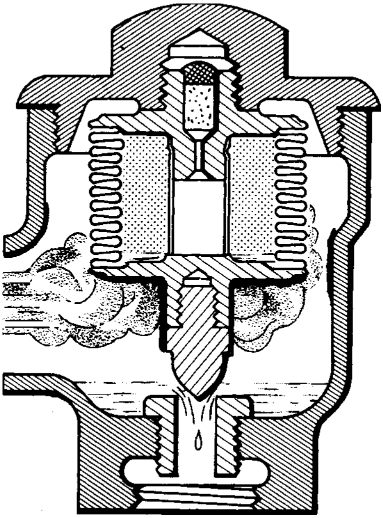


Figure 2-27 All condensate is drained from unit.

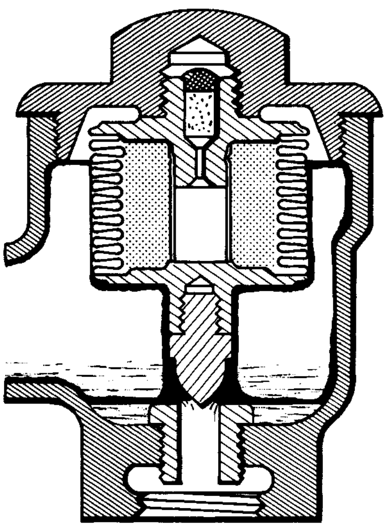


Figure 2-28 Steam completely surrounds the bellows.

during vaporization and causes some problems for the circulation of steam in the system. As steam starts to fill a heating system, it can enter the radiators, convectors, or baseboard units only as fast as the air escapes. For this reason, some means must be provided to vent this air from the system.

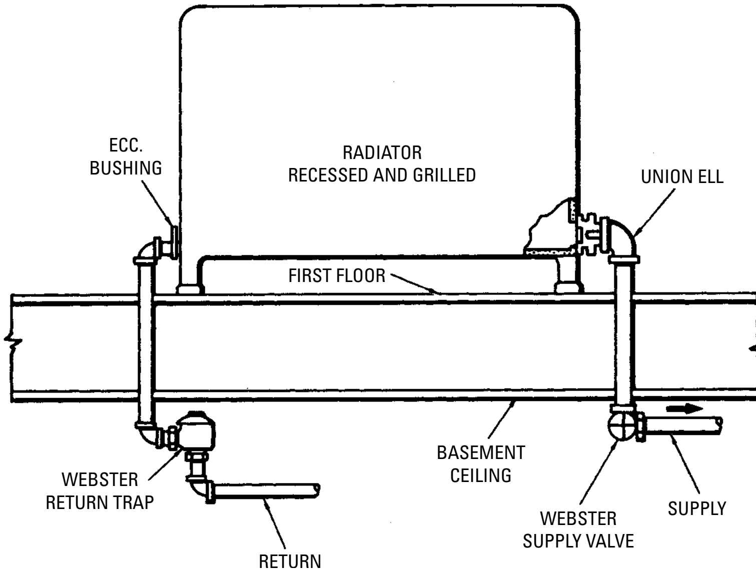


Figure 2-29 Radiator supply and return connections for first-floor installation.

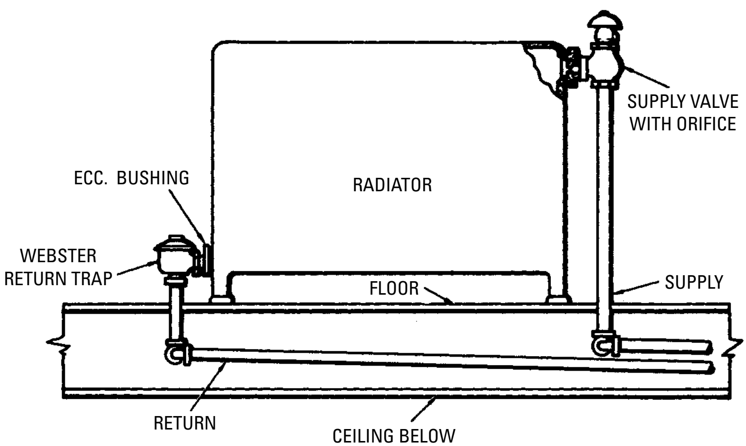


Figure 2-30 Radiator supply and return connections for upper-floor installation.

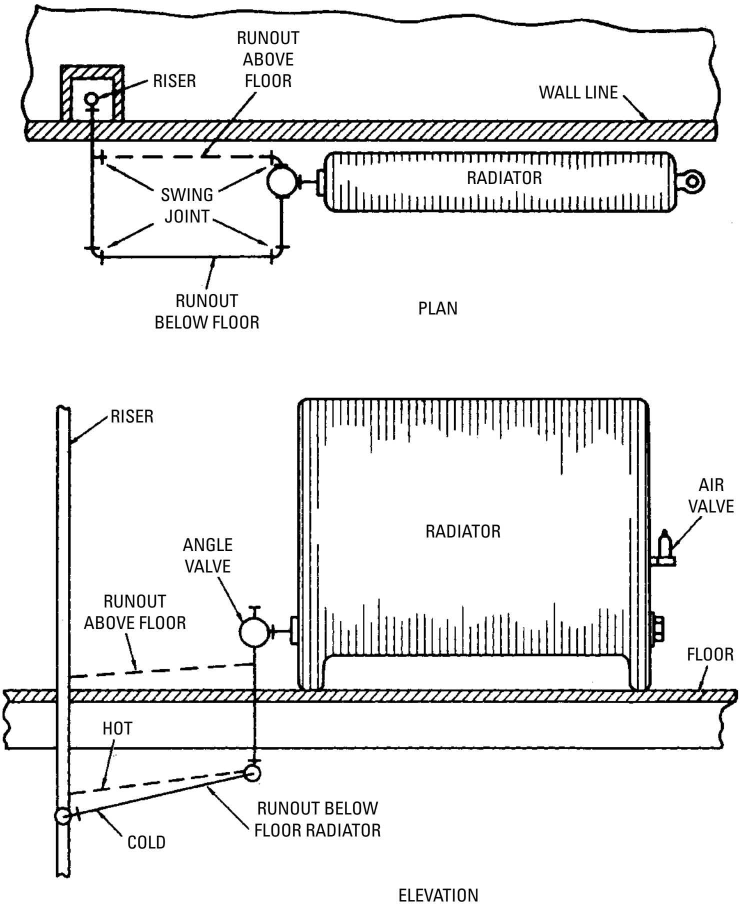


Figure 2-31 One-pipe radiator connections. *(Courtesy 1960 ASHRAE Guide)*

Air Vent Locations

The location of a radiator vent will depend on the type of heating system.

- **Hot-water (hydronic) system radiators.** The air vent is located at the top of the radiator on the side opposite the inlet (supply) pipe.
- **Steam system radiators.** No air valve is required for a radiator in a two-pipe steam heating system. In a one-pipe steam system, the radiator should have an air valve (vent) installed halfway down on the side opposite the inlet pipe.

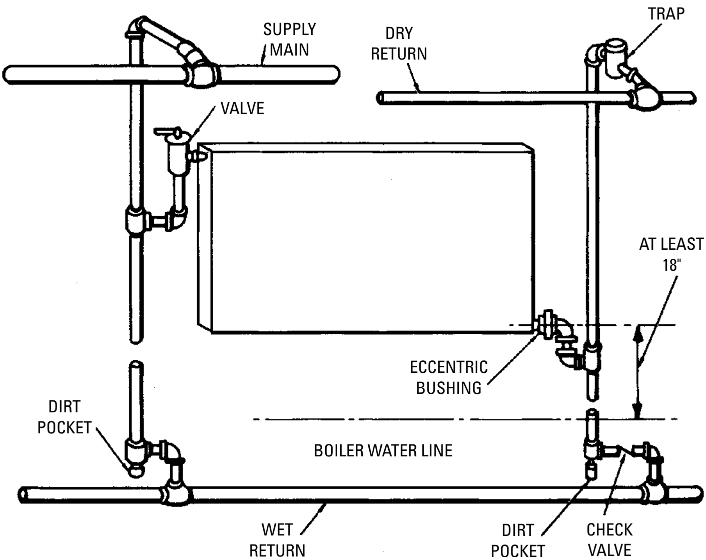


Figure 2-32 Two-pipe connections to radiator installed on wall.

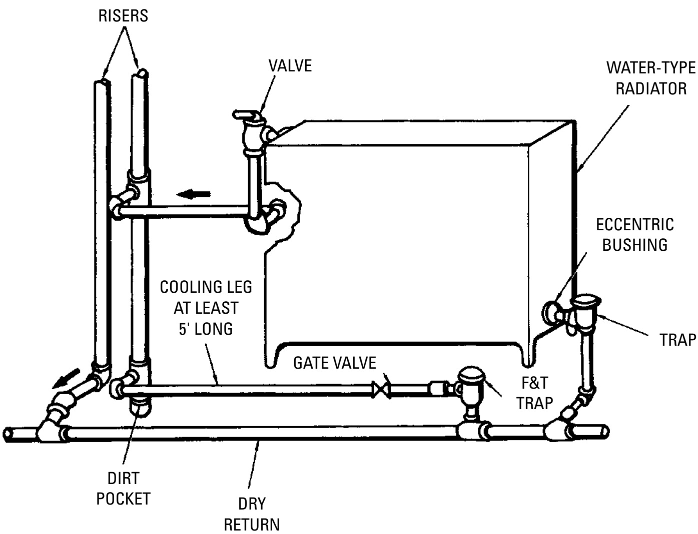


Figure 2-33 Two-pipe top and bottom opposite-end radiator connections. *(Courtesy 1960 ASHRAE Guide)*

Adjustable air valves are often found in systems fired by automatic oil or gas burners. This type of air valve permits the adjustment of radiators varying in size and/or distance from the furnace or boiler so that radiators heat at an equal rate.

Nonadjustable air valves are not recommended because the larger radiators will still contain air after the smaller ones have been completely vented. The same problem occurs with the last radiator on a long main. Often the air valve on this radiator does not have enough time to rid the system of air before the *on* period is completed and the thermostat shuts off the burner. One method of handling this problem is by installing a large-size quick vent at the end of the long main (see Figure 2-34).

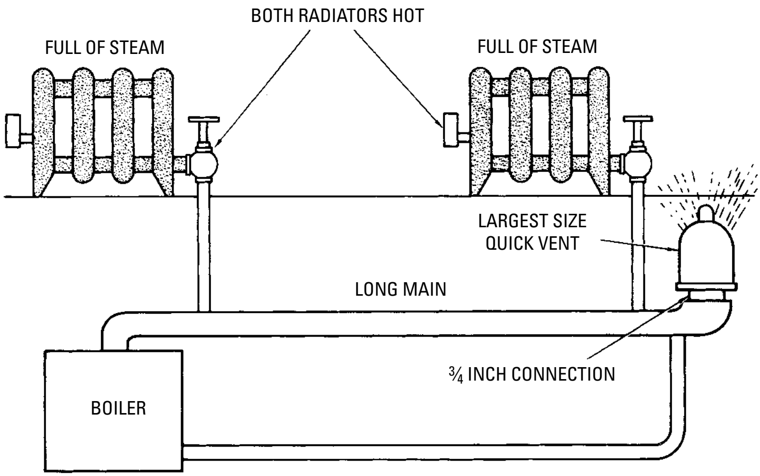


Figure 2-34 Large-size quick vent installed at end of long main.

Double- or triple-venting is an extreme method of solving the problem of a persistently cold radiator (see Figure 2-35). There is usually only one opening for an air valve on a radiator. A second opening can be added by using a ⅛-inch pipe tap and a drill of the proper size.

If a multiple-valve arrangement for a radiator fails to produce the desired results, the only other possibility is to lengthen the burner *on* period. This can be accomplished on oil burners by altering the differential.

Air must also be vented from hot-water heating systems. Trapped air will cause these systems to operate unsatisfactorily, and a means

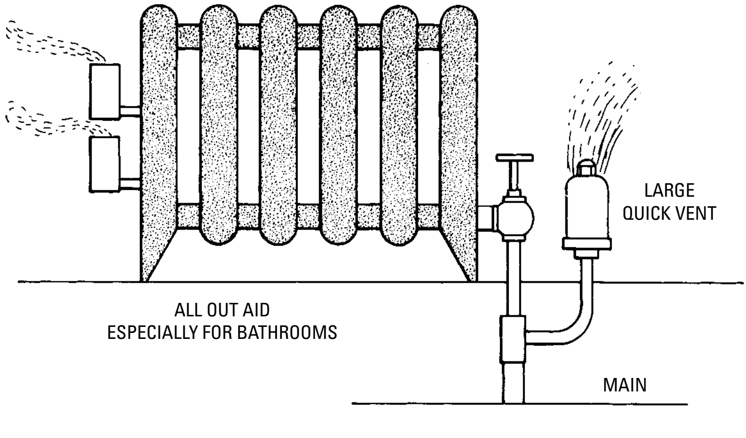


Figure 2-35 Triple-venting a radiator.

should be provided to eliminate it. Manually operated air valves located at the highest levels in the heating system and automatic air valves placed at critical points will usually vent most of the trapped air.

Steam Traps

Steam enters the top of the radiator in a two-pipe steam heating system. As the steam moves through the radiator, a portion of it condenses and the water drips down to the bottom of the unit where it exits through a condensate pipe. In the two-pipe system, a steam trap is installed where the condensate pipe is connected to the radiator. The function of the steam trap is to remove the water (condensate) and prevent any steam from escaping the radiator and entering the condensate return lines. Additional information about steam traps can be found in Chapter 10 ("Steam and Hydronic Line Controls") of Volume 2.

Not all radiators in two-pipe steam heating systems use steam traps to prevent the steam from entering the condensate return lines. Some are equipped with a small check valve, an internal opening, or a seal.

Troubleshooting Radiators

If a radiator in a hot-water or steam heating system is not producing enough heat (or not producing heat at all), it may not be the fault of the radiator. Check the room thermostat and the automatic fuel-burning equipment (gas burner, oil burner, or coal stoker) to determine if they are malfunctioning. Methods for doing this are detailed in the appropriate chapters of Volumes 1 and 2. If you are satisfied that they are operating properly, the problem is probably with the radiator.

Hot water or steam enters a radiator at an inlet in the bottom and must rise against the pressure of the air contained in the radiator. A radiator is equipped with an automatic or manual air valve at the top to allow the air to escape and consequently permit the water or steam to rise.

In radiators equipped with automatic air valves, rising water or steam usually has enough force to push the air in the radiator out through the valve. The valve is automatically closed by a thermostatic control when it comes in contact with the hot water or steam. If a radiator equipped with an automatic air valve is not producing enough heat, the valve may be clogged. This can be checked by closing the shutoff valve at the bottom of the radiator and unscrewing the air valve. If air begins to rush out, open the radiator shutoff valve to see if it will heat up. An increase of heat is an indication that the air valve is clogged. Close the radiator shutoff valve again, remove the air valve, and clean it by boiling it in a solution of water and baking soda for 20 or 30 minutes. The radiator should now operate properly.

A radiator equipped with a manual air valve should be bled of air at the beginning of each heating season. It should also be bled if it fails to heat up properly. This is a very simple operation. Open the manual air valve until water or steam begins to run out. The water or steam running out indicates that all the air has been eliminated from the radiator.

Sometimes radiators are painted to improve their appearance. When a metallic paint (such as aluminum or silver) is used, the heating efficiency is reduced by 15 to 20 percent. If you must paint a radiator, use a nonmetallic paint for all surfaces *facing* the room. Dirty surfaces will also reduce the heating efficiency of a radiator. A good cleaning will eliminate the problem.

Convectors

A *convector* is a heat-emitting unit that heats primarily by convection. In other words, most of the heat is produced by the movement of air around and across a heated metal surface. The air movement across this surface can be gravity-induced or forced. As a result, convectors are classified as either *gravity air convectors* or *forced-air convectors*. They are used in hydronic (forced hot-water) and two-pipe steam heating systems.

Small, upright gravity and forced-air convectors are commonly found in older heating installations. The design of this type of unit was probably influenced by cast-iron radiators. A much more efficient convector is the fin-and-tube baseboard unit (see *Fin-and-Tube Baseboard Units* in this chapter).

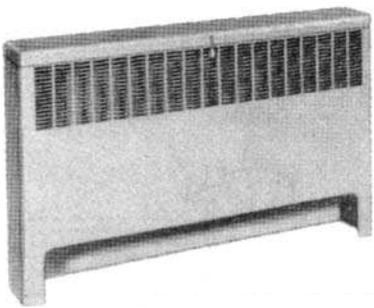


Figure 2-36 Typical radiation convector. *(Courtesy Trane, An American Standard Company)*

An example of a modern convector is illustrated in Figure 2-36. The convector cabinets are available in a variety of different baked-on enamel color finishes. Some convectors have a small door on the front of the cabinet to provide entry for cleaning the heating element (see Figure 2-37). On other convectors, the entire front panel will swing upward for access. The heating element consists of aluminum fins attached to three copper tubes (see Figure 2-38). The tubes are supported by brass headers and hangers on each end of the assembly.

The rating of convectors used in hot-water heating systems is determined by water temperature, temperature drop, and inlet air temperature. The rating of those used in steam heating systems is determined by steam pressure and the entering air temperature. The convector manufacturer provides specifications for its convectors, including sizing data tables.

Convector Piping Connections

The piping connections for a typical gravity convector are shown in Figure 2-39. Supply connections to the convector heating element are made at the top, bottom, or end of the inlet header. Return connections are made at the bottom or end of the header at the opposite end of the unit. Figure 2-40 illustrates two recommended piping connections for convectors used in a hot-water heating system. Typical convector piping connections for units used in steam heating systems are shown in Figures 2-41 and 2-42.

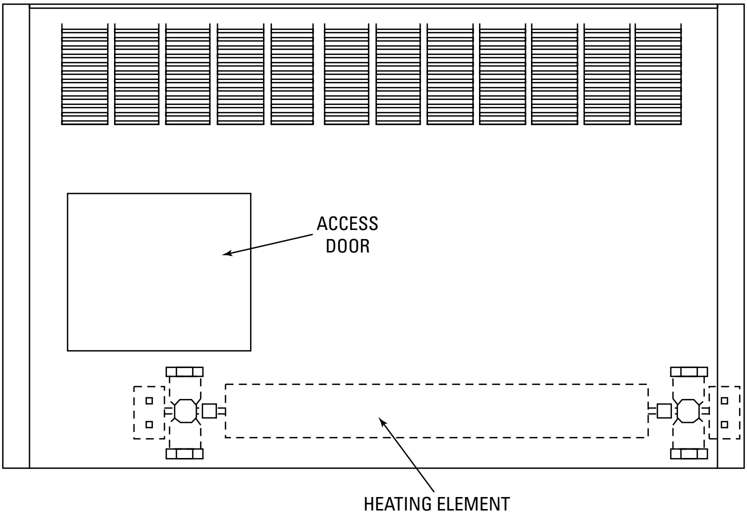


Figure 2-37 Location of access door and heating element assembly.
(Courtesy Trane, An American Standard Company)

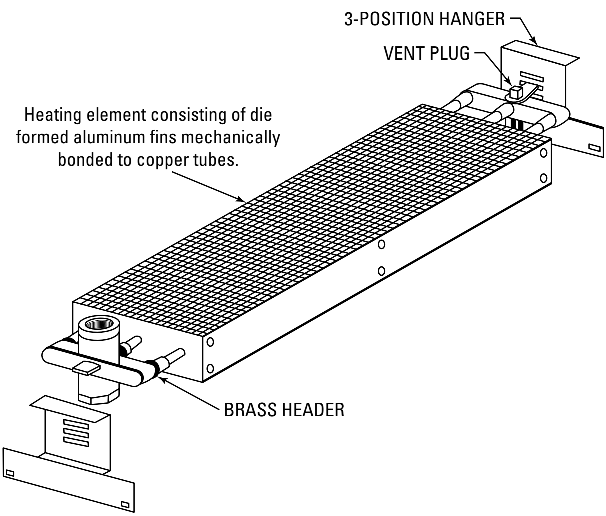


Figure 2-38 Heating element assembly.
(Courtesy Trane, An American Standard Company)

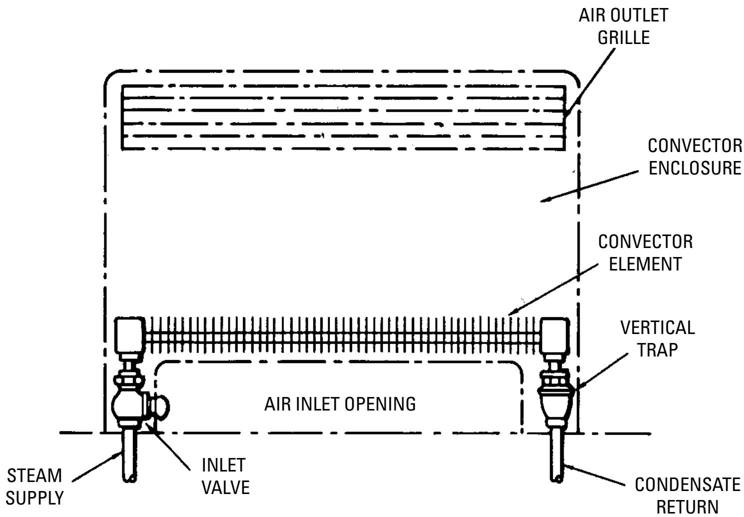


Figure 2-39 Typical convector connections. *(Courtesy 1960 ASHRAE Guide)*

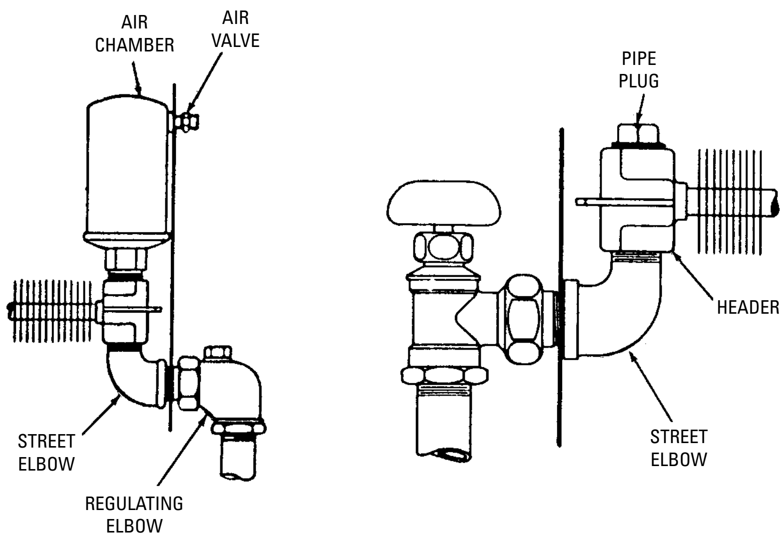


Figure 2-40 Convector piping connections in a hot-water heating system. *(Courtesy Dunham-Bush, Inc.)*

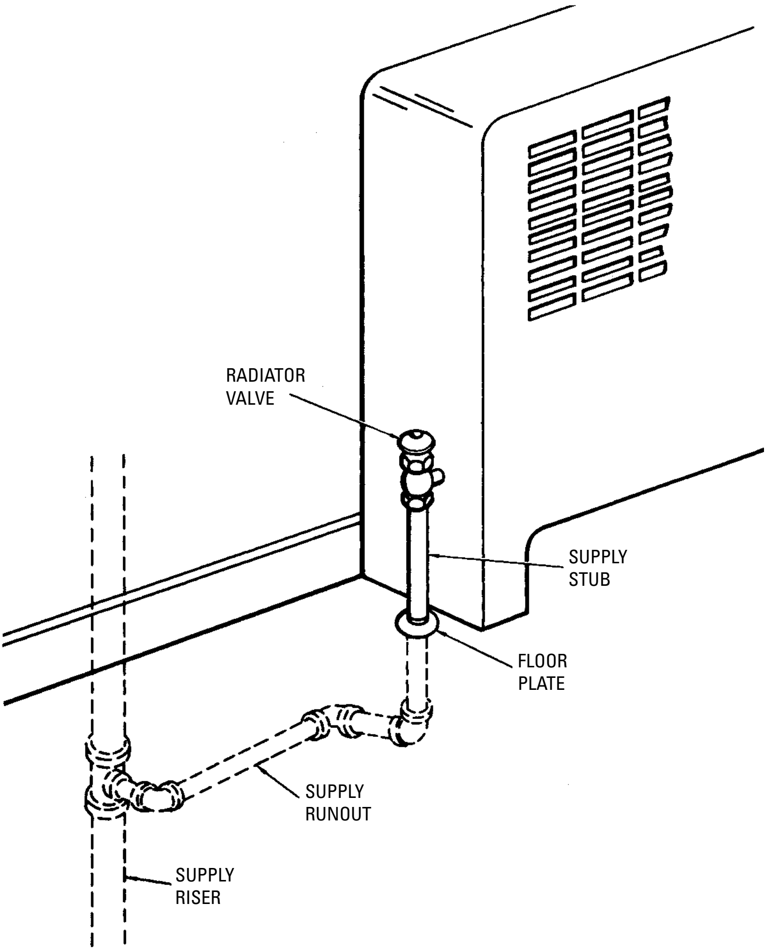


Figure 2-41 Typical convector connections in a steam heating system.
(Courtesy Dunham-Bush, Inc.)

Gravity convector piping connections are very similar to those used with radiators, except that the lines must be sized for a greater condensation rate. The usual method for determining convector capacities is to convert them to the equivalent square feet of direction radiation (EDR):

$$\text{EDR} = \frac{\text{Convector Rating (Btuh)}}{240 \text{ Btu}}$$

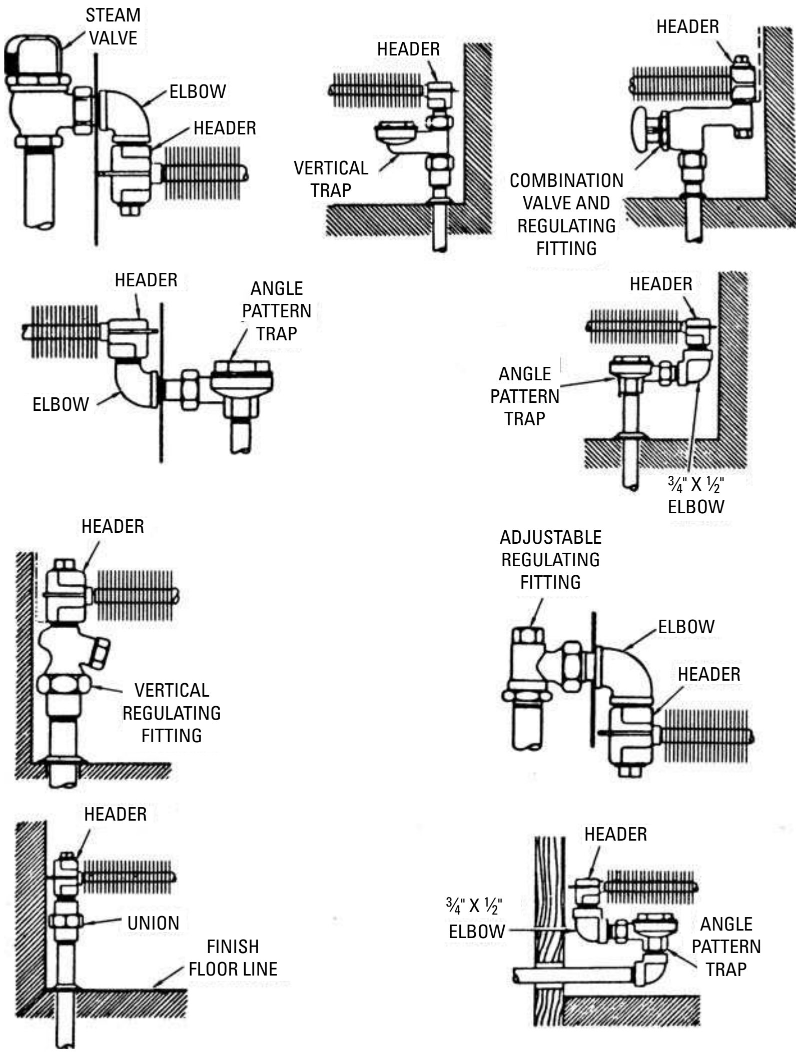


Figure 2-42 Convector piping connections in a steam heating system.

The 240 Btu figure represents the amount of heat in Btu given off by ordinary cast-iron radiators per square foot of heating surface per hour under average conditions.

The connections used for a *forced* hydronic convector are similar to those used with unit heaters (see *Unit Heater Piping Connections* in this chapter).

Hydronic Fan Convectors

Hydronic system fan convectors are equipped with small fans controlled by a fan switch. The fan blows air across the heating element assembly and into the room or space. If there is no heat, a low-limit aquastat will shut off the fan when the temperature drops below a predetermined setting.

Troubleshooting Hydronic Fan Convectors

Check the room thermostat first and then the boiler to determine if either is malfunctioning (see Table 2-4). Procedures for troubleshooting boilers, water heaters, and thermostats are detailed in the appropriate chapters of Volumes 1 and 2.

Table 2-4 Troubleshooting Fan Convectors

Symptom and Possible Cause	*Possible Remedy*
Fan does not operate.	
(a) Low water temperature.	(a) Check for problem with boiler, water heater, or piping and repair.
(b) Low water flow rate.	(b) Check piping and correct.
(c) Tripped circuit breaker or blown fuse.	(c) Reset circuit breaker or replace fuse. If problem continues, request a service call from an electrician or HVAC technician.
(d) Faulty aquastat.	(d) Replace aquastat.
(e) Air-bound coil.	(e) Check bleeder vent and repair.
Poor heat output.	
(a) Low water temperature.	(a) Check boiler or water heater and repair.
(b) Low water flow rate.	(b) Check piping and correct as necessary.
(c) Incorrect clearances around convector.	(c) Check specified clearance in local code and manufacturer's specifications and correct.
Fan operates at only one speed or runs intermittently.	
(a) Broken or loose wiring connection.	(a) Replace wire if connection broken; tighten connection.
(b) Poorly balanced system.	(b) Check piping and correct as necessary.
(c) Air-bound unit.	(c) Check air vent and correct as necessary.

Note

The boiler or dedicated water heater should be set at a minimum temperature of 140°F for the fan convector to operate efficiently.

Check the manufacturer's installation instructions to make certain the convector is properly piped (correct sizing, layout, and so on). If the flow rate for the convector is less than 1 gpm, then there is a piping problem.

Check the wiring to make sure the convector is wired properly, and then examine the wires for loose connections or damaged wiring. If the wiring, piping, and boiler (or water heater) check out all right, the problem is in the convector itself.

Steam and Hot-Water Baseboard Heaters

Baseboard heaters are designed to be installed along the bottom of walls where they replace sections of the conventional baseboard (see Figure 2-43). Locating them beneath windows or along exterior walls is a particularly effective method of eliminating cold drafts.

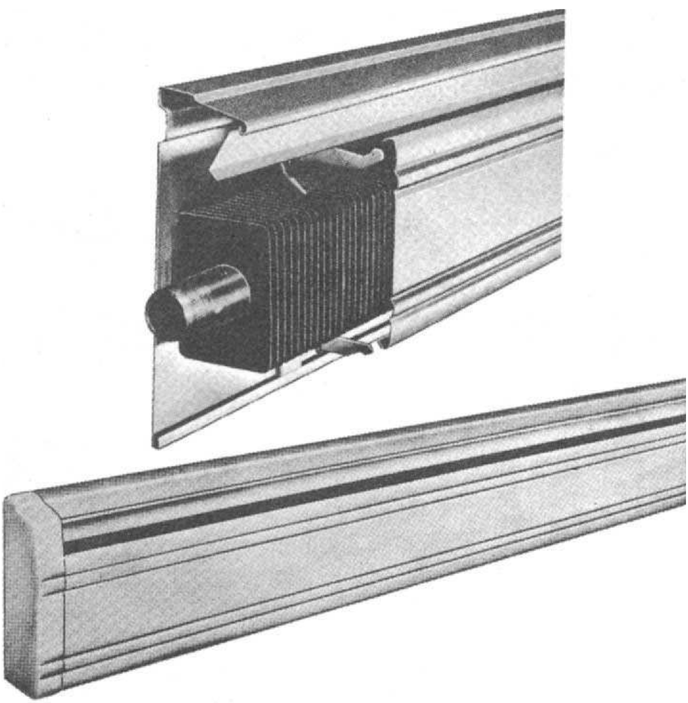


Figure 2-43 Typical baseboard heating installation. *(Courtesy Vulcan Radiator Co.)*

Baseboard heaters are frequently used in steam and hot-water heating systems (see Figures 2-44 and 2-45). In a series-loop system, supply and branch piping can be eliminated by using the baseboard heater to replace sections of the piping. In other words, there is no need for supply and return branches between the baseboard heater and the mains.

Baseboard heaters are also available with electric heating elements controlled by a centrally located wall-mounted thermostat or a built-in thermostat. Each unit is actually a separate heater (see *Electric Baseboard Heaters* in this chapter), but they can be joined and wired together to form a baseboard heating system.

The Institute of Boiler and Radiator Manufacturers (IBRM) has established testing and rating methods of baseboard heat-emitting units. The output for baseboard units is rated in Btu per hour per linear foot.

Construction Details

Two types of baseboard heaters are used in steam and hot-water (hydronic) heating systems: those with separate fins attached to the tubing and those with the fins cast as an integral part of the unit. The integral-fin units are made of cast iron. Those with separate fins are made of nonferrous metals such as copper, aluminum, or alloys.

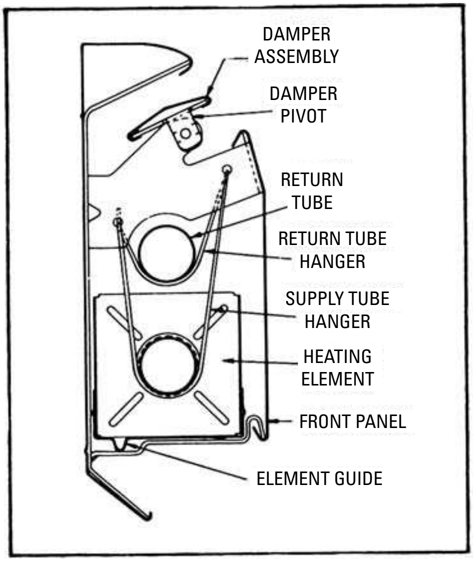
Separate Fin-and-Tube Baseboard Units

An example of a baseboard heater with the fins attached to the tubing is shown in Figure 2-45. The size and length of the tube, as well as the number, size, and spacing of the metal fins, will vary from one manufacturer to the next. Fin shapes, sizes, and spacing can be ordered to specification from the manufacturer. Basically the fins are either square or rectangular (see Figure 2-46). Some will have special design features, such as flared ends (see Figure 2-47).

The assembly of the heating element is covered by a sheet-metal enclosure. Openings are cut into the face of the cove to increase air circulation. When steam or hot water is passed through the tube, the heat is transmitted to the fins by conduction through the metals. The heat transmitted to the fins is transferred to the air by convection.

The heating-element tube is available in a variety of sizes, including ¾, 1, 1¼, and 1½ inches (see Figure 2-48). On short pipe runs, the ¾-inch tube is recommended in order to ensure water velocities in the turbulent flow range. On long runs and with loop systems, it may be desirable to use 1- or 1¼-inch tube sizes.

Use of the small tube sizes results in lower cost for connecting piping in a run and for valves, expansion joints, balancing cocks,



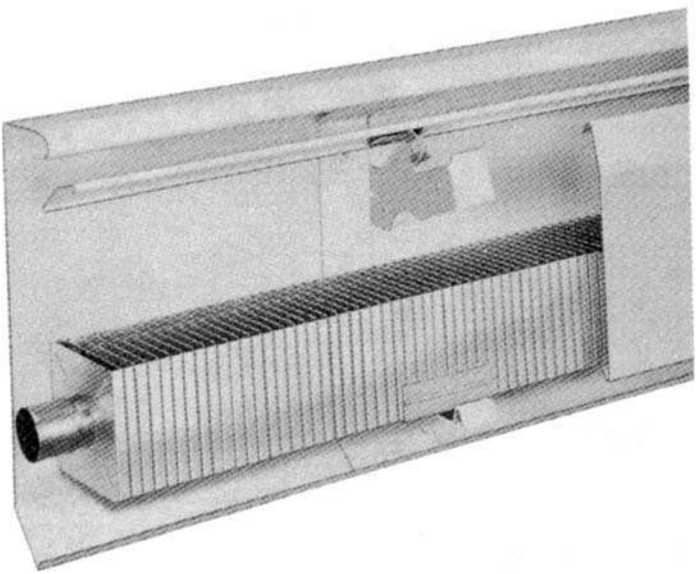


Figure 2-44 Design features of a hot-water heating baseboard unit. *(Courtesy Weil-McLain Co.)*

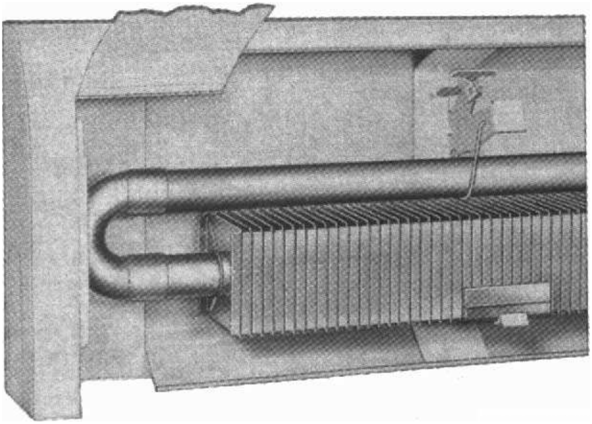


Figure 2-45 Return tube installation for hot-water heating system. *(Courtesy Weil-McLain Co.)*

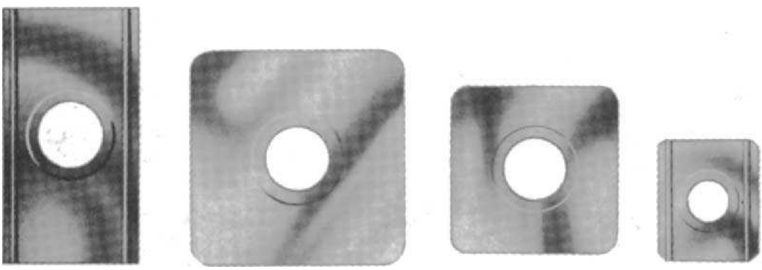


Figure 2-46 Typical fin shapes. *(Courtesy Vulcan Radiator Co.)*

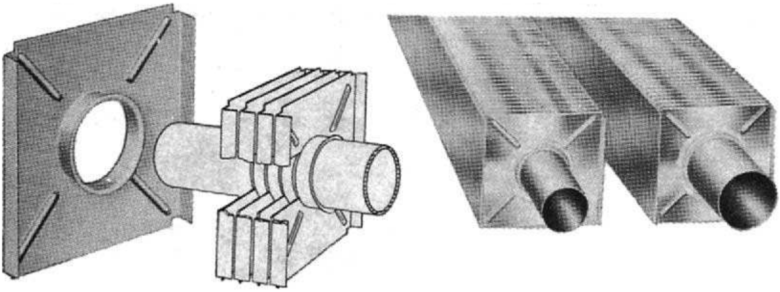


Figure 2-47 Heating-element fins with flared ends. *(Courtesy Weil-McLain Co.)*

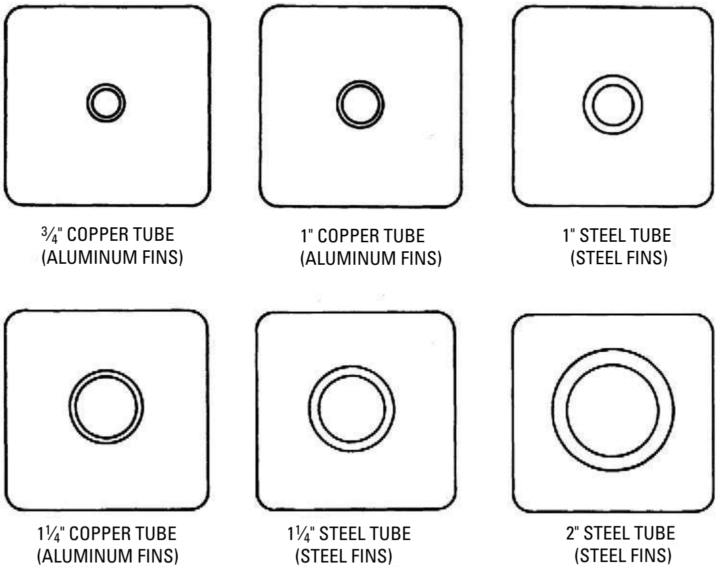


Figure 2-48 Heating-element tube sizes. *(Courtesy Vulcan Radiator Co.)*

and fittings. There is also a lower heating-element cost involved with the small tube sizes.

The fins and tubing can be made of the same or different metals (see Figures 2-49 and 2-50). The following combinations are among those possible:

1. Copper fins on copper tubing.
2. Aluminum fins on copper tubing.
3. Aluminum fins on aluminum tubing.
4. Aluminum fins on steel tubing.
5. Stainless-steel fins on stainless-steel tubing.
6. Cupronickel fins on cupronickel tubing.

These different metals exhibit different heating characteristics, and all are not suitable for the same application. For example, steel heating elements are recommended for high-temperature water systems. Copper-aluminum elements, on the other hand, work well with water temperatures up to 300°F. Copper-aluminum heating elements also produce a high heat output, but the copper tube has a very high rate of expansion (higher than steel). All these factors

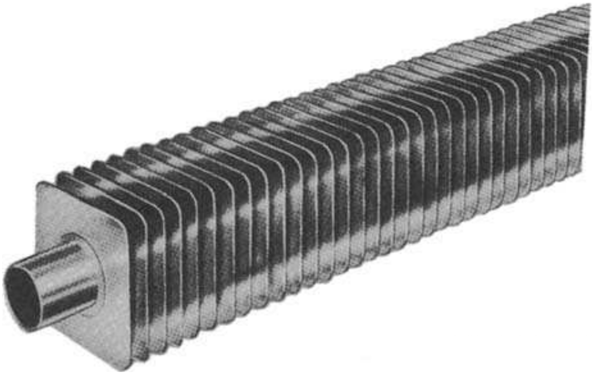


Figure 2-49 Copper-aluminum heating elements.
(Courtesy Vulcan Radiator Co.)

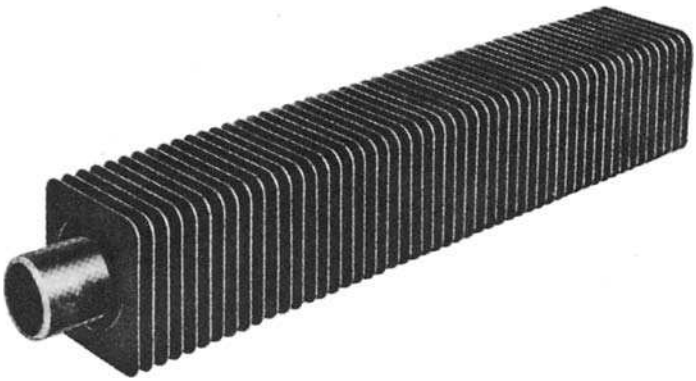


Figure 2-50 Steel heating elements. *(Courtesy Vulcan Radiator Co.)*

have to be taken into consideration when selecting a suitable heating element for the installation.

Integral Fin-and-Tube Baseboard Heaters

A cast-iron baseboard heater with the fins cast as an integral part of the unit is shown in Figures 2-51 and 2-52. These baseboard heaters can be used in series-loop, one-pipe, and two-pipe (reverse-return) forced hot-water heating systems and in two-pipe steam or vapor heating systems. They are not recommended for use in one-pipe steam heating systems.

There are several advantages to using cast-iron baseboard heaters. Because the fins are a part of the casting, they will not bend, dent, or come apart. Cast iron is corrosion resistant and will not expand or

Figure 2-51 Cast-iron baseboard heater with fins cast as an integral part of the unit. *(Courtesy Burnham Corp.)*

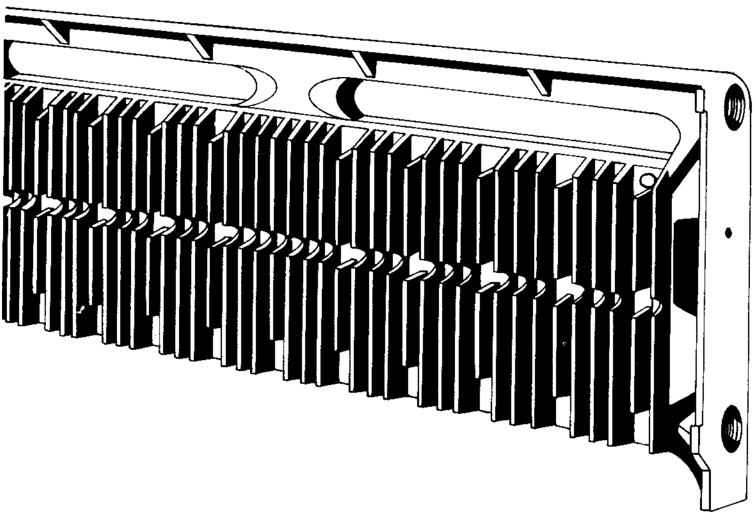


Figure 2-52 Integral fin-and-tube construction details. *(Courtesy Burnham Corp.)*

contract with temperature changes. This last feature eliminates the expansion and contraction noises that frequently occur with nonferrous, separate fin-and-tube units, which allows them to fit closer to the wall.

Installing Baseboard Units

A steel fin-and-tube baseboard heating element will expand as much as ⅛ inch per 10 feet with a 70°F to 200°F temperature rise.

A copper element will expand as much as 1⁄16 inch per 10 feet under the same conditions. This potential expansion of the heating element must be provided for when installing the system or problems will arise. The following provisions are recommended:

1. Allow a clearance of at least 1⁄4 inch around all piping that passes through floors or wall partitions.
2. Wrap pipe passing through a floor or wall partition with a felt or foam sleeve to act as a cushion (see Figure 2-53).

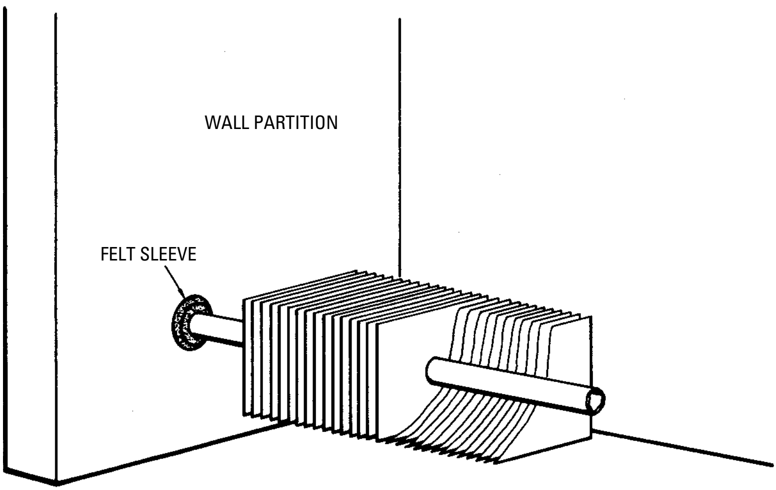


Figure 2-53 Clearance provided for expansion through wall partition.
(Courtesy Vulcan Radiator Co.)

3. Try to limit straight runs of pipe to a maximum of 30 feet. Wherever longer runs are necessary, install a bellows-type expansion joint near the center and anchor the ends.
4. Where a baseboard system extends around a corner, provide extra clearance at the ends (expansion will generally occur away from the corner) (see Figure 2-54).
5. When a baseboard system is installed around three adjacent walls (forming a U), always use an expansion joint in the center leg of the U (see Figure 2-55).
6. When making piping connections, be sure to keep all radiator elements in proper vertical position so that fin edges will not touch other metal parts.

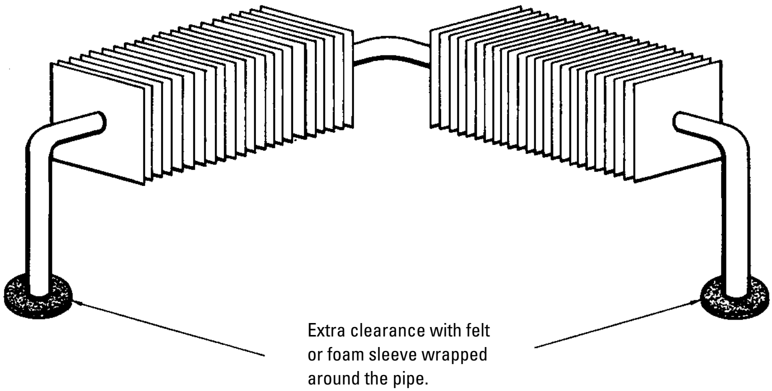


Figure 2-54 Extra clearance should be provided for an extension around a corner. *(Courtesy Vulcan Radiator Co.)*

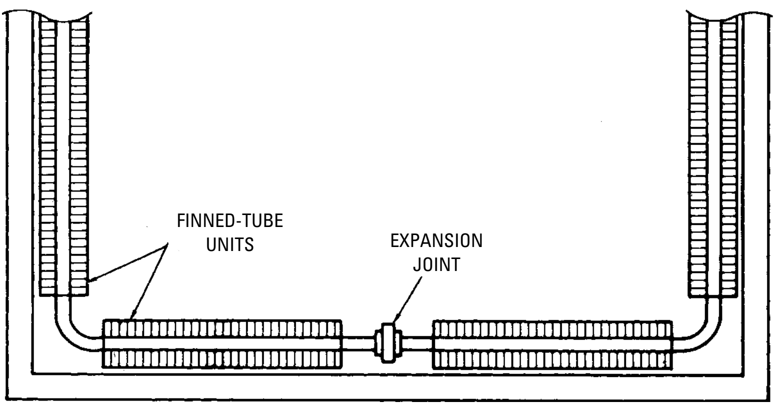


Figure 2-55 Location of expansion joint.

7. Be sure to support all mains and other piping runs adequately so that their weight will not cause bowing of the heating elements.
8. Install a felt sleeve around the pipe where it rests against a rigid hanging strap (see Figure 2-56).

Before installing the baseboard heater, check the walls carefully for straightness. The baseboard heaters must be absolutely straight or their operating efficiency will be reduced. Therefore, it would be a mistake to use a wall to align the units if the wall were not straight.

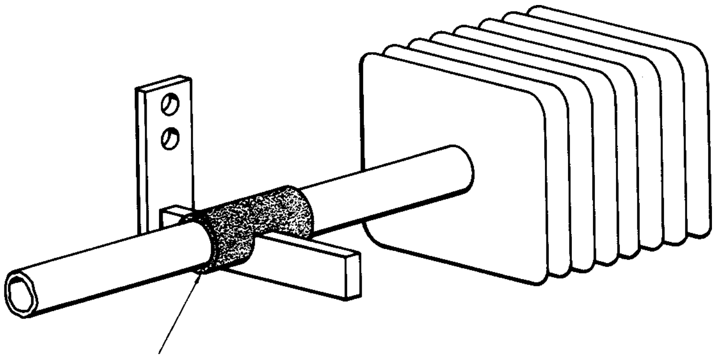


Figure 2-56 Felt support for heating element. *(Courtesy Vulcan Radiator Co.)*

Shims may have to be used on wavy walls to keep the baseboard system straight.

Many baseboard heaters can be recessed the depth of the plaster. The back of each unit is nailed to the studs before plastering, and the top of the baseboard heater hood serves as a plaster stop. The top accessories must be installed before plastering.

The procedure for installing a steam or hot-water baseboard heating system may be summarized as follows:

1. Place the backing of the unit against the wall surface or studs (in a recessed installation) and mark the location of the studs (see Figure 2-57).
2. Punch holes in the backing and screw it to the studs.

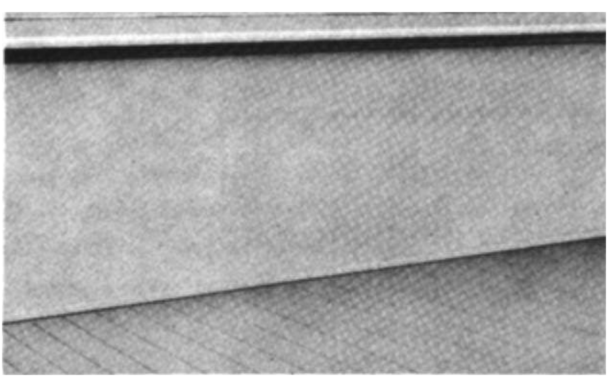


Figure 2-57 Unit back installed flush against wall surface or studs. *(Courtesy Vulcan Radiator Co.)*

3. Install cover support brackets approximately 3 feet apart (see Figure 2-58).
4. Place cradle hangers on rivet head and set the heating element on the cradles, making sure the fins are vertical and that all hangers are free to swing (see Figure 2-59).

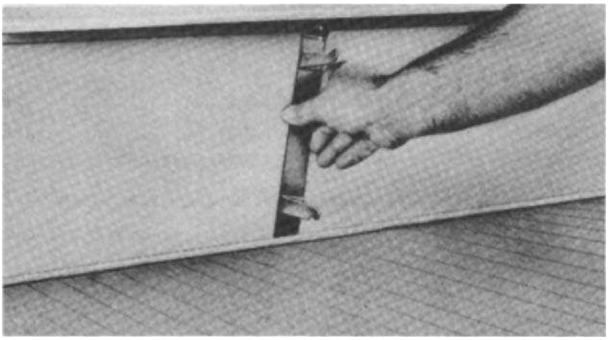


Figure 2-58 Installing support brackets.
(Courtesy Vulcan Radiator Co.)

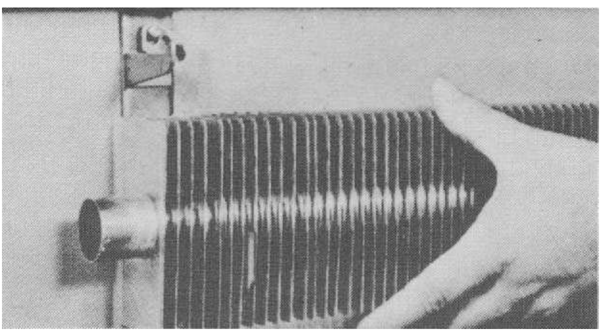


Figure 2-59 Setting heating elements in place.
(Courtesy Vulcan Radiator Co.)

5. Complete piping and test for leaks before snapping on the fronts.
6. Snap the front cover onto the support brackets by hooking the top lip over the upper arms and snapping the bottom lip over the bottom arms (see Figure 2-60).
7. Add joining pieces and end enclosures where appropriate (see Figures 2-61 and 2-62).

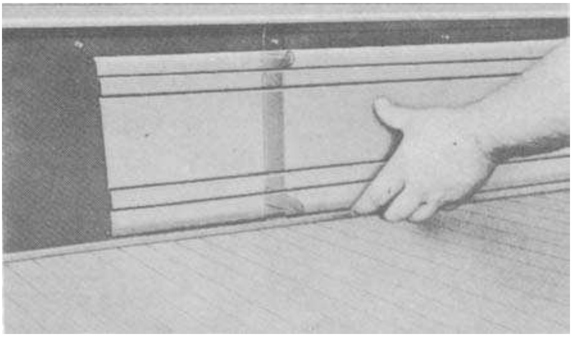


Figure 2-60 Snapping on the front cover.
(Courtesy Vulcan Radiator Co.)

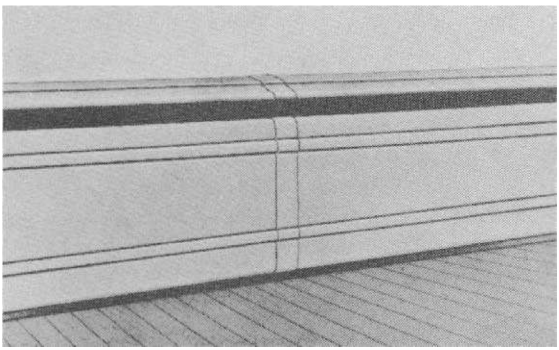


Figure 2-61 Installing joint pieces. *(Courtesy Vulcan Radiator Co.)*

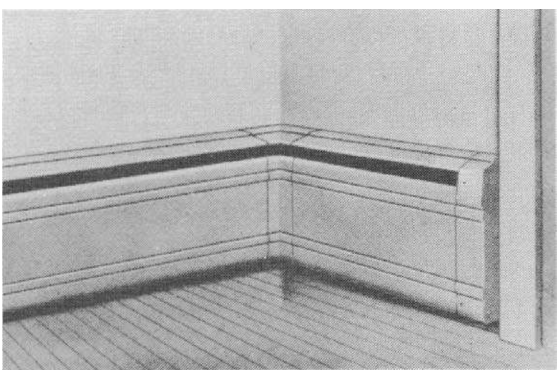


Figure 2-62 Installing corner and end enclosures.
(Courtesy Vulcan Radiator Co.)

Hot-water heating systems can be divided by temperature into the following three types:

1. High-temperature water systems, 350°F to 450°F.
2. Medium-temperature water systems, 250°F to 350°F.
3. Low-temperature water systems, below 250°F.

Although low-temperature hot-water heating systems are the predominant type used in the United States, there is a growing tendency to apply high-temperature water not only to underground distribution piping (as in district heating) but also to direct radiation.

When fin-tube baseboard units are used in a high-temperature hot-water heating system, care must be taken to keep the enclosure surface temperature to a minimum. This can be accomplished as follows:

1. Use the highest enclosure height practical.
2. Use heating elements only one row high.
3. Use a maximum fin spacing of 33 per foot.
4. Spread the heating element out along the entire wall length.
5. Limit the water temperature to that necessary to offset building heat loss.

Because of the higher heat level, the expansion of heating elements becomes more of a factor with high-temperature hot-water heating systems. As a result, more expansion joints should be used along the length of the heating elements than is the case with low-temperature water.

Baseboard Heater Maintenance

The baseboard heaters used in steam or hot-water heating systems must be routinely cleaned and vacuumed to ensure that the convective fins are clean. If the fins are covered with a layer of dust or dirt, it will impede the radiation of heat into the room or space. Remove the baseboard cover at least once every two months to check the cleanliness of the fins.

Electric Baseboard Heaters

Electric baseboard heaters are designed for use in residential, commercial, industrial, and institutional heating systems. This chapter will be primarily concerned with a description of residential heaters. The electric heaters designed for use in commercial, industrial, or institutional installations differ from the residential type by being larger in capacity; otherwise, they are essentially identical in design (see Figure 2-63).

An electric baseboard heater contains one or more heating elements placed horizontally. Each electric heating element is a unit assembly consisting of a resistor, insulated supports, and terminals for connecting the resistor to the electric power supply.

By definition, a resistor is a material used to produce heat by passing an electrical current through it. Solids, liquids, and gases may be used as resistors, but solid resistors are the type most frequently used. Resistors may be made up of wire or metal ribbon, supported by refractory insulation, or embedded in refractory insulating material surrounded by a protective sheath of metal. A typical heating element used in Vulcan electric baseboard heaters is

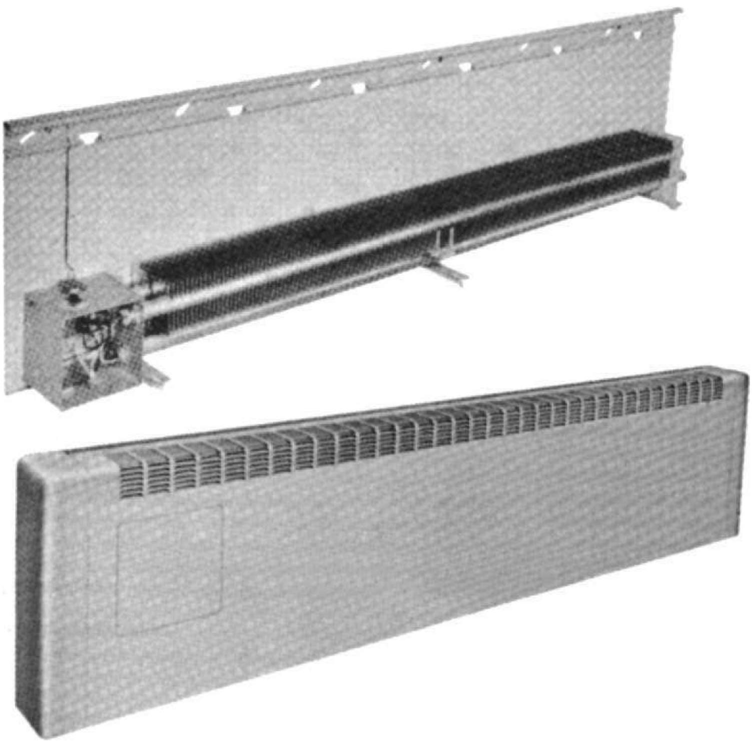


Figure 2-63 Duraline electric heater. *(Courtesy Vulcan Radiator Co.)*

shown in Figure 2-64. It consists of nichrome heater coils embedded in a ceramic core.

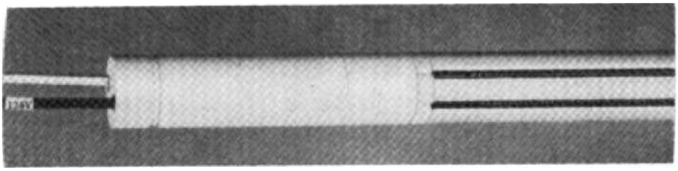


Figure 2-64 Heater core. *(Courtesy Vulcan Radiator Co.)*

Each resistor is generally rated from 80 to 250 watts (270 to 850 Btu per hour) per linear foot of baseboard unit. The manufacturer will give the ratings for each unit (rather than per linear foot) but will also include its overall length in the data.

Either wall-mounted or built-in thermostats can be used to control the heating elements in electric baseboard heaters. These thermostats (either low-voltage or line voltage types) are designed for single- or multiple-unit control with single- or two-stage heating elements. *Normally*, multiple-unit control is not feasible with two-stage units or with a built-in thermostat. It is recommended that single-stage heating units be used when it is necessary or desirable to control more than one unit from one thermostat.

Close control of temperatures can be obtained by installing a time-delay relay in the electric baseboard unit. This type of relay is particularly useful when a time delay is needed on switch make or break. Additional information about time-delay relays is included in Chapter 6 of Volume 2 ("Other Automatic Controls").

A temperature-limit switch (thermal cutout) should be installed in each unit to prevent excessive temperature buildup. The maximum surface temperature for each baseboard enclosure should be limited to 190°F. Exceeding this limit may result in damage to the heater.

A typical temperature-limit switch used in an electric baseboard installation is the linear capillary type that ensures constant protection over the entire length of the heater. An automatic resetting feature allows the heater to resume operation once conditions return to normal. The temperature-limit switch is usually located between the heater and the thermostat or disconnect switch in the wiring (see Figures 2-65 and 2-66). The only exception occurs when a built-in simultaneous switching thermostat is used (see Figure 2-67).

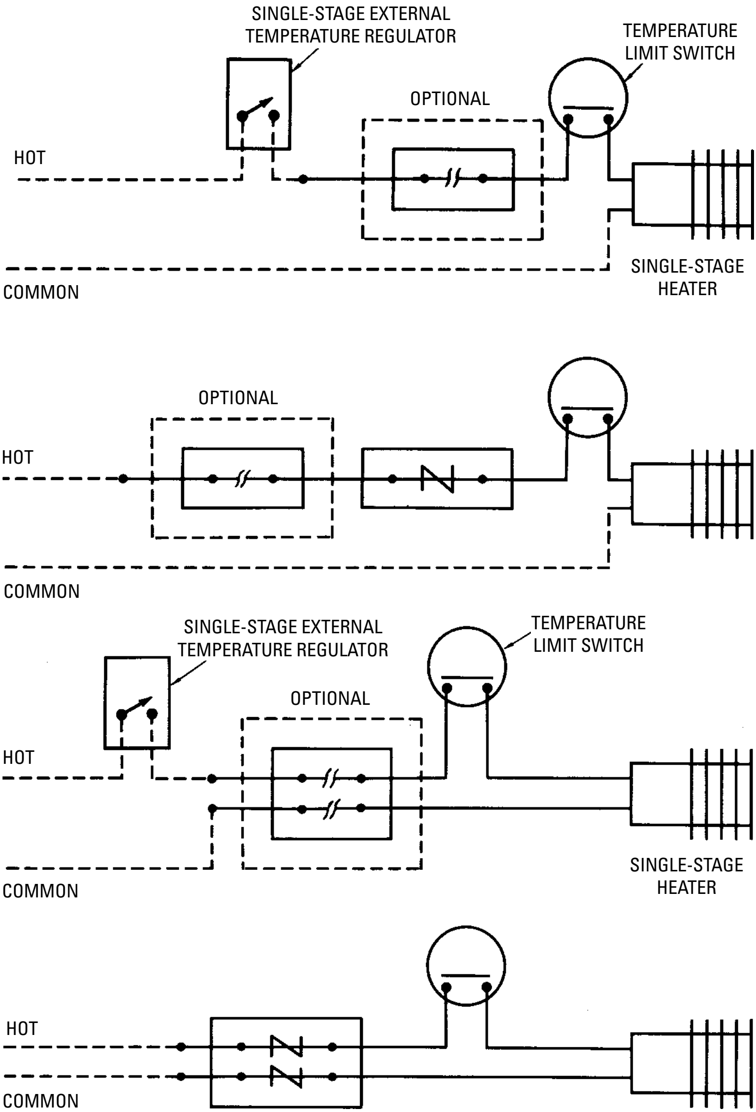


Figure 2-65 Single-stage wiring diagrams. *(Courtesy Vulcan Radiator Co.)*

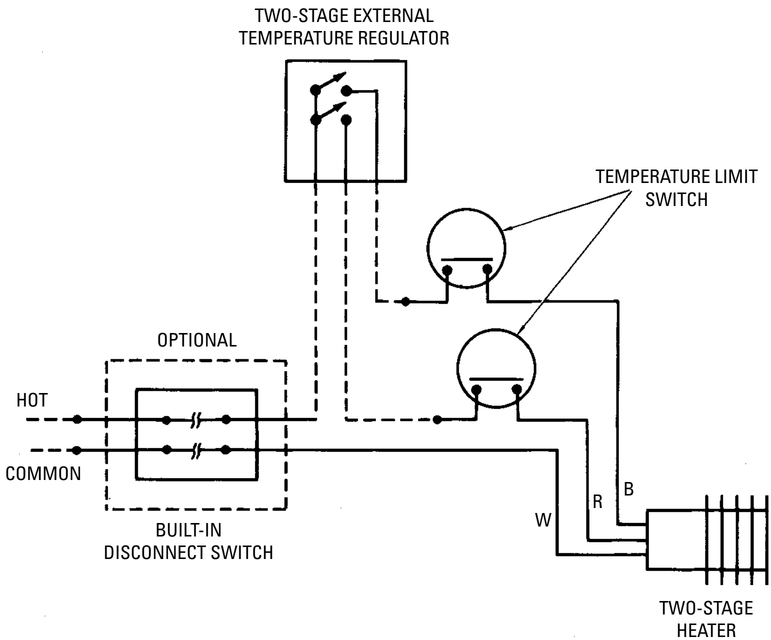


Figure 2-66 Two-stage wiring diagram. *(Courtesy Vulcan Radiator Co.)*

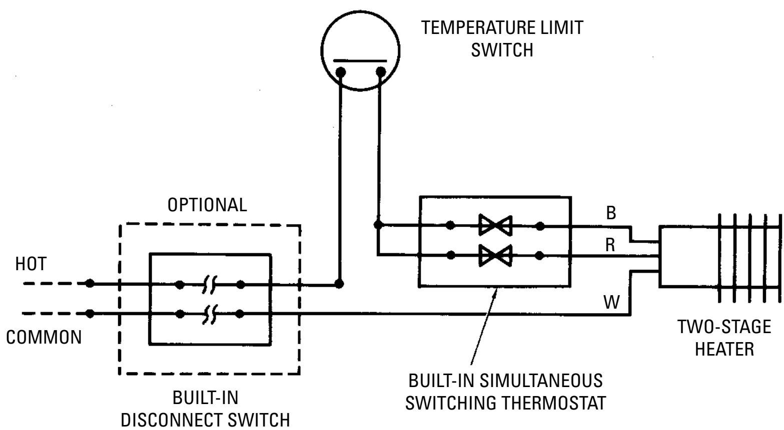


Figure 2-67 Two-stage wiring diagram with built-in simultaneous switching thermostat. *(Courtesy Vulcan Radiator Co.)*

In a baseboard heating system, each temperature-limit switch must be wired to break the electrical circuit *only* to the heating element or elements of the unit on which it is installed.

Installing Electric Baseboard Heaters

Read the manufacturer's instructions carefully before attempting to install an electric baseboard heater. Particular attention should be paid to wiring instructions and required clearances. Check the local codes and ordinances before beginning any work. All installation must comply with local and national electrical codes, with the former taking precedence.

Caution

> To prevent electrical shock and possible equipment damage, *always* disconnect the power supply before connecting or disconnecting wiring.

Warning

> Special care must be taken when installing a line voltage (240 VAC) thermostat. A 240-VAC electric shock may cause serious injury or death.

A *minimum* clearance is generally required from the bottom of an electric heater to any obstructing surface, such as a floor, floor covering, ledge, or sill. The amount of clearance will depend on the particular unit and manufacturer.

Check the heater operating voltage on the model before installing it. The watt output of an electric heating unit depends on the supply (line) voltage. When the supply voltage equals the rated voltage of the unit, the output will equal the rated watts. *Never* connect a heater to a supply voltage greater than 5 percent above the marked operating voltage on the model label. A heater connected to a supply voltage that is *less* than the marked voltage on the model label will result in a watt output that is less than the model label rating. This will cause a reduced heating effect, which should be taken into consideration when determining heating requirements.

Note

> Connecting a 120-volt baseboard heater to a 240-volt circuit will cause the heating element to overheat and destroy the heater. Connecting a 240-volt heater to a 120-volt circuit, on the other hand, will result in the heater delivering only about 25 to 30 percent of its designed output.

A change in watt output with respect to a variation in supply voltage may be conveniently calculated with the following formula:

$$2 \times (\text{supply voltage} - \text{rated voltage}) \times \text{amps at related voltage} = \text{change in watt output.}$$

For example, the change in watt output for a 120-volt/500-watt/4.2-amp heating unit connected to a 115-volt line can be calculated as follows:

$$\begin{aligned} &2 \times (115 \text{ volt} - 120 \text{ volt}) \times 4.2 \text{ amp} \\ &\quad = 2 \times (-5 \text{ volt}) \times 4.2 \text{ amp} \\ &\quad = -10 \text{ volt} \times 4.2 \text{ amp} \\ &\quad = -42 \text{ watt change in output.} \end{aligned}$$

Thus, the output of this unit at 115 volts will be 458 watts (500 watts − 42 watts). The use of these calculations should be restricted to a +10-volt difference in the supply voltage at 120 volts and a +20-volt difference, or 208 volts, 240 volts, and 277 volts.

Some manufacturers of electric baseboard heating equipment produce heaters designed for installation as individual units or as components of a larger baseboard heating system. The procedure for installing individual units is as follows:

1. Locate the unit on the wall so that the *minimum* clearance is maintained between the bottom edge of the heater and the *finished* flooring (see Figure 2-68).

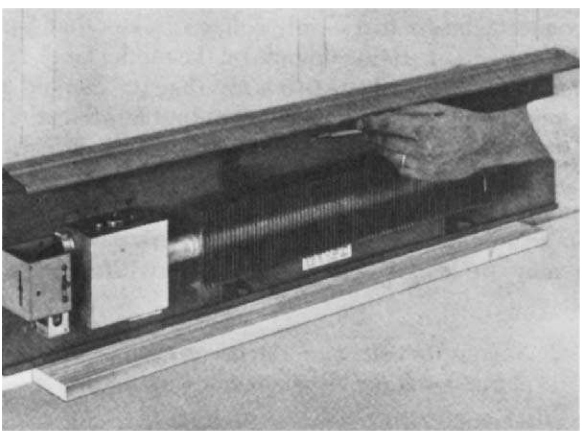


Figure 2-68 Locating and marking the heater. *(Courtesy Vulcan Radiator Co.)*

2. Position the unit so that the knockouts in the junction box are aligned with the electrical rough-in location.
3. Locate the wall studs or mullions, and mark the location on the backing of the unit.
4. Drill or punch mounting holes in the backing a suitable distance below the hood and above the bottom edge.
5. Connect armored or nonmetallic sheathed cable through the knockout in the backing or bottom of the junction box (see Figure 2-69). When entering through the backing, make up electrical connector, slide excess cable back into the wall space, and nail or screw the heater backing to the wall.

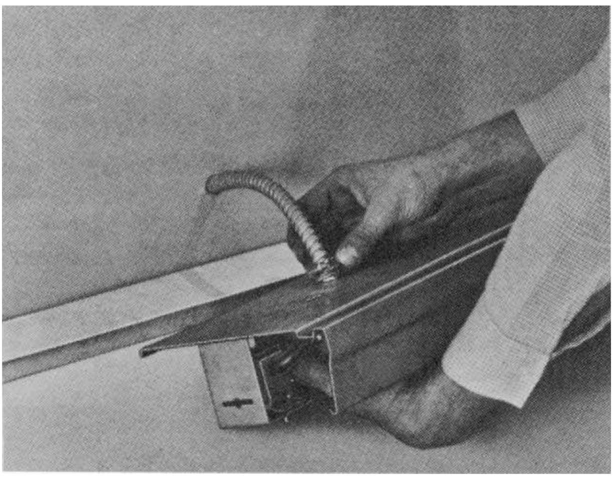


Figure 2-69 Making the electrical connections.
(Courtesy Vulcan Radiator Co.)

6. Make electrical connection of branch circuit wiring to the heater. Maintain continuity of grounding (see next paragraph).
7. Snap the heater cover over the brackets and at the same time align the thermostat operating shaft (built-in thermostats with the hole in the cover) (see Figure 2-70).
8. Slide the end enclosures over each end of the unit (see Figure 2-71), and tighten the cover screws (see Figure 2-72).

For each electric heater unit, continuity of grounding must be maintained through circuit wiring devices. All branch circuit wiring

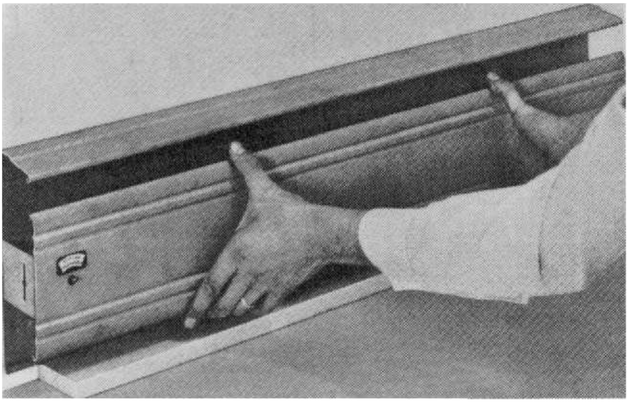


Figure 2-70 Snapping cover over brackets. *(Courtesy Vulcan Radiator Co.)*

and connections at the heater must be installed in accordance with local codes and regulations and the appropriate sections of the most recent edition of the *National Electrical Code*.

Individual electric heaters can be mounted and wired to form a continuous baseboard heating system. The units used in a baseboard system should be ordered with a right-end mounted junction box to facilitate the wiring of the adjacent unit. The instructions for installing individual electric heaters should be followed for each unit in the baseboard system (see steps 1–7 of aforementioned installation procedure).

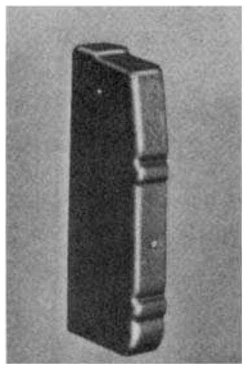


Figure 2-71 Typical end enclosure. *(Courtesy Vulcan Radiator Co.)*

As shown in Figure 2-73, straight-line installation along a wall is simply a matter of butting the two units and connecting them with a joining piece (see Figure 2-74). Inside- and outside-corner installation methods are shown in Figures 2-75 and 2-76.

Kickspace Heaters

A typical kickspace heater is shown in Figure 2-77. It consists of a copper tube with an attached aluminum finned heating element, a 115-volt electric motor, and a blower/fan. Hot water from the boiler is circulated through the copper tube inside the unit. The

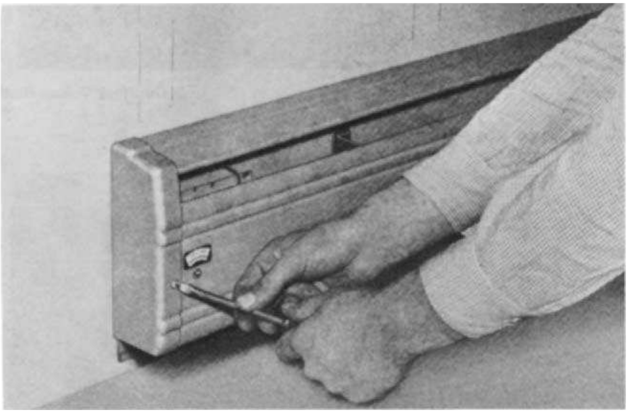


Figure 2-72 Tightening cover screws. *(Courtesy Vulcan Radiator Co.)*

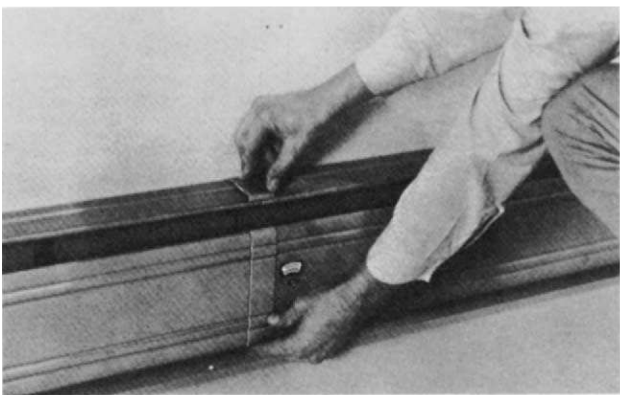


Figure 2-73 Straight-line installation. *(Courtesy Vulcan Radiator Co.)*

blower, which is driven by the small electric motor, forces air across the heating element, picks up the heat, and sends it into the room. The blower is turned on or off automatically in response to the thermostat setting. The blower speed is set manually. The blower motor operates in conjunction with a 120°F (49°C) reverse-acting aquastat.

Kickspace heaters are designed for use in one-pipe or two-pipe hydronic heating systems or in a series loop where pressure and temperature drop can be tolerated. They are used beneath kitchen sinks, along short entrances and hallways, and inside bathrooms where space restrictions do not permit the installation of the longer baseboard heaters. Kickspace heaters are not designed for use in steam heating systems. They are also not recommended for use in a gravity-flow hot-water system unless a separately installed pump is provided to circulate the water.

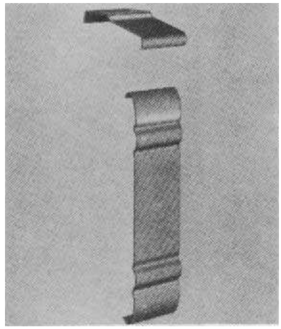


Figure 2-74 Joining piece.

(Courtesy Vulcan Radiator Co.)

Kickspace heaters are offered in three models: horizontal heaters, vertical heaters, and surface-mounted wall heaters. The horizontal models are installed beneath kitchen cabinets, bathroom sink enclosures, and similar areas where vertical height is limited. The vertical models are installed fully recessed between wall studs. The air is discharged upward through a louvered front panel. The surface-mounted wall model is mounted on the interior surface of a wall. The air is discharged evenly through a louvered front panel in an upward direction.

Floor and Window Recessed Heaters

Recessed radiation is designed for installation below large glass areas that extend to the floor and do not permit the use of baseboard radiation. The heat-emitting unit illustrated in Figure 2-78 is an example of recessed radiation used in a hydronic heating installation.

A typical hot-water recessed radiation heater consists of an enclosure, a finned element, two element glides, two rubber grommets, and a floor grille with or without dampers (see Figure 2-79). The operating principle of this unit is relatively simple. The air entering the unit at the cool-air inlet is separated from the rising heated air by a baffle (see Figure 2-80). The baffle is designed to separate the cool inlet air from the rising heated air and to accelerate the flow of air through the unit for maximum heat output. The baffle is held in position by a guide on each end of the enclosure and a bracket in the center.

Figures 2-81 and 2-82 show openings used to accommodate recessed floor units in a wood floor and in masonry construction. In a wood floor installation where the unit is to be installed parallel to the joists, an opening with the same dimensions as shown should be prepared by installing headers between joists.

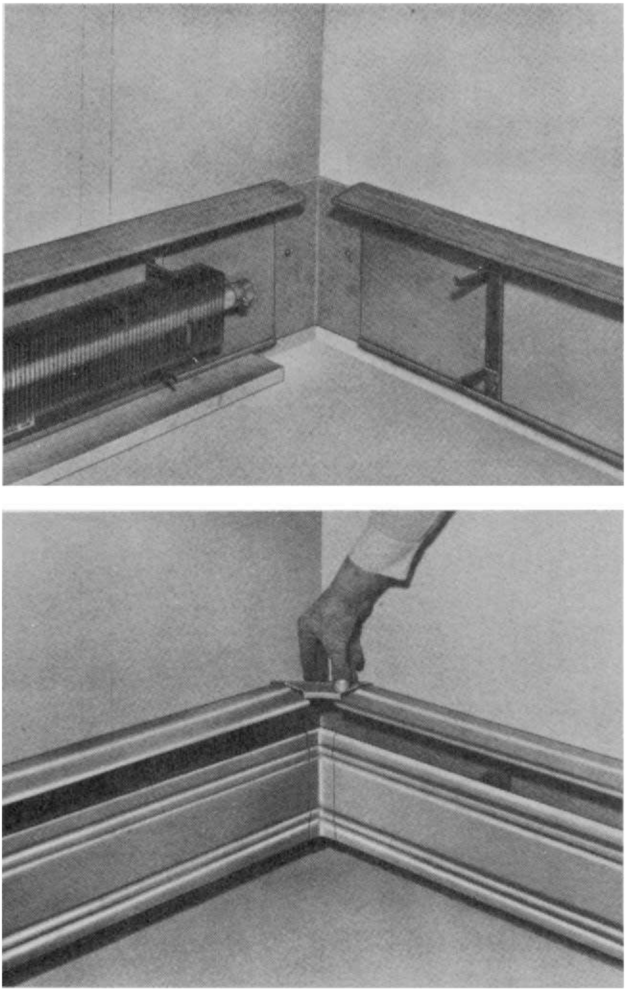


Figure 2-75 Inside-corner installation. *(Courtesy Vulcan Radiator Co.)*

Unit Heaters

A *unit heater* is an independent, self-contained appliance designed to supply heat to a given space. It is frequently referred to as a *space heater.*

The typical unit heater consists of a heating element, a fan or propeller and motor, and a metal casing or enclosure. Unit heaters supply heat by forced convection using steam, hot water, gas, oil, or

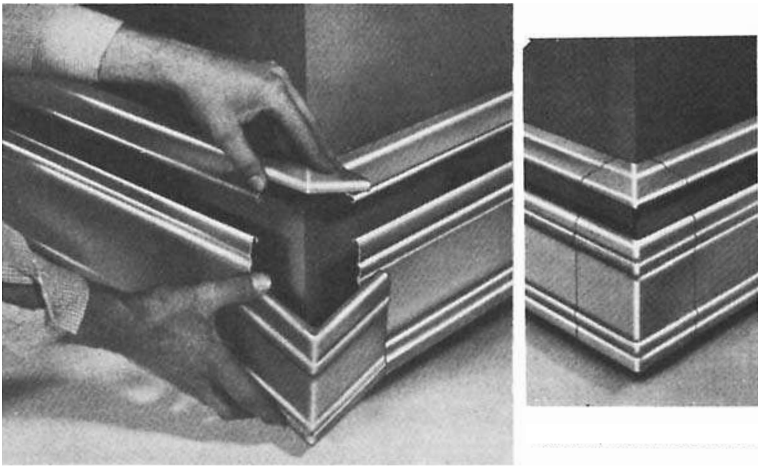


Figure 2-76 Outside-corner installation. *(Courtesy Vulcan Radiator Co.)*

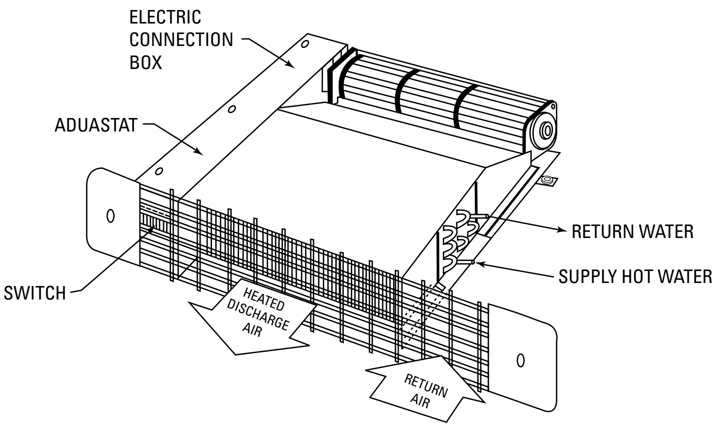


Figure 2-77 Kickspace heater. *(Courtesy Beacon/Morris)*

electricity as the heat source. The air is drawn into the unit heater and forced over the heating surfaces by a propeller or a centrifugal fan before it is expelled on a horizontal or vertical air current (see Figure 2-83).

Horizontal heaters have a specially designed broad-blade fan and are used for horizontal discharge space and spot heating assignments. When equipped with louver fin diffusers, the air stream can be directed in an unlimited number of diffusion patterns. A typical horizontal pipe suspended unit heater is shown in Figure 2-84.

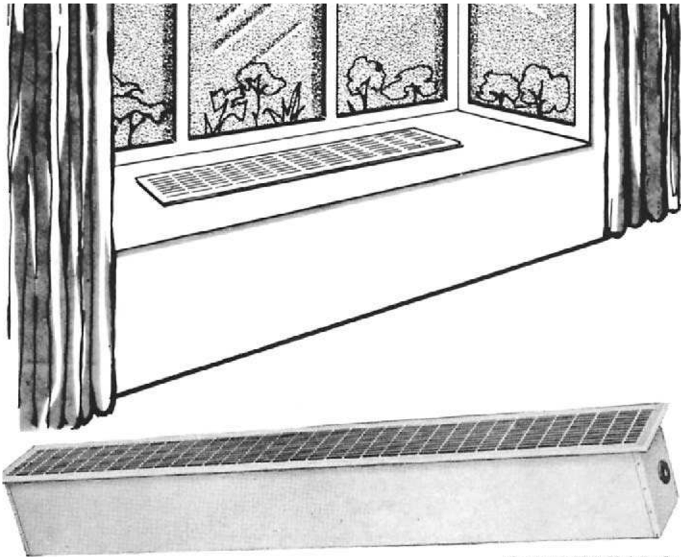


Figure 2-78 Typical floor recessed unit. *(Courtesy Weil-McLain Co.)*

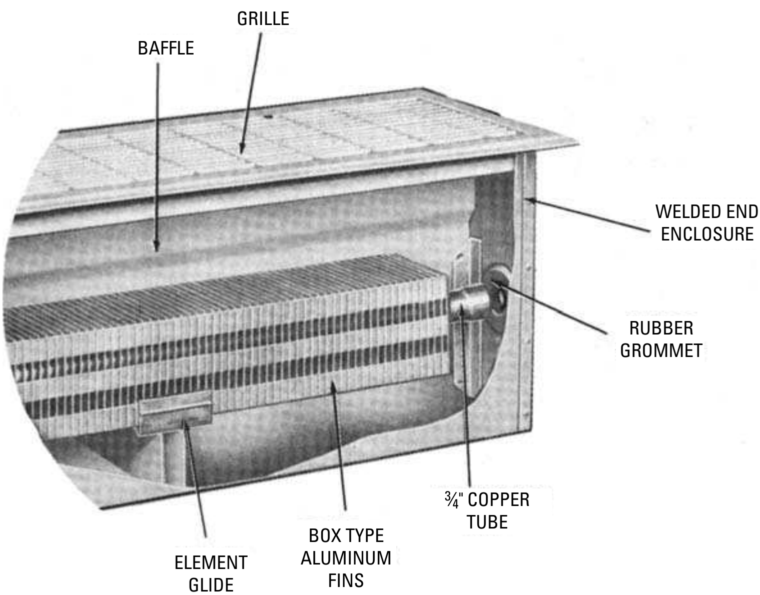


Figure 2-79 Typical components of a recessed radiation unit. *(Courtesy Weil-McLain Co.)*

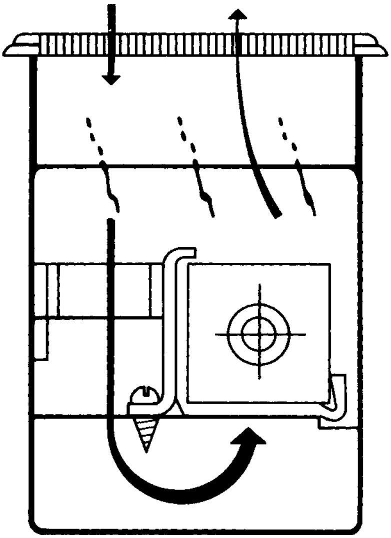


Figure 2-80 Operating principle. *(Courtesy Weil-McLain Co.)*

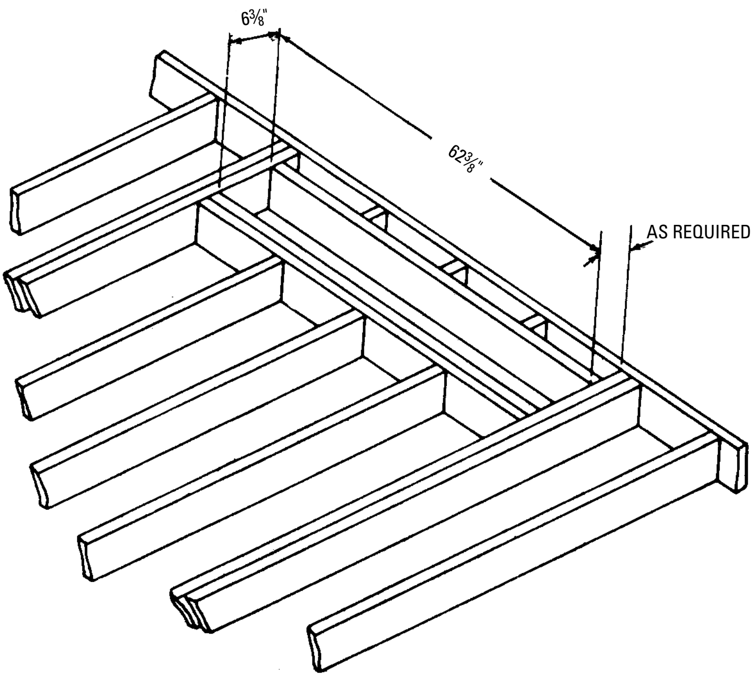


Figure 2-81 Wood floor opening. *(Courtesy Weil-McLain Co.)*

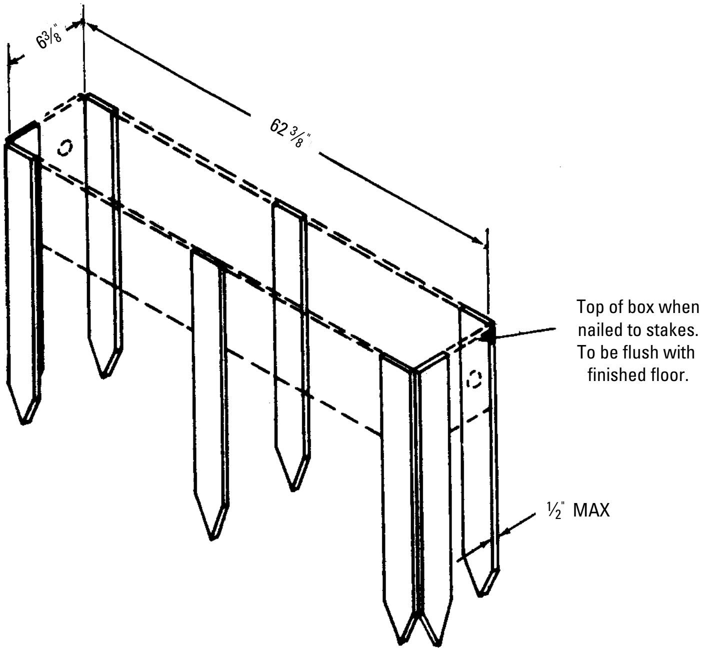


Figure 2-82 Stake arrangement for masonry floor opening.
(Courtesy Weil-McLain Co.)

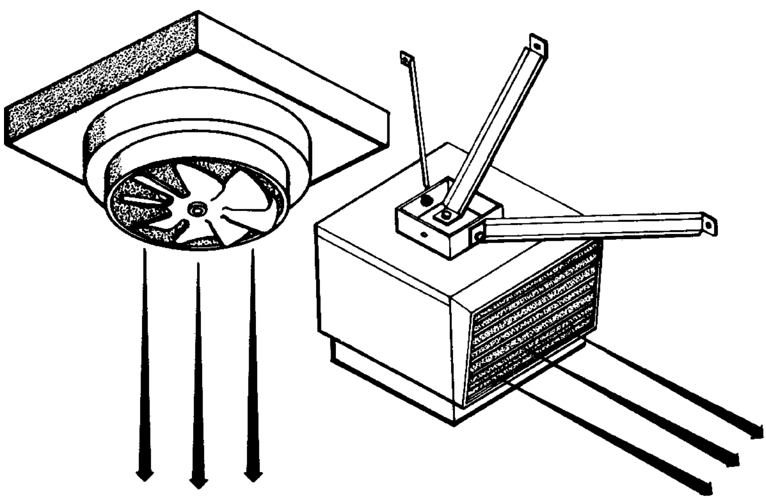


Figure 2-83 Typical air discharge paths. *(Courtesy Vulcan Radiator Co.)*

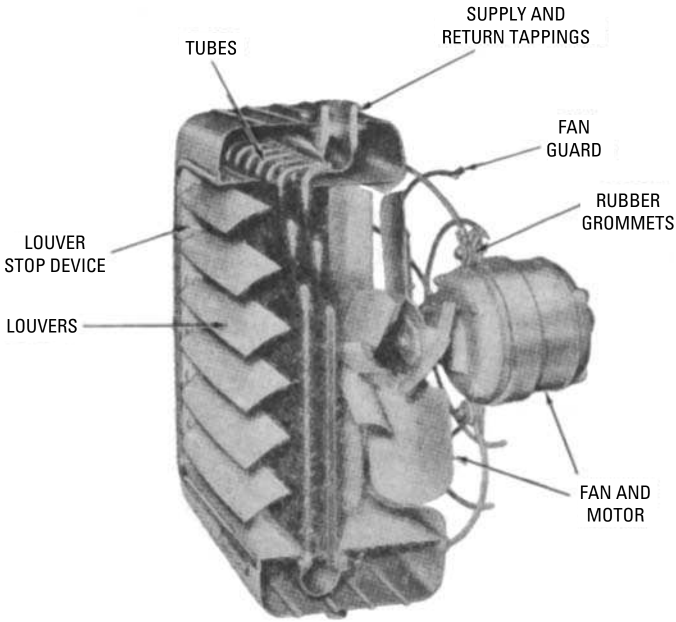


Figure 2-84 Direct pipe suspended horizontal unit heater.

Forced-air unit heaters are small blower units that exhibit several times the capacity of a gravity circulation unit of the same size.

Unit Heater Piping Connections

The following general notes on piping propeller unit heaters are presented based on competent engineering installation practice:

1. Suspend unit heaters securely with provisions for easy removal.
2. Make certain that units hang level vertically and horizontally.
3. Provide for expansion in supply lines. Note swing joints in suggested piping arrangements.
4. Provide unions adjacent to unit heaters in both supply and return laterals. Also provide shutoff valves in all supply laterals.
5. Use 45°-angle runoffs from all supply and return mains.
6. Make certain that you have provided minimum clearances on all sides. Clearances will be specified in the heater manufacturer's installation literature.

7. When required, dirt pockets should be formed with pipe of the same size as the return tapping of the unit heater.
8. Pipe in the branching line should be the same size as the tapping in the trap.

Figures 2-85 through 2-90 illustrate typical piping details for propeller-type horizontal unit heaters used in steam and hot-water heating systems.

The vapor steam system shown in Figure 2-85 uses an overhead steam main and a gravity dry return. Strainer and float-type steam traps are used between the unit heater and the return main. A float-type air vent is installed below the float trap.

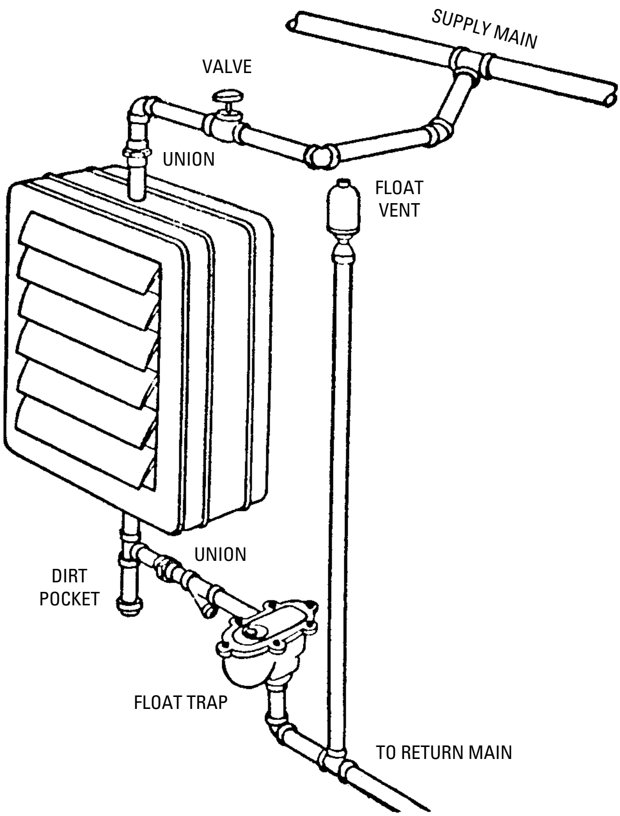


Figure 2-85 Piping connections for a vapor steam heating system.

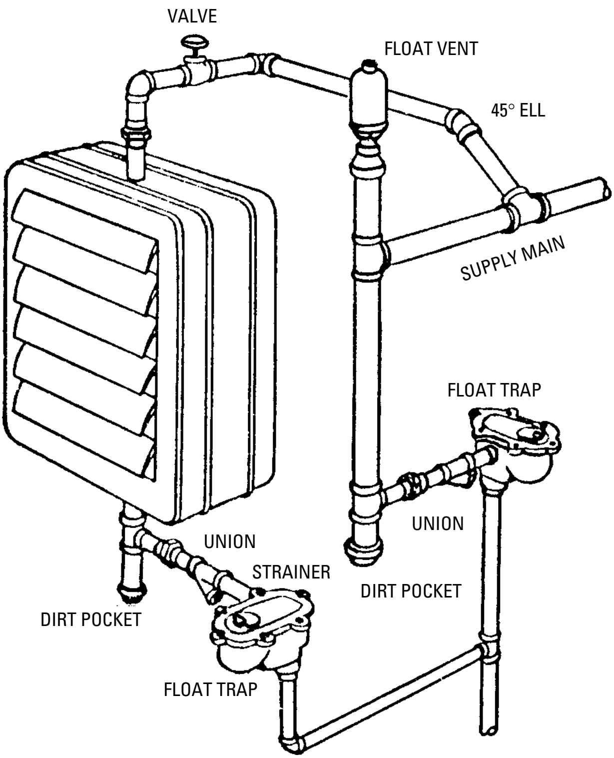


Figure 2-86 Piping connections for a low-pressure or vacuum steam heating system.

As shown in Figure 2-86, the overhead steam main of a low-pressure or vacuum system can be vented and dripped independently. The steam supply to the unit heater is taken off the top of the main. The float vent is eliminated on systems using a vacuum pump.

Overhead supply and return mains are used (with bottom connections to the mains) in forced hot-water heating systems. The supply main is connected to the bottom of the unit heater. Either an automatic air vent or manual vent (pet cock) can be used at the high point on the return main (see Figure 2-87).

In the two-pipe steam system shown in Figure 2-88, the steam supply of the unit heater is taken from the top of the main. The return from the unit heater is vented before dropping to the wet return. The distance to the water line of the boiler must be sufficient to allow for the pressure drop in the piping.

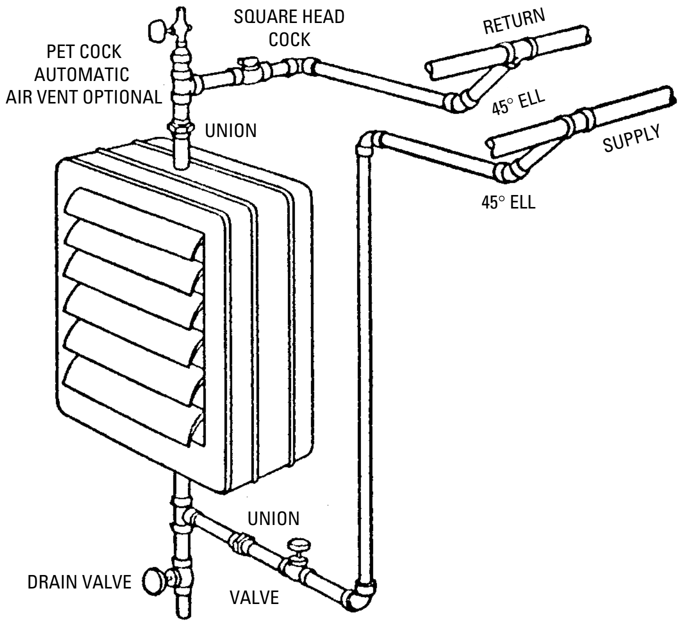


Figure 2-87 Piping connections for a forced hot-water heating system.

Both an overhead supply main and an overhead return are used in the high-pressure steam system shown in Figure 2-89. The top of the bucket trap must be located below the return outlet of the coil for complete drainage of the condensation.

Unit heater piping connections for a Trane high-pressure steam system are illustrated in Figure 2-90. In this system, an overhead supply main is used with a lower return main. Where steam pressure fluctuates over a wide range, a swing-check valve should be placed in the return lateral between the strainer and the bucket trap to prevent reverse flow of the condensation or steam flashing when the pressure drops suddenly. The top of the bucket trap must be located below the return outlet of the coil for complete drainage of the condensation.

Unit Heater Controls

Two control systems are used with unit heaters. The simpler type provides on-off operation of the fan. The other system provides

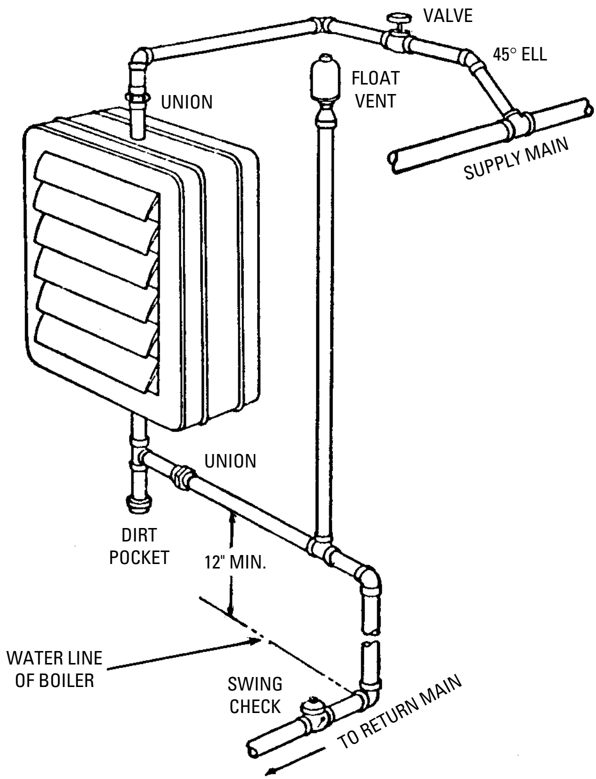


Figure 2-88 Piping connections for a two-pipe steam heating system.

modulating control of the heat source and continuous operation of the fan. It is considered the more effective control system.

Modulating control is obtained with either pneumatic or electric equipment. It allows a constant discharge of warm air and eliminates intermittent blasts of hot air. The continuous circulation prevents air stratification, which occurs when the fan is off. A proportional room thermostat governs a valve that controls the heat source or a bypass around the heating limit. Fan operation is governed by an auxiliary switch or a limit thermostat. Either device is designed to stop the fan when the heat is shut off.

In an on-off control system, the fan motor is controlled by a room thermostat. A backup safety device in the form of a limit

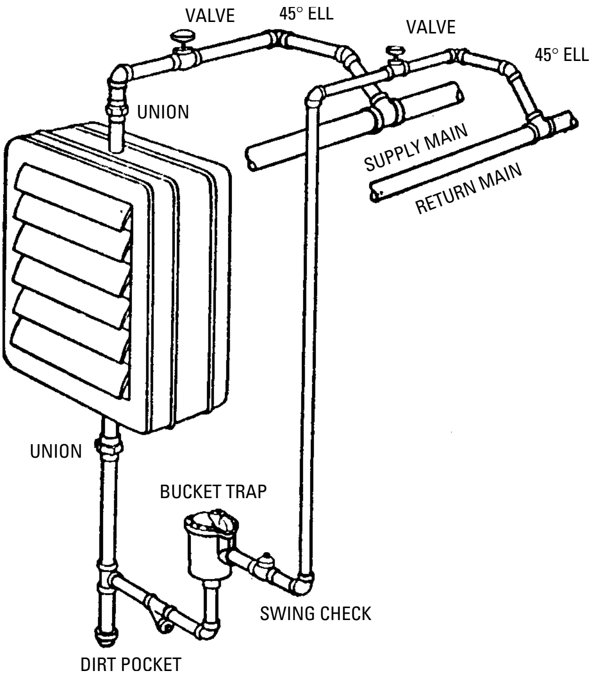


Figure 2-89 Piping connections for a standard high-pressure steam heating system.

thermostat will stop the fan when heat is no longer being supplied to the unit heater.

Gas-Fired Unit Heaters

A gas-fired unit heater is designed to operate on either natural or propane gas (see Figure 2-91). These units should be installed in a location where there will be sufficient ventilation for combustion and proper venting under normal conditions of use.

Local codes and regulations should be followed closely when installing a gas-fired unit heater.

The automatic controls used to operate a gas-fired unit heater closely resemble those found on other types of gas heating equipment, such as furnaces, boilers, and water heaters. For example, the unit heater illustrated in Figure 2-92 is equipped with a 24-volt gas valve with a built-in pilot relay, pilot gas adjustment, shutoff device for use with a thermocouple-type pilot for complete gas shutoff operation, and a gas-pressure regulator.

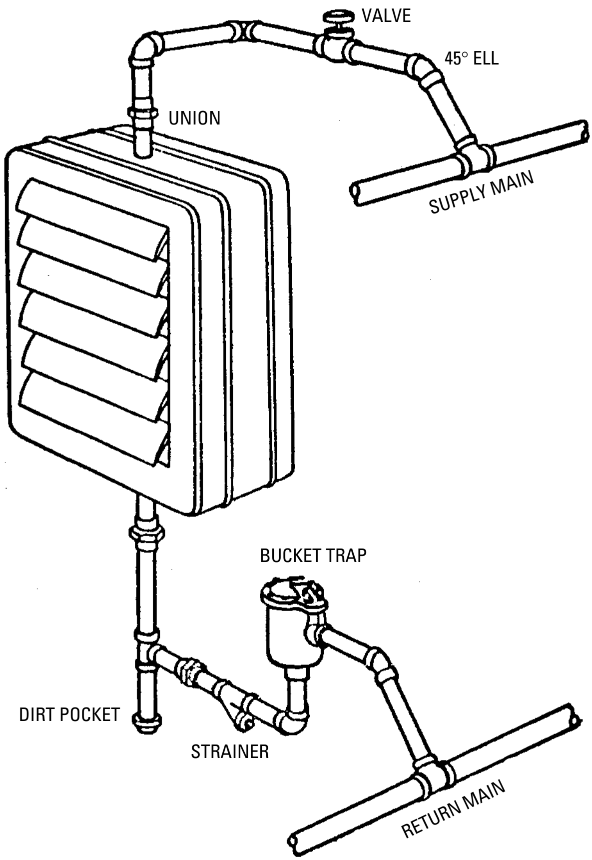


Figure 2-90 Piping connections for a Trane high-pressure steam heating system. *(Courtesy The Trane Co.)*

A separate gas-pressure regulator and pilot valve are generally supplied with control systems when the gas valve does not have a built-in gas-pressure regulator. The usual fan and limit controls are used on most gas-fired unit heaters. A wiring diagram for a typical control system is shown in Figure 2-93.

Oil-Fired Unit Heaters

Direct oil-fired, suspended unit heaters operate on the same principle as the larger oil-fired heating equipment (furnaces, boilers, water heaters, and so on). An oil burner located on the outside of

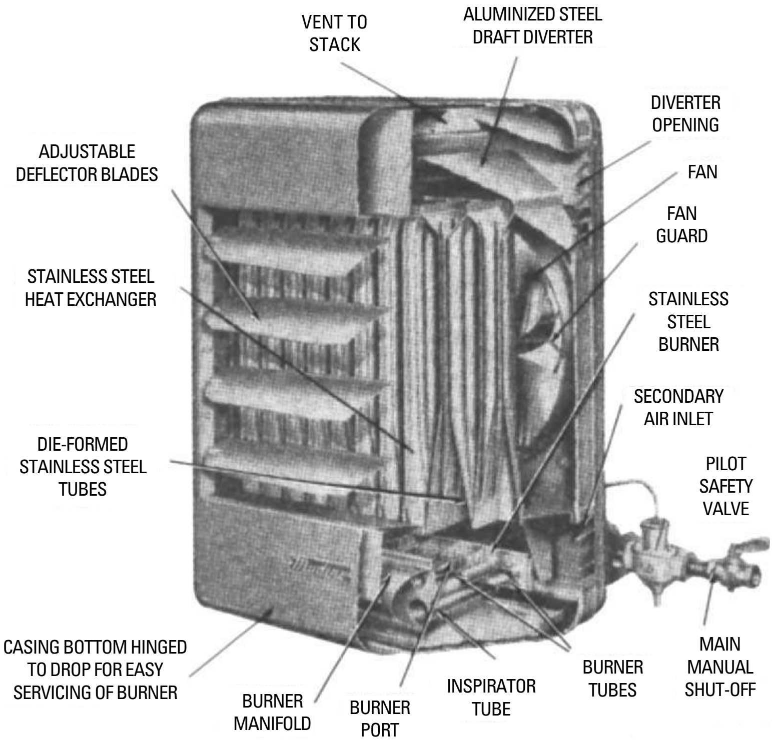


Figure 2-91 Modine gas-fired unit heater showing principal components. *(Courtesy Janitrol)*

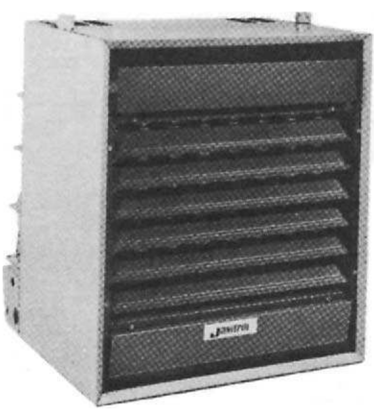


Figure 2-92 Gas-fired unit heater. *(Courtesy National Oil Fuel Institute)*

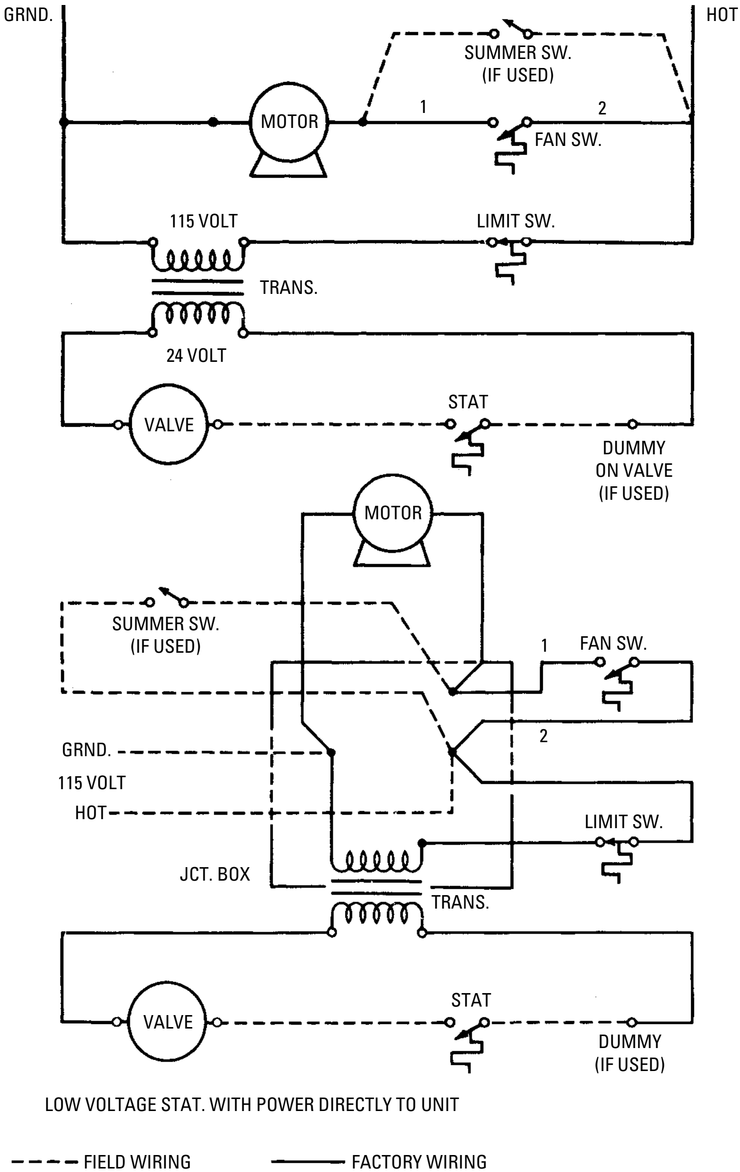


Figure 2-93 Wiring diagram for a gas-fired unit heater. *(Courtesy Janitrol)*

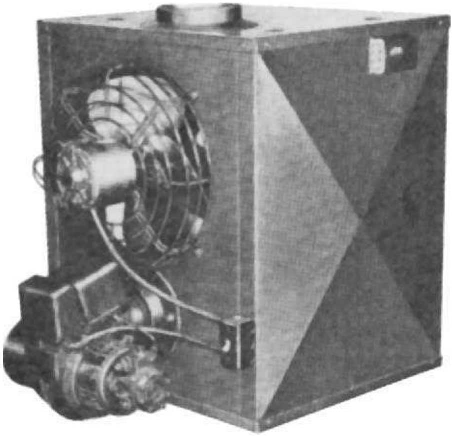


Figure 2-94 Oil-fired unit heater. *(Courtesy National Oil Fuel Institute)*

the unit supplies heat to the combustion chamber, and a fan blows the heat into the room or space to be heated (see Figure 2-94).

An oil-fired unit heater should be located where it will heat efficiently and where it will receive sufficient air for combustion. Proper venting is also important. The waste products of the combustion process must be carried to the outdoors.

Chapter 3

Fireplaces, Stoves, and Chimneys

Until recently, fireplaces, stoves, ranges, wood heaters, and similar heating apparatus were the only sources of heat for cooking, domestic hot water, and personal comfort. These apparatus generally burned solid fuels, such as wood, coke, or the different types of coal, but many later models could also be modified to burn fuel oil, gas (both natural and manufactured), and kerosene.

Central heating and the availability of clean, inexpensive, nonsolid fuels (natural gas, oil, and electricity) have relegated these heating apparatus to a minor, decorative role except in remote rural areas of the country. At least this has been the situation until the late 1960s. The growing interest among people in leaving the cities and returning to the land, and the rising cost and potential scarcity of the more popular heating fuels, has brought renewed interest in the solid-fuel-burning fireplace, stove, range, and heater.

Fireplaces

A fireplace is essentially a three-sided enclosure in which a fire is maintained. The heat from the fire enters the room from the open side of the enclosure. The traditional masonry fireplace is a recessed opening in the wall directly connected to a chimney. Modern prefabricated, freestanding fireplaces resemble stoves, but their operating principle is still that of the traditional fireplace; that is to say, heat is radiated from the opening out into the room.

Although a fireplace is not as complicated an apparatus as the furnace or boiler of a modern central heating system, its location, dimensions, and construction details still require careful planning if maximum heating efficiency and trouble-free operation are desired. These aspects of fireplace design and construction are examined in the sections that follow.

Fireplace Location

The location of the fireplace is determined by the location of the chimney. Unfortunately, chimney location—particularly in newer homes—is too often dictated by how the chimney will look, rather than how it will work. As a result, the chimney is often made too low or located where it may be obstructed by a section of the house or building. The top of the chimney should be at least 2 feet higher than the roof.

Fireplace Dimensions

The principal components of a masonry fireplace are described in the next section (*Fireplace Construction Details*). The following components are important to the operation of a fireplace:

1. The opening
2. The throat
3. The smoke chamber (and shelf)
4. The damper
5. The flue

These components are interdependent and must be properly dimensioned with respect to one another or the fireplace will not operate properly. Table 3-1 lists typical dimensions for finished masonry fireplaces, and these dimensions are identified in Figures 3-1, 3-2, and 3-3.

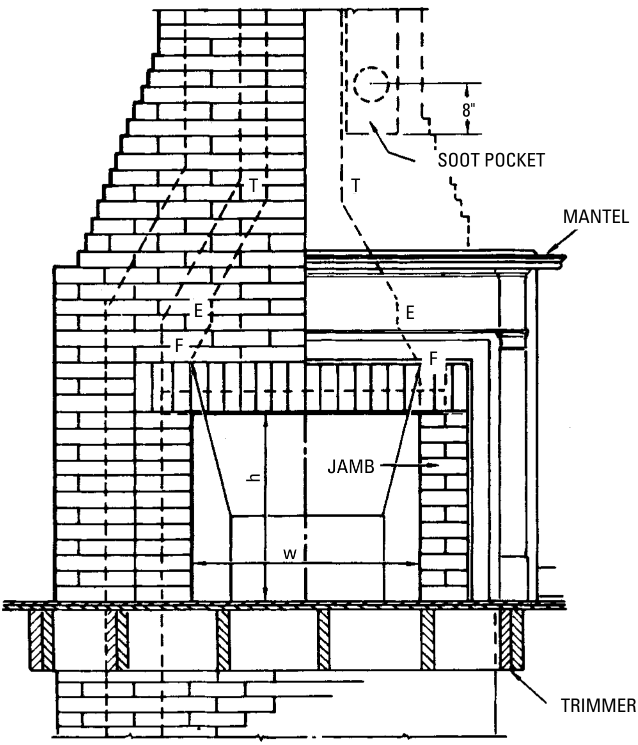


Figure 3-1 Fireplace elevation.

Table 3-1 Recommended Dimensions for a Finished Masonry Fireplace (Letters at heads of columns refer to Figures 3-1, 3-2, and 3-3.)

Opening							
Width, w	*Height, h*	*Depth, d*	*Minimum Back (Horizontal), c*	*Vertical Back Wall, a*	*Inclined Back Wall, b*	*Outside Dimensions of Standard Rectangular Flue Lining*	*Inside Diameter of Standard Round Flue Lining*
(in)	*(in)*	*(in)*	*(in)*	*(in)*	*(in)*	*(in)*	*(in)*
24	24	16–18	14	14	16	8½ by 8½	10
28	24	16–18	14	14	16	8½ by 8½	10
24	28	16–18	14	14	20	8½ by 8½	10
30	28	16–18	16	14	20	8½ by 13	10
36	28	16–18	22	14	20	8½ by 13	12
42	28	16–18	28	14	20	8½ by 18	12
36	32	18–20	20	14	24	8½ by 18	12
42	32	18–20	26	14	24	13 by 13	12
48	32	18–20	32	14	24	13 by 13	15
42	36	18–20	26	14	28	13 by 13	15
48	36	18–20	32	14	28	13 by 18	15
54	36	18–20	38	14	28	13 by 18	15
60	36	18–20	44	14	28	13 by 18	15
42	40	20–22	24	17	29	13 by 13	15
48	40	20–22	30	17	29	13 by 18	15
54	40	20–22	36	17	29	13 by 18	15
60	40	20–22	42	17	29	18 by 18	18
66	40	20–22	48	17	29	18 by 18	18
72	40	22–28	51	17	29	18 by 18	18

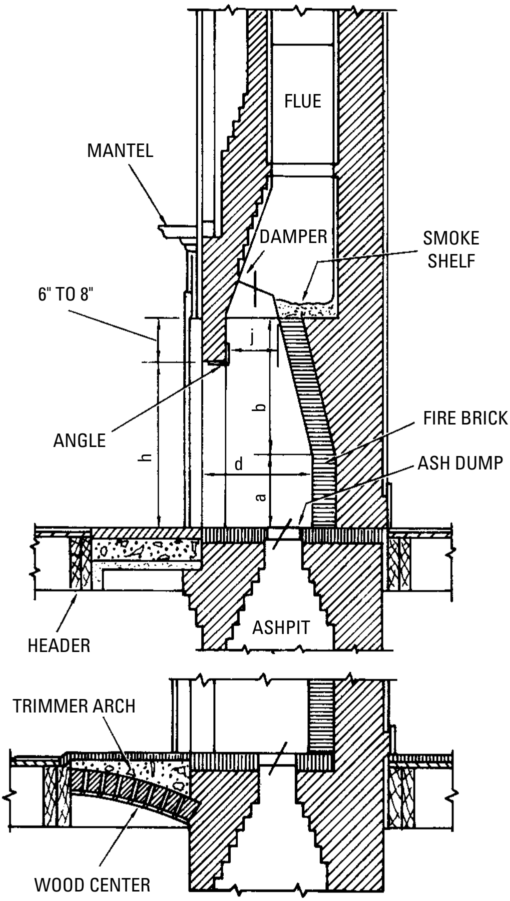


Figure 3-2 Fireplace sectional view illustrating two types of hearth construction.

The dotted lines and letters (*FF*, *EE*, and *TT*) in Figure 3-1 are used to indicate the dimensions of the throat, smoke chamber, and flue. The throat (or damper opening) is identified by the line *FF* in Figure 3-1. The throat should be approximately 6 to 8 inches (or more) above the bottom of the lintel. The area of the throat should be not less than that of the flue, and its length should be equal to the width of the fireplace opening.

Starting approximately 5 inches above the throat (that is, at line *EE*), the inner wall surfaces should gradually slope inward approximately 30° to the beginning of the chimney flue (line *TT* in Figure 3-1).

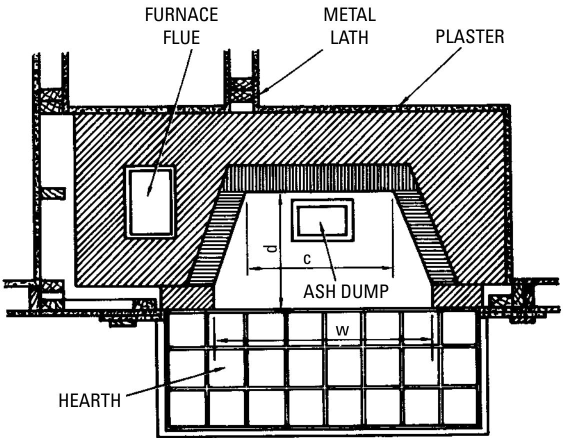


Figure 3-3 Fireplace plan.

The smoke chamber is the area between the throat and the beginning of the flue (that is, between lines *EE* and *TT* in Figure 3-1). The smoke shelf is the area extending from the throat to the line of the flue wall (see Figure 3-2). This dimension will vary depending on the depth of the firebox. The damper opening (throat) should *never* be less than the flue area.

Fireplace Construction Details

Construction details of a typical masonry fireplace are shown in Figure 3-4. Because this type of fireplace is recessed in a wall, it is easier and less expensive to build it while the structure is under construction.

The principal components of a masonry fireplace are as follows:

1. Firebox
2. Lintel
3. Mantel
4. Hearth
5. Ashpit
6. Ash dump
7. Cleanout door
8. Smoke chamber
9. Smoke shelf
10. Throat

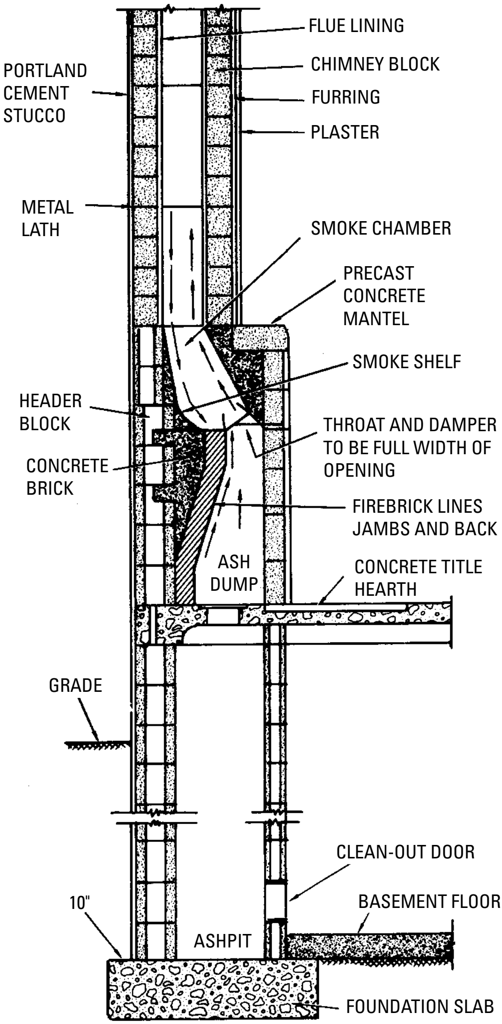


Figure 3-4 Construction details of a masonry fireplace.

11. Damper
12. Flue and flue lining

Firebox, Lintel, and Mantel

That portion of the fireplace in which the fire is maintained is sometimes called the *firebox*. This is essentially a three-sided enclosure

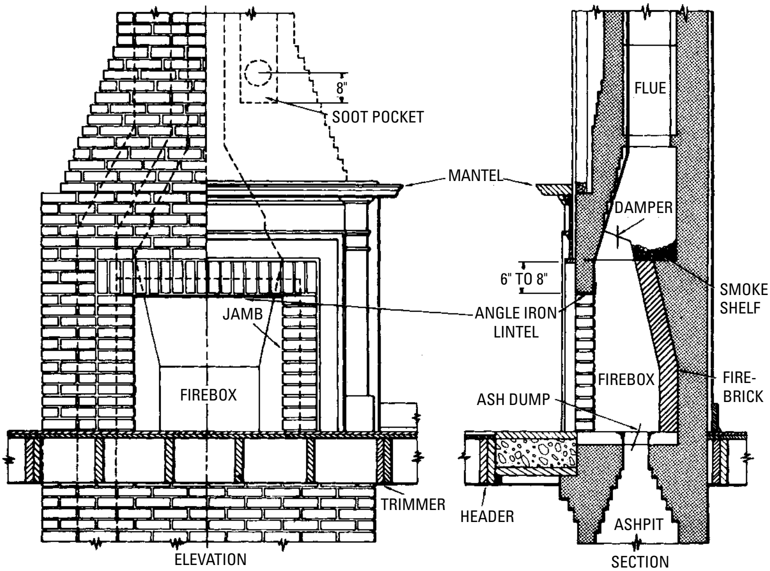


Figure 3-5 Firebox, lintel, and mantel.

with the open side facing the room. The area (in square inches) of the fireplace opening is directly related to the area of the chimney flue. The rule-of-thumb is to make the fireplace opening approximately 12 times the area of the flue.

As shown in Figure 3-5, the *lintel* spans the top of the fireplace opening. This is a length of stone or metal used to support the weight of the fireplace superstructure. The *mantel* is a horizontal member extending across the top of the fireplace where it generally serves a decorative function. Sometimes the terms mantel and lintel are used synonymously. When this is the case, the mantel is used in the form of a wood beam, stone, or arch and functions as a lintel to support the masonry above the fireplace opening.

Fireplace Hearth

The *hearth* is the surface or pavement in the fireplace on which the fire is built. The hearth is sometimes made flush with the floor and will extend out in front of the fireplace opening where it provides protection to the floor or floor covering against flying embers or ashes (see Figure 3-3). The recommended length of the hearth is the width of the fireplace opening *plus* 16 inches.

Ash Dump, Ashpit, and Cleanout Door

Figure 3-6 Centrally pivoted ash dump.
(Courtesy Portland Stove Foundry Co.)

An *ashpit* is a chamber located beneath the fireplace where the ashes from the fire are collected. An *ash dump* should be installed in the hearth toward the back of the fireplace. This is a metal plate that is pivoted so that the ashes can be easily dropped into the ashpit (see Figure 3-6). Ashes are removed from the ashpit through a *cleanout door* (see Figure 3-7).

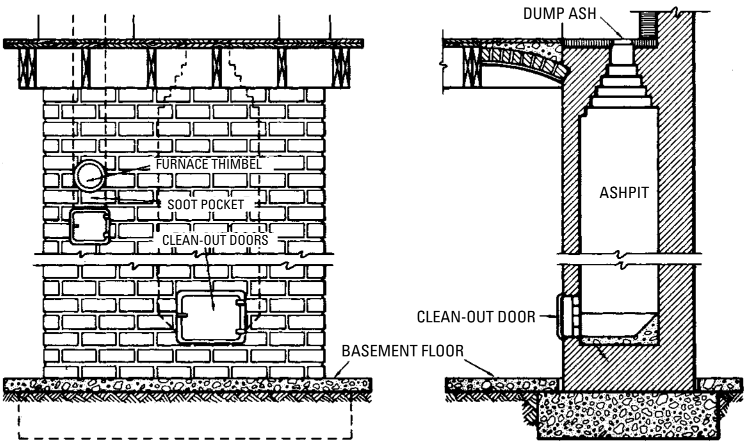


Figure 3-7 Location of ash dump, ashpit, and cleanout door.

Smoke Chamber

The *smoke chamber* of the fireplace is a passage leading from the throat to the chimney flue (see Figure 3-4). It should be constructed so that it slopes at a 45° angle from the smoke shaft to the flue opening. The smoke chamber should also be constructed so that a smoke shelf extends straight back from the throat to the back of the flue line. The purpose of the smoke shelf is to prevent downdrafts from flowing into the fireplace. The damper should be mounted on the smoke shelf so that it covers the throat when it is closed. When open, the damper functions as a baffle against downdrafts.

Fireplace Dampers

One of the most frequent complaints about fireplaces is smoke backing up into the room. This condition, particularly if it persists, can usually be traced to a problem with the damper.

On very rare occasions, a fireplace and chimney will be built without a damper. When this is the case, the construction should be modified to incorporate a suitable damper; otherwise, it will be impossible to build and maintain a fire in the fireplace.

The damper should be installed at the front of the fireplace and should be wide enough to extend all the way across the opening. The two most common locations for a fireplace damper are shown in Figures 3-8 and 3-9. If the damper is placed higher up in the chimney, it is controlled with a long operating handle extending to just under the edge of the fireplace opening.

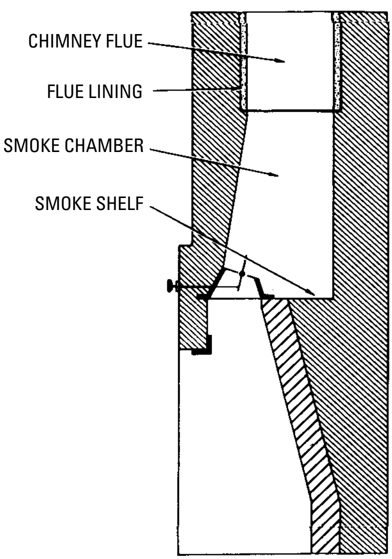


Figure 3-8 Damper mounted on edge of smoke shelf.
(Courtesy Portland Stove Foundry Co.)

A rotary-control damper designed for use in the throat of a fireplace is shown in Figure 3-10. This particular damper has a tilting lid that rotates on its lower edge rather than on centrally located pivots like other rotary dampers (see Figure 3-11). The lid is operated by a brass handle attached to a rod that extends through the face brick or tiling over the fireplace opening. Dampers equipped with ratchet-control levers are shown in Figure 3-12.

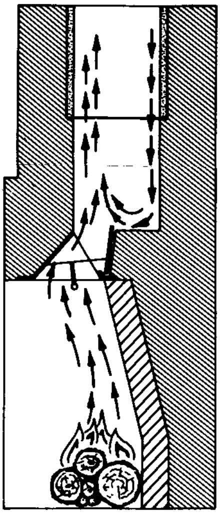


Figure 3-9 Damper installed just above the fireplace opening. *(Courtesy Portland Stove Foundry Co.)*

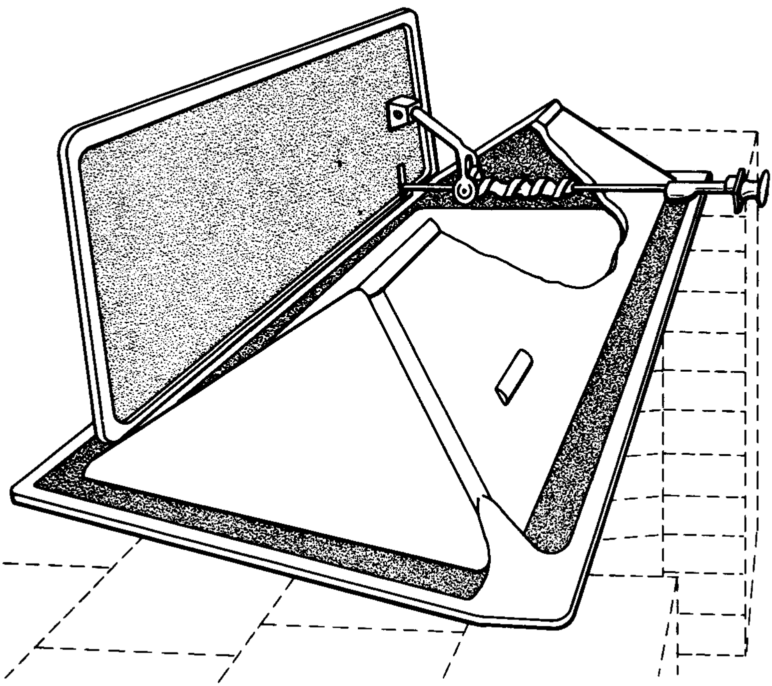


Figure 3-10 Rotary damper with lid that rotates on its lower edge. *(Courtesy Portland Stove Foundry Co.)*

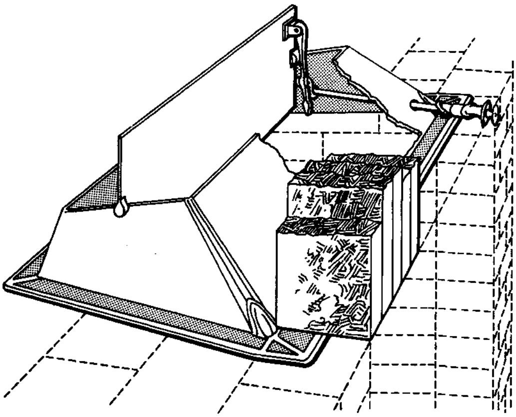


Figure 3-11 Rotary damper with lid that tilts on centrally located pivots. *(Courtesy Portland Stove Foundry Co.)*

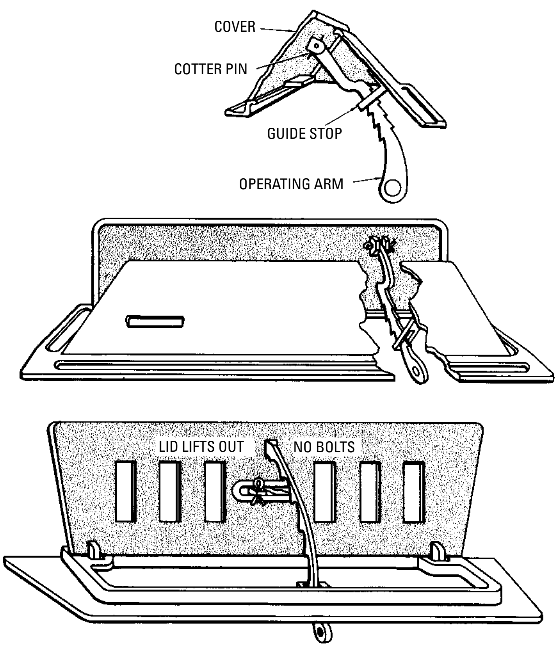


Figure 3-12 Damper equipped with ratchet-control levers.
(Courtesy Portland Stove Foundry Co.)

Modified Fireplaces

A *modified fireplace* consists of a heavy metal manufactured unit designed to be set in place and concealed by brickwork or other masonry construction (see Figures 3-13, 3-14, and 3-15).

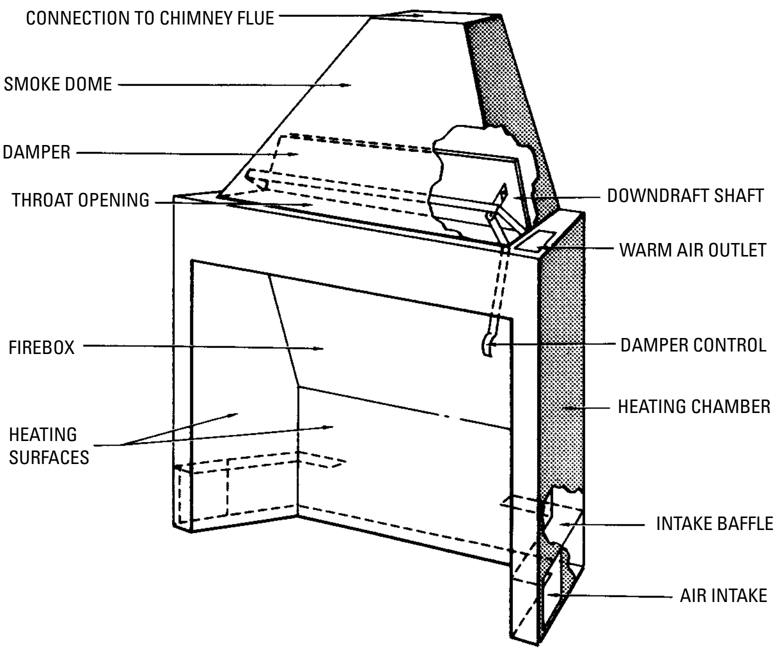


Figure 3-13 Prefabricated firebox used in the construction of a modified fireplace.

Modified fireplaces are usually more efficient than the all-masonry type because provisions are made for circulating the heated air. As shown in Figure 3-16, cool air enters the inlets at the bottom and is heated when it comes into contact with the hot surface of the metal shell. The heated air then rises by natural circulation and is discharged through the outlets at the top. These warm-air outlets may be located in the wall of the room containing the fireplace, in the wall of an adjacent room, or in a room on the second floor. Sometimes a fan is installed in the duct system to improve the circulation.

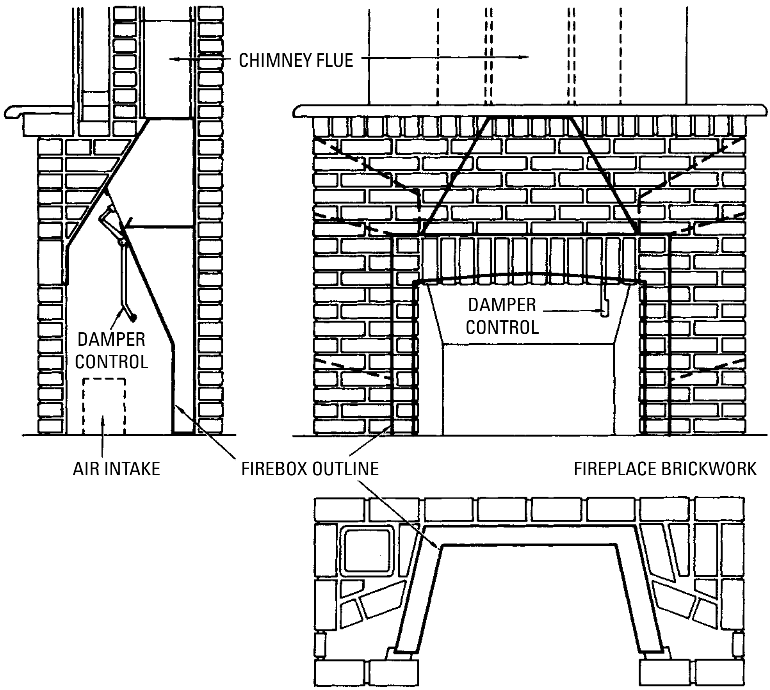


Figure 3-14 Construction details of a modified fireplace.

Freestanding Fireplaces

A *freestanding fireplace* is a prefabricated metal unit sold at many hardware stores, building supply outlets, and lumberyards.

Some typical examples of freestanding fireplaces are shown in Figures 3-17 and 3-18. These fireplaces are exposed on all sides, and their operation is essentially identical to stoves. They are available in a wide variety of styles and colors, and they are easy to install and operate. Because they are lightweight, no special supportive foundation is necessary, although it is a good idea to install a base under the unit to prevent stray sparks and embers from falling onto the floor or floor covering. Most local codes and regulations require that a protective base be used, and the manufacturer's installation literature probably also recommends its use.

The protective base serves the same purpose as a hearth extension on a masonry or modified fireplace. The base should be made from some sort of noncombustible material and should be large

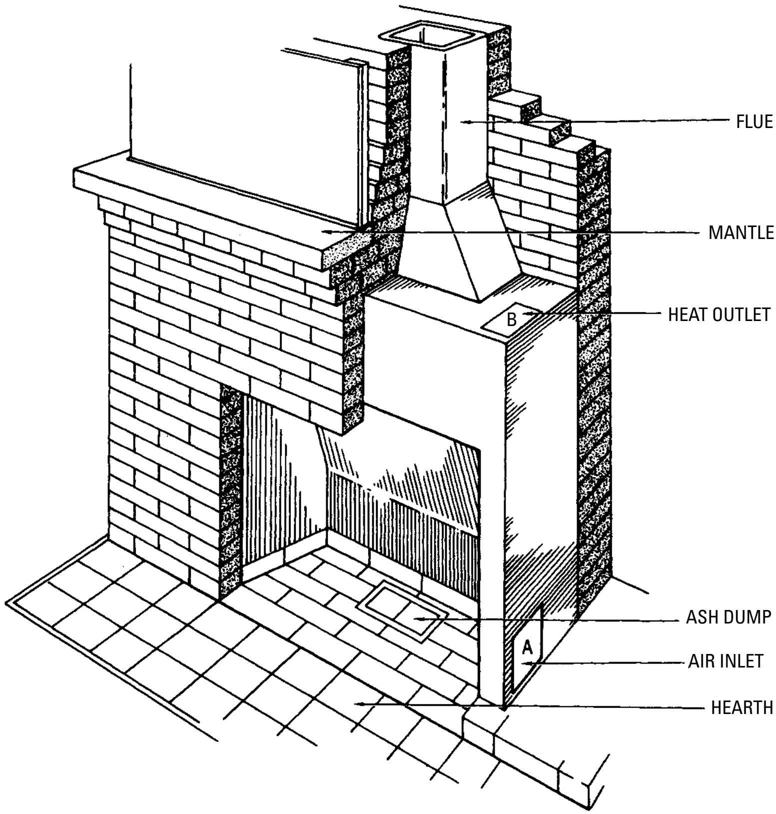


Figure 3-15 Typical modified fireplace.

enough in area to extend at least 12 inches beyond the unit in all directions (see Figure 3-19).

Rumford Fireplace

Most of the heat produced by a fireplace is radiant heat. Radiant heat moves in a straight line from its source to the nearest solid object, which may be a wall, floor, ceiling, or a piece of furniture, leaving the air through which it passes unaffected. These solid objects absorb the radiant heat and transfer it to the air by conduction and convection. The fireplace design that produces the maximum amount of radiant heat is the Rumford fireplace.

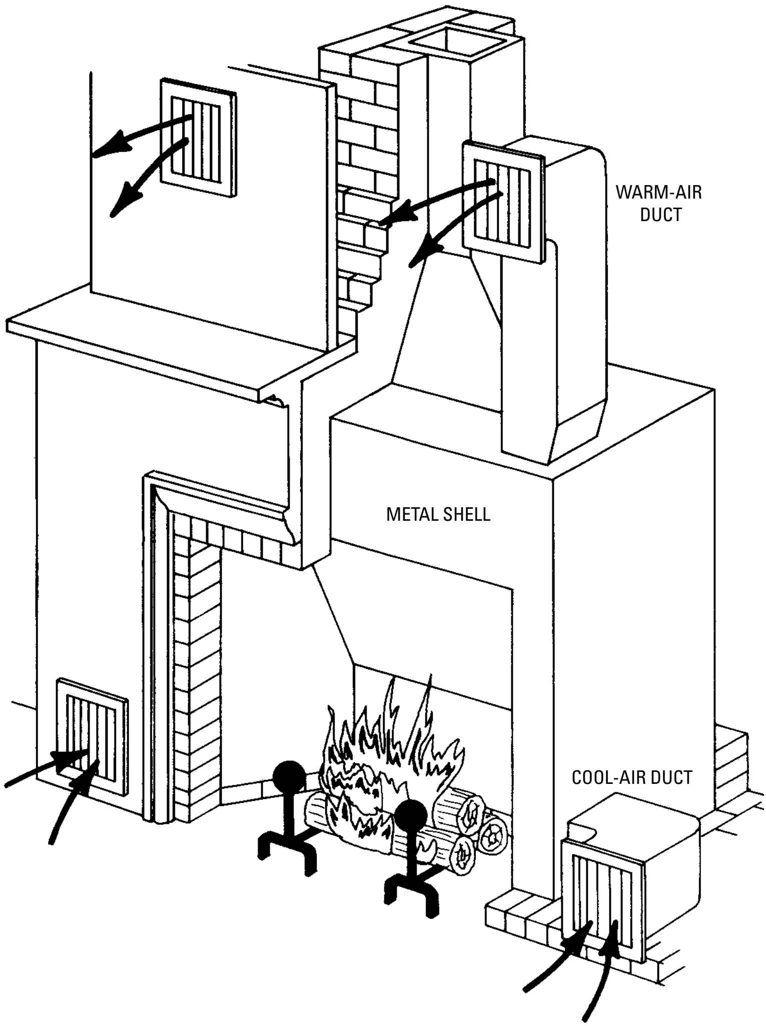


Figure 3-16 Operating principles of a modified fireplace.

Count Rumford and His Fireplace

The Rumford fireplace is not a modern design. It was invented in the eighteenth century by Benjamin Thompson, an American and a contemporary of Benjamin Franklin. Both Thompson and Franklin were concerned with the problem of improving the efficiency of the fireplace, which was the primary heat source for structures in the eighteenth century. The fireplaces of that time were smoky, sources of drafts, passageways for heat to escape from the rooms, and inefficient producers of heat. Benjamin Franklin's successful approach to the problem was to replace the masonry fireplace built into the wall of the structure with a freestanding, metal, wood-burning stove. Franklin stoves were used for both space-heating and cooking. Benjamin Thompson's approach was to redesign the dimensions of the fireplace to make it more efficient. The design proved very successful, and many Rumford fireplaces were built and used as primary space-heating sources for houses until they were replaced by central heating systems in the late nineteenth and early twentieth centuries. Thompson left America in 1796 and settled in Europe, where he lived for the remainder of his life. It was during that period that he was awarded the title Count Rumford. The name Rumford later became associated with his fireplace design.

A Rumford fireplace differs from a traditional one principally in its shallower firebox, its steeply angled sidewalls (built at a sharp 45° angle), and its lower fireback (back wall) (see Figure 3-20). This type of firebox radiates heat down to the floor at different angles instead of straight into the room on a horizontal path, as

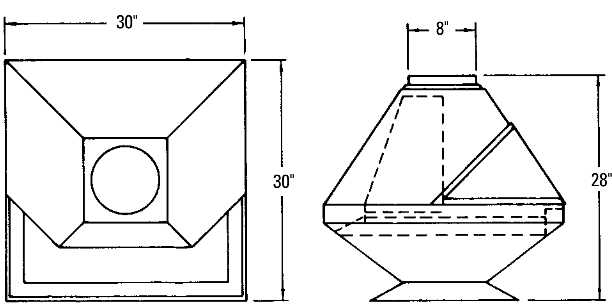


Figure 3-17 Wall-model freestanding fireplace. *(Courtesy Malm Fireplace, Inc.)*

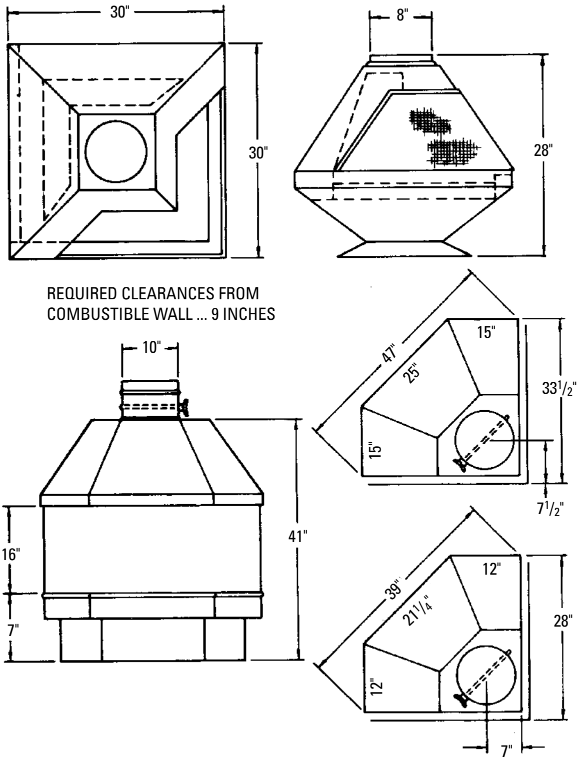


Figure 3-18 Corner-model freestanding fireplace. *(Courtesy Malm Fireplace, Inc.)*

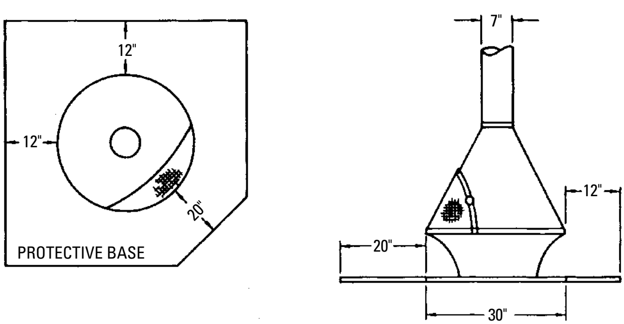


Figure 3-19 Dimensions of a typical protective base showing clearances of fireplace. *(Courtesy Malm Fireplace, Inc.)*

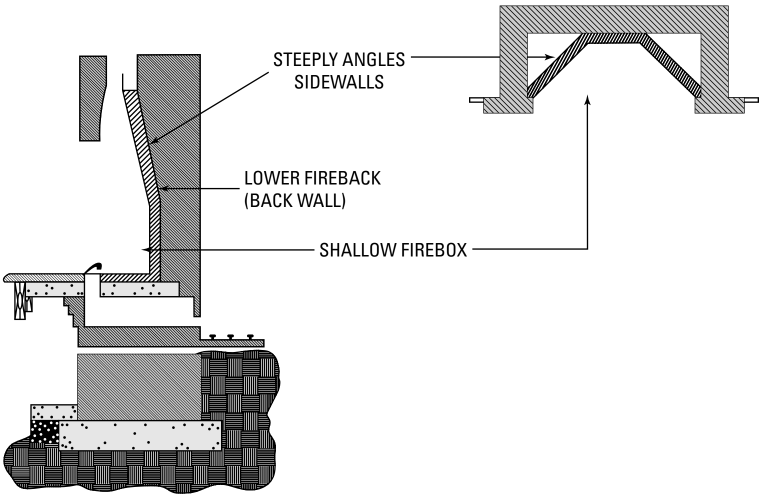


Figure 3-20 Distinguishing features of a Rumford fireplace.

does a traditional fireplace. The floor absorbs the radiant heat and transfers it to the room air by conduction and convection.

The throat of a Rumford fireplace is located in such a way that a plumb line can be dropped from the center of the throat to the center of the firebox (see Figure 3-21). This straight vertical path from the firebox to the chimney flue minimizes turbulence which, when present, restricts the flow of smoke and gases. Turbulence in a Rumford fireplace can be further reduced by modifying the horizontal smoke shelf so that it slopes upward from the throat to the vertical wall of the flue.

A damper is normally installed at the throat of a Rumford fireplace, as in traditional types, but some Rumford fireplaces also have dampers at both the throat and the top of the chimney. In theory, the use of two dampers traps warm air in the chimney, thereby preventing cold downdrafts. The best performance for a Rumford fireplace is obtained by using an exterior air supply.

Chimney Draft

A properly designed and constructed chimney is essential to a fireplace because it provides the draft necessary to remove the smoke and flue gases. The motive power that produces this natural draft is the slight difference in weight between the column of rising hot flue gases *inside* the chimney and the column of colder and heavier air *outside* the chimney.

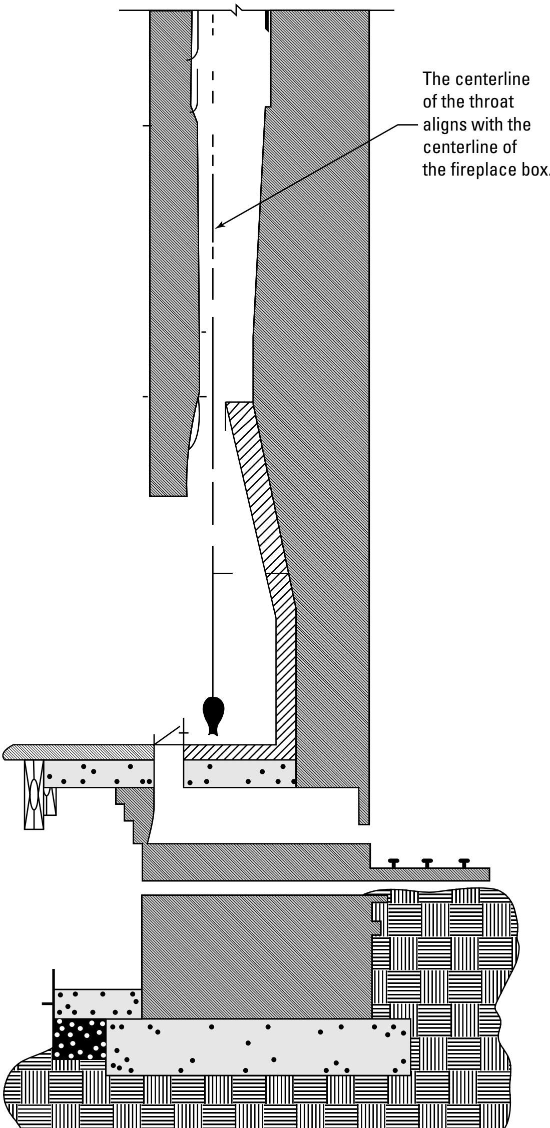


Figure 3-21 Straight vertical path from center of Rumford fireplace to chimney flue.

Table 3-2 Correction Factors for Altitudes Above Sea Level

Altitude (in feet)	*Correction Factor*
1000	0.966
2000	0.932
3000	0.900
5000	0.840
10,000	0.694

The intensity of the draft will depend on the height of the chimney and the difference in temperature between the columns of air on the inside and the outside. It is measured in inches of a water column.

The theoretical draft of a chimney in inches of water at sea level can be determined with the following formula:

$$D = 7.00\,H\left(\frac{1}{461 + T} - \frac{1}{461 + T_1}\right)$$

where D = theoretical draft
H = distance from top of chimney to grates
T = temperature of air outside the chimney
T_1 = temperature of gases inside the chimney

For altitudes *higher* than sea level, the calculations obtained in the formula should be corrected by the factors listed in Table 3-2. Thus, if the structure is located at an altitude of approximately 1000 feet, the results obtained in the formula should be multiplied by the correction factor 0.966 to obtain the correct draft for that altitude.

Chimney Construction Details

Because of its height and weight, a masonry chimney should be supported by a suitable foundation. This foundation should extend *at least* 10 inches below the bottom of the chimney and a similar distance beyond its outer edge on all sides (see Figure 3-4). The foundation can be made more stable by making the base larger in area than the top. This can be accomplished by stepping down the footing at an angle.

Chimney Cap

The *chimney cap* (or *capping*) is both a decorative and functional method of finishing off the top of the chimney (see Figure 3-22). Built of brick, concrete, or concrete slab, the chimney capping tends to counteract eddy currents coming from a high roof. The slab-type

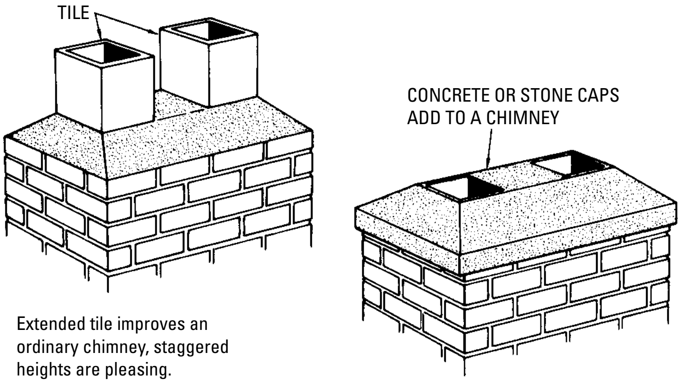


Figure 3-22 Typical chimney caps.

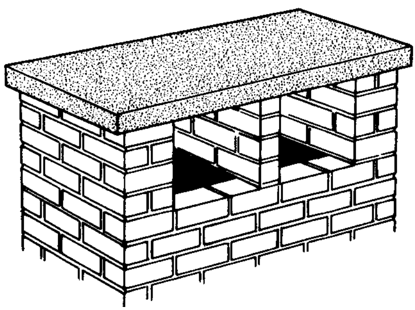


Figure 3-23 Slab-type chimney capping.

capping shown in Figure 3-23 is an effective means of preventing downdrafts. Chimney cappings are usually designed to harmonize with the architecture of the structure.

Chimney Flues and Chimney Liners

The *chimney flue* is the passage through which the smoke, gases, and other products of the combustion process travel to the outdoors. A *chimney liner* (sometimes called a *flue liner* or *flue lining*) is a metal tube inserted into the chimney to protect its walls against the potentially damaging gases of the combustion process. It is also used to size the diameter of the chimney flue opening for different appliances. The chimney liner must be code-approved for use in chimneys. Aluminum chimney liners are recommended for use with gas appliances.

Although most flues are lined with a fireproof material, chimneys with walls 8 inches or more in thickness do not need a flue lining. Fired-clay linings are used for flues in chimneys having walls less than 8 inches thick. Chimneys without a flue lining should be carefully pargeted and troweled so that the surface is as smooth as possible.

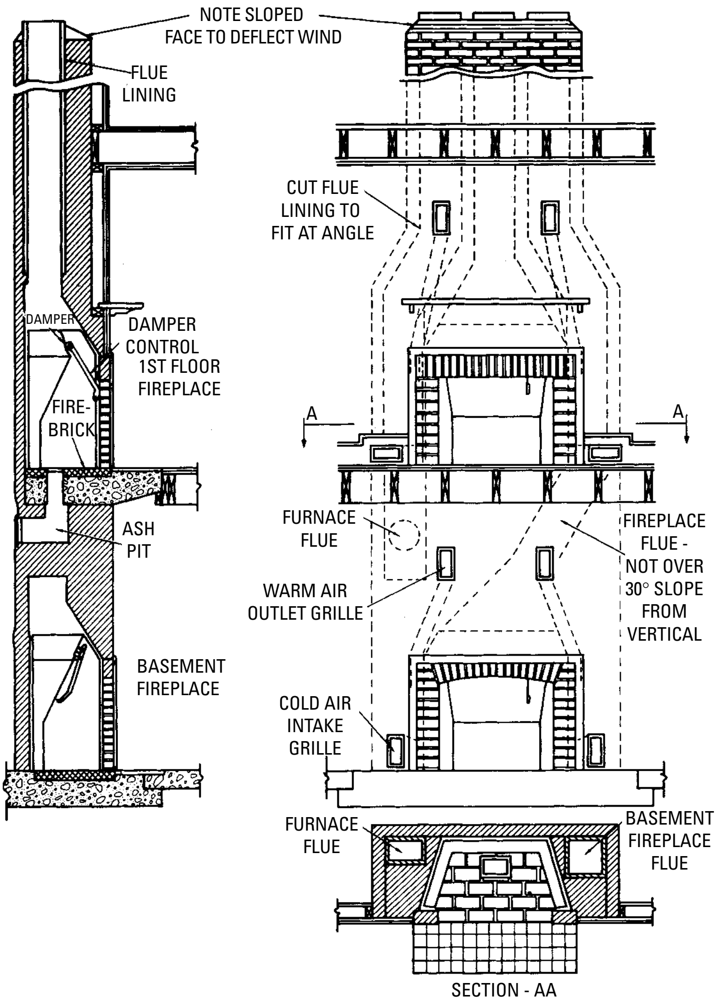


Figure 3-24 Chimney with more than one flue.

Flue construction is very important. If the flue is too small, it will restrict the passage and slow the rise of the flue gases. A flue that is too large will cause the fireplace to smoke when the fire is first started. Because the flue is too large, the fire takes longer to heat the air, and consequently the flue gases are initially slow to overcome the heavy cold air found in the chimney.

If the same chimney is used to serve fireplaces on two or more floors, *each* fireplace should have a separate flue (see Figure 3-24). This also holds true when a furnace (or boiler) and one or more fireplaces use the same chimney. Each heat source should be connected to a separate flue in the chimney.

Do not allow two (or more) flues to end on the same level at the top of the chimney. Doing so can result in smoke or gases from one flue being drawn down into the other one. One of the flues should be at least 6 inches higher than the other.

Smoke Pipe

The *smoke pipe* is used to connect the heating equipment to the chimney flue. *Never* allow the smoke pipe to extend beyond the flue lining in the chimney or it will obstruct the flow of smoke and other gases (see Figures 3-25 and 3-26).

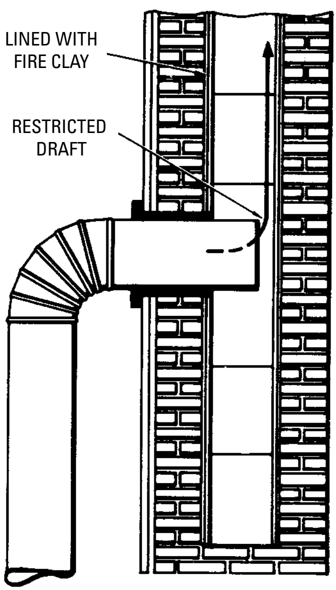


Figure 3-25 Smoke pipe extending too far into chimney.

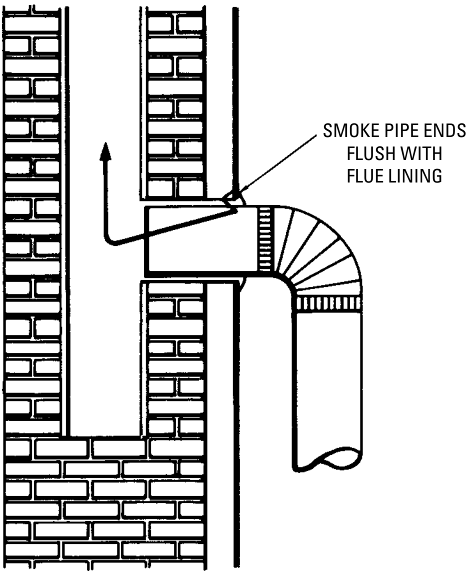


Figure 3-26 Proper connection of smoke pipe to chimney flue.

Cleanout Trap

Chimneys used with coal-fired and oil-fired heating equipment should be equipped with cleanout traps. Access is provided in the ashpit (see Figure 3-4).

Chimney Downdraft

Sometimes the air will not rise properly in a chimney and will fall back into the fireplace or stove. This *downdraft* (or *backdraft*) condition results in poor combustion, smoke, and odors. It is generally caused by either deflected air currents or chilled flue gases.

Air currents can be deflected down into a chimney by higher nearby objects, such as a portion of the structure, another building, a tree, or a hill. It is therefore important to build the chimney higher than any other part of the structure or any nearby objects. Because the deflected air entering the chimney has not passed through a hot fire, it will cool the air in the flue and weaken the draft. When the air becomes cooler, it also becomes heavier and falls back down into the chimney.

Chimneys built on the outside of a structure, particularly those exposed on three sides, must have walls at least 8 inches thick in order to prevent chilling of the flue gases. Remember that flue gases must not be allowed to cool. The cooler the gas, the heavier it becomes.

Prefabricated Metal Chimneys

Prefabricated (factory-built) metal chimneys are commonly made of 24-gauge galvanized steel or 16-ounce copper (see Figures 3-27 and 3-28). These chimneys normally can be used with any type of gas-, oil-, wood-, or coal-burning appliance; however, check the Underwriters Laboratories (UL) certification for the intended fuel use because some are restricted to gas fuels.

Freestanding fireplaces, such as those illustrated in Figures 3-17, 3-18, and 3-19, are equipped with lengths of pipe designed to extend upward from the top of the unit for approximately 8 feet (see Figure 3-29). These lengths of pipe are available with porcelain enamel surfaces that match the color of the fireplace.

Prefabricated metal chimneys are designed for ceiling support installation, through-the-wall installation, and cathedral ceiling or open-beam installation (see Figures 3-30 and 3-31). Check the local codes and regulations before installing a metal chimney. Closely follow the chimney manufacturer's installation instructions.

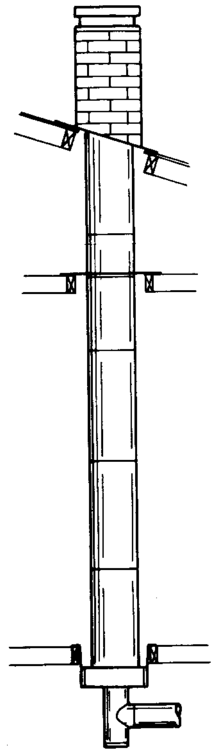


Figure 3-27 Prefabricated metal chimney used with oil-, gas-, coal-, and wood-burning fireplaces. *(Courtesy Metalbestos)*

Note

> Both double-wall and single-wall metal chimney pipes are available. A single-wall pipe is considered an extreme fire hazard.

Troubleshooting Fireplaces and Chimneys

Table 3-3 lists the most common problems associated with the operation of a fireplace.

Stoves, Ranges, and Heaters

A *stove* is a device used for heating or for both heating and cooking purposes (see Figures 3-32 and 3-33). Heating is generally regarded

Table 3-3 Troubleshooting Fireplaces and Chimneys

Symptom and Possible Cause	***Possible Remedy***
Persistent smokiness.	
(a) No damper.	(a) Install a suitable damper.
(b) Damper set too low.	(b) Correct.
(c) Damper too narrow.	(c) Extend damper all the way across opening.
(d) Damper set at back of fireplace opening.	(d) Relocate damper to the front.
(e) No smoke shelf.	(e) Install smoke shelf.
(f) No smoke chamber or poorly designed one.	(f) Install a suitable smoke chamber or make necessary modifications in old one.
(g) Fireplace opening too large for flue size.	(g) Reduce the size of opening.
(h) Insufficient combustion air.	(h) Open window a crack or provide other means of supplyingcombustion air.
(i) Downdrafts occur.	(i) Extend chimney higher; protect chimney opening with cap designed to deflect downdraft.
(j) Chimney clogged with debris.	(j) Clean chimney.
Fire dies out.	
(a) Insufficient combustion air.	(a) Open window a crack or provide other means of supplying combustion air.
(b) Clogged or dirty flue.	(b) Check flue; correct and/ or clean.
(c) Closed damper.	(c) Open damper.
(d) Fuel logs too green.	(d) Replace with suitable logs.
(e) Fuel logs improperly arranged.	(e) Rearrange and rebuild fire.

as the primary function of a stove. The heat is delivered to the room by both radiation and convection.

Brick, tile, and masonry stoves first appeared in Europe as early as the fifteenth century. The first cast-iron stove was produced in Massachusetts in 1642, but it was a rather crude device by modern

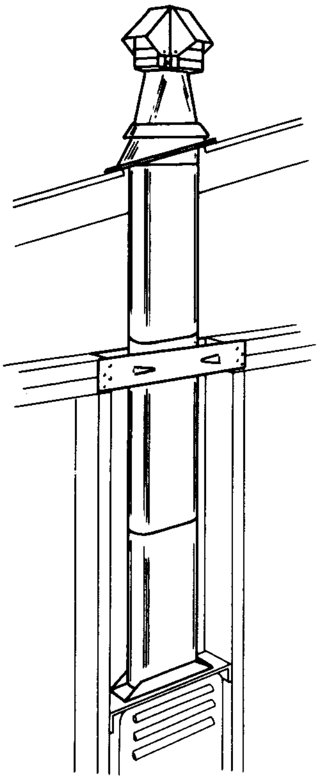


Figure 3-28 Vent pipe design for wall heaters with inputs up to 65,000 Btu. *(Courtesy Metalbestos)*

standards because it had no grates. Benjamin Franklin revolutionized the design of the stove with the introduction in 1742 of the model that bears his name (see Figure 3-34).

Sometimes the terms stove and range are used synonymously. This confusion, or blurring of the differences between the two, probably results from the incorporation of such features as an oven, cooking surface, and hot-water tank in the design of the stove (see Figures 3-35 through 3-38).

A *range* is a cooking surface and an oven combined in a single unit. It differs from a stove by being *specifically* designed for cooking, although it can supply a certain amount of warmth to the kitchen.

Ranges can be divided into a number of different categories depending on the type of fuel used. There are four basic categories of ranges:

1. Gas ranges
2. Electric ranges

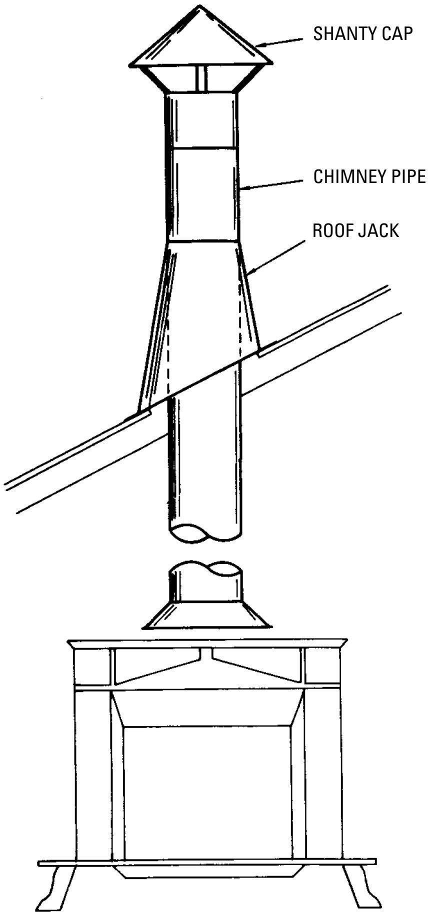


Figure 3-29 Shanty cap and pipe.
(Courtesy Portland Stove Foundry Co.)

3. Kerosene ranges
4. Solid-fuel ranges

Gas ranges use both natural and manufactured gases. Kerosene ranges have been further developed to use either gasoline or fuel oil. The solid fuels used in ranges include wood, charcoal, coal (lignite, bituminous, anthracite), and coke.

The range shown in Figure 3-39 uses wood, coal, or oil. The fuel grates and ashes (from the ashpit) are removed through the front of the range. These ranges also contain a large removable copper tank, which is used to supply hot water for cooking and other purposes.

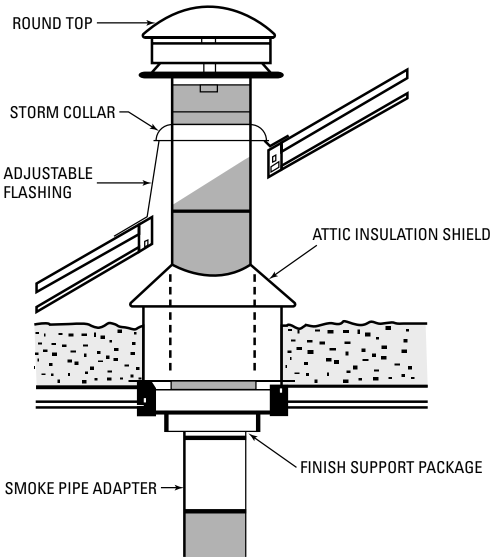


Figure 3-30 Prefabricated metal chimney and vent details (ceiling support installations).

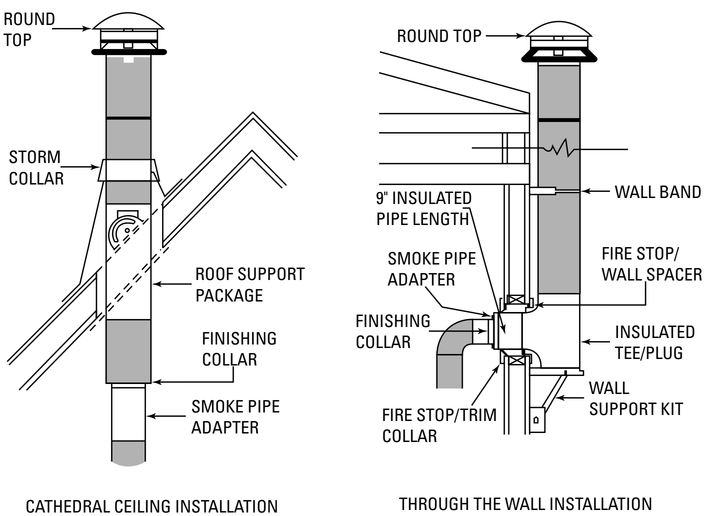


Figure 3-31 Prefabricated metal chimney and vent details (through-the-wall and cathedral ceiling installations).

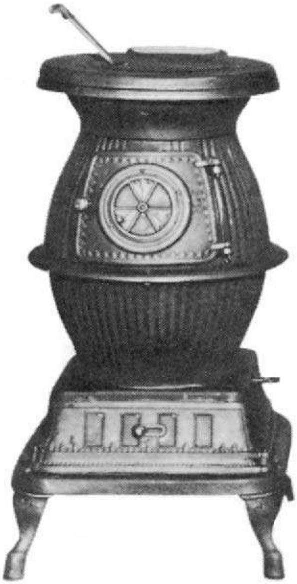


Figure 3-32 Wood-burning parlor stove. *(Courtesy Portland Stove Foundry Co.)*

Figure 3-33 Atlantic box stove. *(Courtesy Portland Stove Foundry Co.)*

Figure 3-34 The Franklin stove with folding doors. *(Courtesy Portland Stove Foundry Co.)*

Figure 3-35 Reproduction of the eighteenth-century cast-iron stove. *(Courtesy Portland Stove Foundry Co.)*

Figure 3-36 Reproduction of the 1812 Franklin stove.
(Courtesy Portland Stove Foundry Co.)

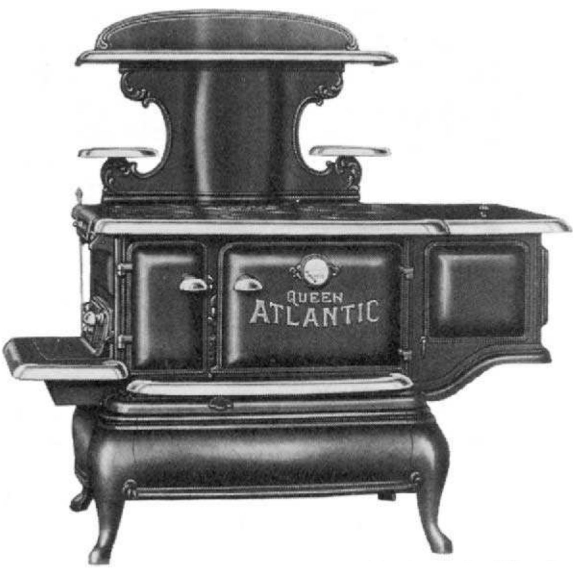


Figure 3-37 Wood- and coal-burning range.
(Courtesy Portland Stove Foundry Co.)

Figure 3-38 Franklin cast-iron stove based on the 1742 design. *(Courtesy Portland Stove Foundry Co.)*

A *wood heater* is a device used specifically to provide heat to a room or a similarly limited space. These are wood-burning units that can also be equipped to burn coal, oil, or gas. These heaters are similar to stoves in their operating principle. They should not be confused with unit (space) heaters, which are suspended from ceilings or walls and operate on a completely different principle (see Chapter 2, "Radiators, Convectors, and Unit Heaters").

Some wood-burning stoves are equipped with a thermostat. The thermostat consists of a bimetallic helix coil that opens and closes a damper in response to temperature changes. The damper opens just enough to admit precisely the amount of combustion air necessary to maintain the heat at a comfortable level.

A mat or floor protector made of some sort of fireproof material should be placed under a stove, range, or heater to protect the floor or floor covering against live sparks or hot ashes. These units should also be placed as far from a wall or partition as is necessary to prevent heat damage.

Installation Instructions

Before installing a new stove, make certain the chimney is large enough to accept the necessary smoke pipe. If another stove or

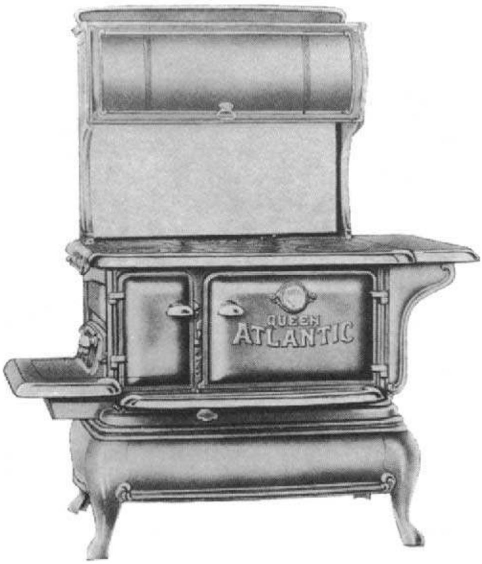


Figure 3-39 Cast-iron range used with coal, wood, or oil. *(Courtesy Portland Stove Foundry Co.)*

furnace is using the same chimney flue, connect the stove above or below the other one (*never* at the same level). The area of a chimney flue should be about 25 percent larger than the area of the smoke pipe that enters the chimney.

The same design and construction features required for a chimney serving a fireplace also apply to one used with a stove. If there is no chimney, then one must be built.

Operating Instructions

Stoves are similar to fireplaces in that they possess no power in themselves to force smoke up a chimney. The pipe and chimney provide the draft, and if they are defective, the stove will not work satisfactorily.

The installation must be capable of providing sufficient air for the combustion process. At the same time, it must be able to expel smoke and other gases to the outdoors.

Chapter 4

Water Heaters

A *water heater* is an appliance designed to heat water for such purposes as cooking, washing, and bathing. This water is generally referred to as *domestic hot water* or *potable water.*

The most commonly used water heater is the vertical tank-type stand-alone unit used in residences and small commercial buildings. It is independent of the space heating system and is a separately fired water heater. Other water heaters depend on an external heat source such as a boiler. The domestic hot water is heated when it circulates through a heat exchanger inserted in the hot-water or steam heating boiler. These heat exchangers are used only with boilers. In a warm-air heating system, domestic hot water is provided by an independent and separately fired water heater.

Types of Water Heaters

Water heaters can be divided into several groups or classes. The most common classifications are based on the following criteria:

1. Size and intended usage.
2. Heating method.
3. Heat-control method.
4. Fuel type.
5. Flue location and design.
6. Recovery rate.

Water heaters are classified as either domestic or commercial water heaters on the basis of their size and intended usage. Domestic water heaters are those with input rates up to 75,000 Btu per hour. Water heaters regarded as commercial types have input rates in excess of 75,000 Btu per hour. Temperature is another of the criteria used to distinguish between domestic and commercial water heaters. For commercial usage, hot-water temperatures of 180°F or more are generally required. The hot water used in residences does not normally exceed 180°F. For domestic usage, 140°F is generally considered adequate.

Another method of classifying water heaters is by how the heat is applied. Direct-fired water heaters are those in which the water is heated by the direct combustion of the fuel. In indirect water heaters, the service water obtains its heat from steam or hot water and not directly from the combustion process. The advantages and disadvantages of both direct-fired and indirect water heaters are described elsewhere in this chapter.

The heat-control method in a water heater may be either automatic or manual (nonautomatic). All water heaters used in residences are now of the automatic type.

Natural gas or propane, oil, coal, electricity, steam, or hot water can be used to heat the water in a water heater. Either steam or hot water can be used as the heat-conveying medium in indirect water heaters. Neither, of course, is a fuel. The fuels used to heat the domestic water supply are gas, oil, and coal. Gas is by far the most popular fuel. Oil is gaining some popularity, but it still falls far short of gas. The use of coal as a fuel for heating water is now found only in rare cases. Although electricity is not a fuel, in the strict sense of the word, it is generally used along with the three fossil fuels as an additional category for classification.

Quite often, water heaters are classified on the basis of flue location and design. This is a particularly useful criterion for classifying the various automatic storage-type water heaters.

Water heaters can also be classified on the basis of their recovery rate. Quick-recovery water heaters are capable of producing hot water at a more rapid recovery rate than the slow-recovery types. Quick-recovery heaters are often used in commercial structures where there is a constant demand for hot water.

Direct-Fired Water Heaters

A *direct-fired water heater* is one in which the water is heated by the direct combustion of a fuel such as gas, oil, or coal. The combustion flame directly impinges on a metal surface, which divides the flame from the hot water. This metal surface is quite often (but not always) the external wall of the hot-water storage tank. It serves as a convenient heat transfer surface.

A direct-fired water heater is easily distinguished from an indirect water heater (see *Indirect Water Heaters* later in this chapter), which uses an intermediate heat-conveying medium such as steam or hot water, and an electric water heater, which depends on an immersed electric heating element for its heat.

Automatic Storage Water Heaters

The underfired automatic storage heater in which a single tank is used for both heating and storing the water is the most common water heater used in houses, apartments and small commercial buildings. These heaters generally have a 30-, 40-, or 50-gallon storage capacity, although it is possible to purchase automatic storage heaters with capacities ranging from 70 gallons to several hundred gallons.

Automatic storage heaters are classified according to the placement of the flue. Using flue placement as a basis for classification, *gas-fired* automatic storage water heaters can be divided into the following three basic types:

1. Internal or center flue.
2. External channel flue tank.
3. External flue and floating tank.

The internal or center flue gas-fired water heater (see Figure 4-1) is very economical to manufacture, but proper flue baffling is required for good efficiency.

The external channel flue gas-fired water heater provides a much larger heating surface than the center flue. As shown in Figure 4-2, the entire bottom surface of the tank serves as the heating surface. Heating is from the bottom of the tank, which acts to increase efficiency.

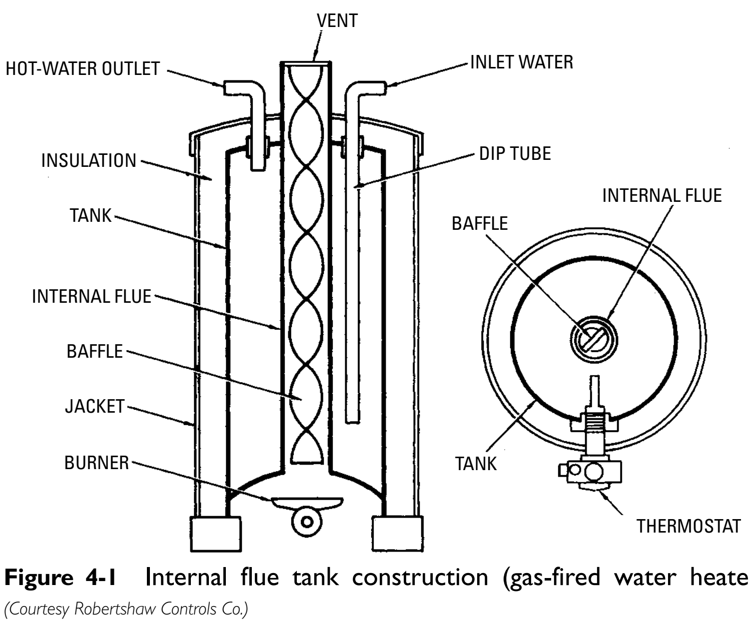


Figure 4-1 Internal flue tank construction (gas-fired water heater). *(Courtesy Robertshaw Controls Co.)*

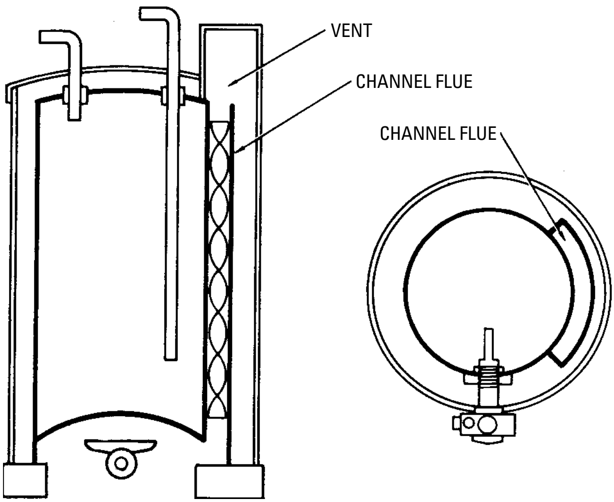


Figure 4-2 External channel flue tank construction (gas-fired water heater). *(Courtesy Robertshaw Controls Co.)*

An even larger heat transfer surface is provided by the external flue and floating tank water heater illustrated in Figure 4-3. Both the full bottom and sides of the tank serve as heat transfer surfaces. The heat (and gases) passes around the storage tank and exits through the vent.

The tank and flue construction of oil-fired automatic storage water heaters is very similar to gas-fired types. The major difference between the two lies in the combustion chamber. In gas-fired water heaters, the burners are located inside the combustion chamber (see Figures 4-1, 4-2, and 4-3). In oil-fired water heaters, the oil burner is mounted externally, and the flames are shot into the combustion chamber (see Figure 4-4).

Additional information about automatic storage water heaters can be found in this chapter in the section *Gas-Fired Water Heaters*.

Multicoil Water Heaters

Sometimes the size of a structure or its use will result in a greater demand for hot water than a conventional water heater can supply. When this is the situation, it is recommended that a *multicoil*, or *large-volume*, *water heater* be installed. These water heaters resemble instantaneous heaters externally but differ by containing more than one heating coil. The separate heating coils are connected to manifolds operated by a thermostat inserted in the storage tank.

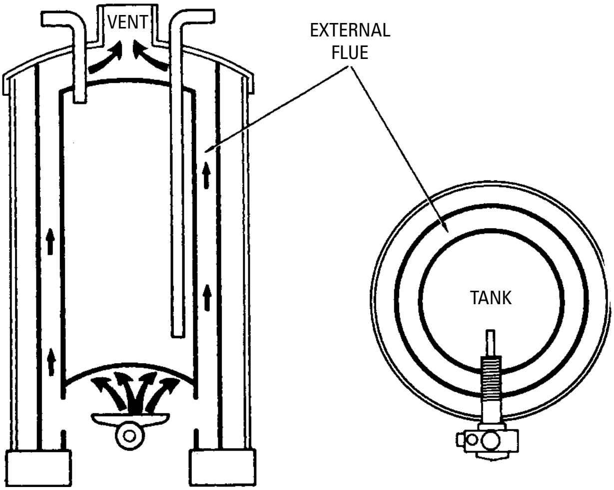


Figure 4-3 Floating-tank external flue construction (gas-fired water heater). *(Courtesy Robertshaw Controls Co.)*

Because multicoil water heaters have large storage tanks, they are suitable for use in restaurants, clubs, and structures of similar size and use.

Multiflue Water Heaters

The *multiflue water heater* was developed for commercial uses to satisfy the need for greater heat transfer surface and to efficiently remove the higher volume of noncombustible gases resulting from the higher gas inputs. The diagram of a gas-fired multiflue water heater is shown in Figure 4-5. Compare this with the diagram of the oil-fired multiflue water heater illustrated in Figure 4-4. Each is essentially a vertical fire-tube boiler enclosed in an insulated jacket.

Multiflue water heaters are characterized by a relatively high hot-water recovery rate. These heaters are used in conjunction with auxiliary storage and

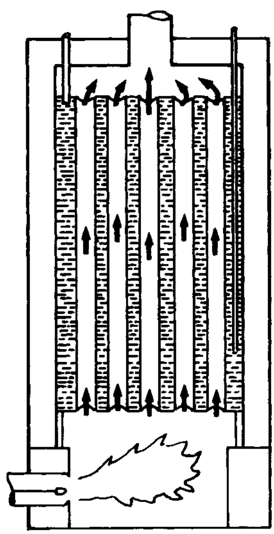


Figure 4-4 Oil-fired multiflue design used in some high-capacity commercial water heaters. *(Courtesy National Oil Fuel Institute)*

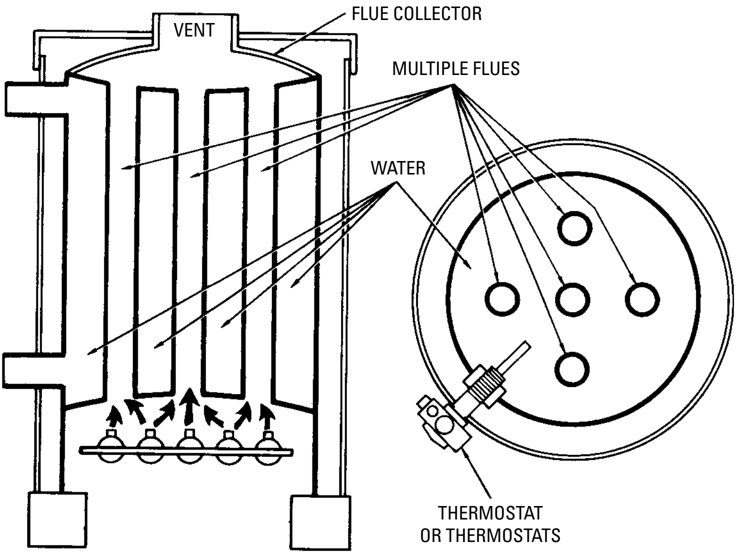


Figure 4-5 Multiple-flue, multiple-burner commercial water heater. *(Courtesy Robertshaw Controls Co.)*

are frequently employed as booster heaters. It is common usage to refer to a multiflue water heater as a *booster heater.*

Instantaneous Water Heaters

Automatic *instantaneous water heaters* (also sometimes called *point-of-use water heaters*) are self-contained units available in capacities ranging up to 445 gallons per hour (or up to 7.43 gallons per minute at 100° temperature rise) (see Figure 4-6).

Basically, an instantaneous heater consists of a large copper coil suspended over a series of burners. The copper coil, burners, valves, and thermostats are all enclosed in a protective steel casing. An instantaneous water heater does not have a hot-water storage tank; this feature distinguishes them from other types of commercial water heaters, such as the multicoil and multiflue.

The water to be heated circulates through the copper coil. The operating principle of these heaters is very simple and ideal for situations requiring intermittent use. Any pressure drop in the system (such as that caused by opening a faucet) provides the necessary power to force open the gas valve and allow gas to flow to the burners. The gas is ignited by the pilot, and the water in the coil is

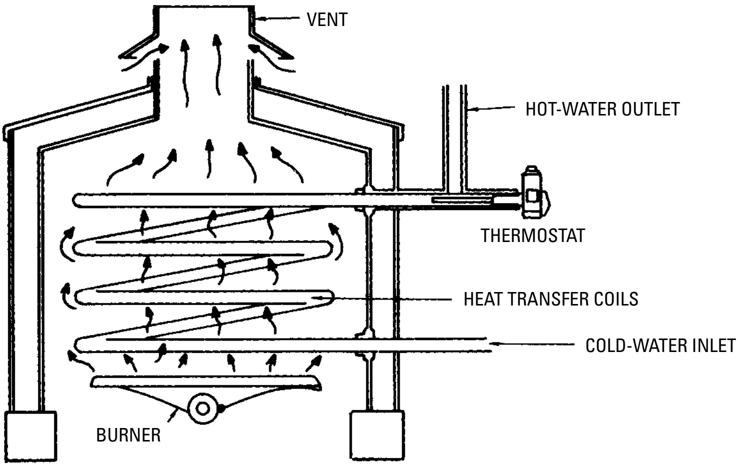


Figure 4-6 Instantaneous water heater. *(Courtesy Robertshaw Controls Co.)*

heated to the desired temperature. These heaters are ideally suited for those public buildings or sites that require periods of high demand (for example, public washrooms, sports arenas, ballparks, stadiums, or recreational centers).

Indirect Water Heaters

An *indirect water heater* uses either steam or hot water to heat the water used in the domestic hot-water supply system.

In small, residential-type boilers, a water heater element consisting of straight copper tubes with U-bends or a coiled tube is located in the hottest portion of the boiler water (see Figures 4-7 and 4-8). It is positioned at the side of the boiler to create rapid natural circulation. Because there is no separate water storage tank, this type of unit is commonly called a *tankless water heater.*

In steam boilers, the copper tubes are generally placed below the water line in the boiler. The system is designed so that the water is heated after a single passage through the copper tubes.

Another type of indirect water heater utilizes a separate water heater outside the boiler (see Figure 4-9). Hot water from the boiler flows into the heater and around copper coils containing the domestic hot-water supply before returning to the boiler. The water inside the coils is heated and returned to a hot-water storage tank, which is usually located at a level slightly higher than the heating boiler.

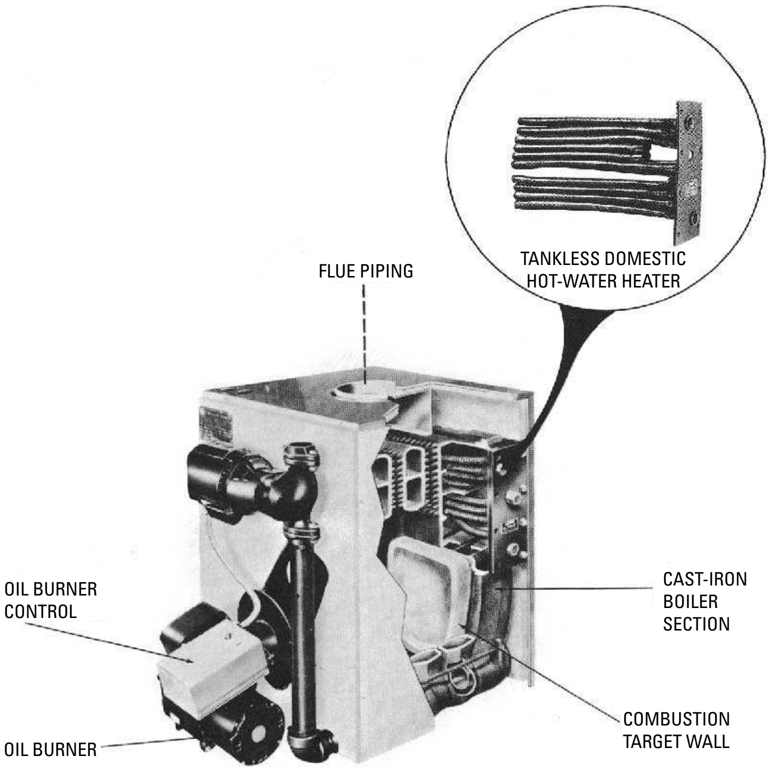


Figure 4-7 Oil-fired hydronic boiler with a straight-tube tankless water heater. *(Courtesy Burnham Corp.)*

The water to be heated can also be circulated *around* tubes through which steam is circulated. The steam tubes are submerged in a steel tank as shown in Figure 4-10. As in all methods of indirect heating, the domestic water supply is kept sealed off from the hot water or steam being used to heat it.

Indirect water heaters of the type illustrated in Figure 4-11 are essentially space-heating boilers with built-in coil bundles through which the hot water circulates. They differ from hot-water space-heating boilers in the following two ways:

1. The coils are sized to absorb the *total* output of the boiler.
2. Water temperatures do not exceed 210°F.

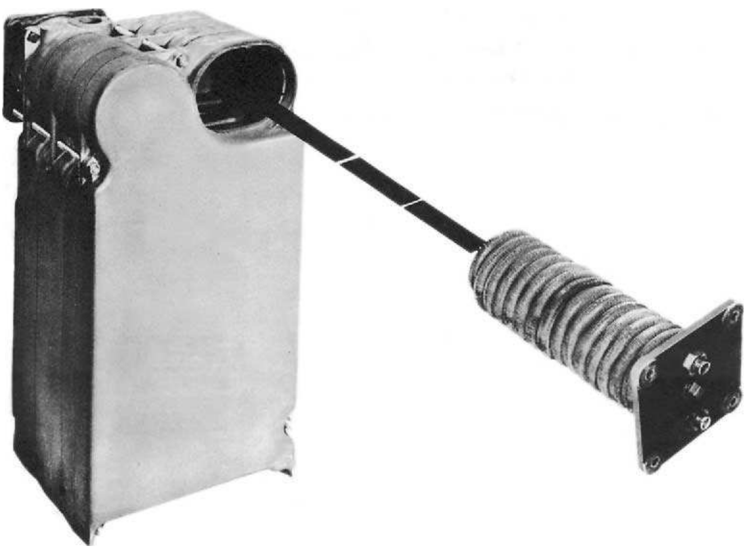


Figure 4-8 Oil-fired hydronic boiler with a coiled-tube tankless water heater. *(Courtesy H.B. Smith Co., Inc.)*

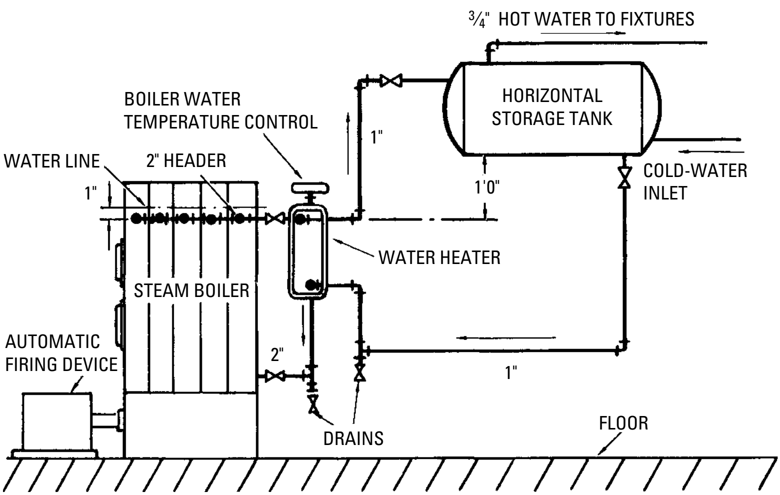


Figure 4-9 Separate indirect water heater mounted outside the boiler. *(Courtesy 1965 ASHRAE Guide)*

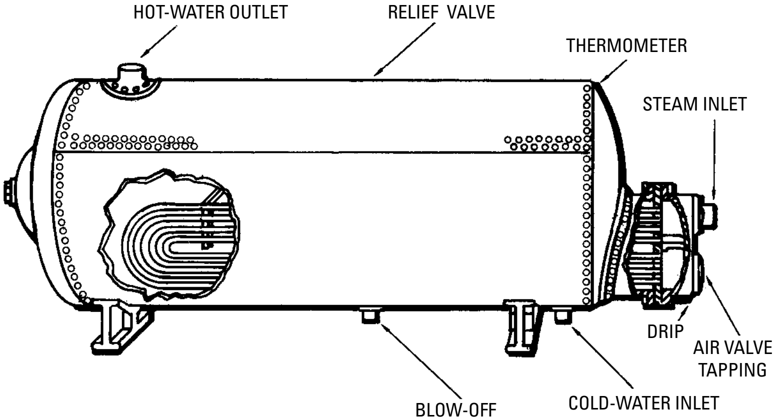


Figure 4-10 Indirect water heater in which the water is circulated around steam-filled tubes. *(Courtesy 1965 ASHRAE Guide)*

These indirect water heaters may be used as instantaneous heaters. Because they can be used with any size storage tank, there is no real upper limit on their storage capacity. The same is true of their recovery rate.

The principal advantages of an indirect water heater are the following:

1. Longer operating life (the metal surfaces of the heater are not directly exposed to a flame).

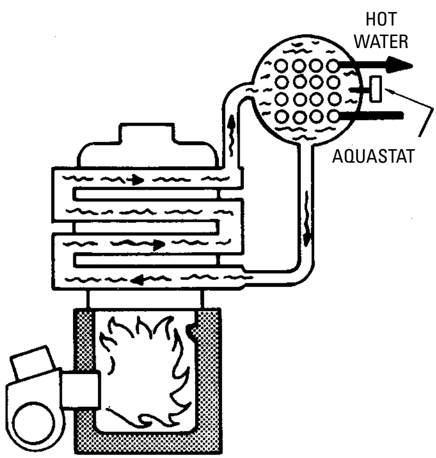


Figure 4-11 Indirect water heater with built-in coils designed to absorb the total heat output of the boiler. *(Courtesy Hydrotherm, Inc.)*

2. Scale formation and corrosion in the secondary heat exchanger coils are minimized because of the relatively low operating temperatures.
3. No hot-water storage tank (with the accompanying circulator, controls, and piping) is required if the heater has been properly sized.

Quick-Recovery Heaters

This class of heater, as the name implies, has the ability to produce hot water at a more rapid rate than the slow-recovery type. It is frequently employed where repeated heavy requirement for hot water makes it essential to have a sufficient amount of water available on demand.

Thermostats used are of the throttling or snap-action type. Primarily the throttling thermostat is the one in which the amount of gas valve opening is directly proportional to the temperature changes of water in the tank. In the snap-action thermostat, the change from a completely open to a completely closed position of the valve, or vice versa, is accomplished by a snap action produced by a clicker diaphragm motivated by the temperature in the tank.

The essential difference between the slow- and quick-recovery heater lies in the amount of gas consumed by each unit. Thus, for example, a quick-recovery heater with a 25,000-Btu input will deliver 25 gallons of hot water per hour indefinitely, whereas a slow-recovery heater can never burn more than a certain relatively low and known amount of gas with an accompanying reduction in hot-water delivery.

Slow-Recovery Heaters

The gas-fired slow-recovery water heater is designed to keep a supply of hot water in the storage tank and, by means of a constantly burning gas flame, deliver hot water continuously to this tank.

Thermostats employed can be of the graduating or snap-action type. With the graduating thermostat, the burner operates between a low and high flame—the low position of the flame serving as a pilot to keep the heater lighted and serving as a source of standby heat.

The slow-recovery automatic water heater is very economical since it can never burn more than a certain amount of gas, depending on the regulation offered by the thermostat. Also, the small amount of heating surface keeps the standby loss at a minimum, making this type of heater very advantageous where economy is the primary consideration.

Heat Pump Water Heaters

A *heat pump water heater* consists of a small electrically operated compressor, the heat pump and domestic water supply controls, and a water storage tank (see Figure 4-12). It uses the heat of the air in the room and the energy used to operate its compressor to heat the water in its storage tank. Unlike conventional gas-fired or electric resistance water heaters, the heat pump water heater does not create heat. It transfers heat from one point to another. It is essentially a small heat pump that uses the room air as the heat source and the water in the storage tank as the heat sink. Because it is a heat pump, it can also cool the air and dehumidify it.

In some heat pump water heater installations, the heat pump and water storage tank are separate. A water pump and piping flow loop are used to circulate the water between the heat pump water heater and the water storage tank. The water is heated in the heat pump water heater and stored in the tank.

The principal advantage of using a heat pump water heater with a separate water tank is that either can be replaced independently of the other when they malfunction. Another important advantage is their location flexibility.

The heat pump water heater may also be an integral part of the water storage tank. In these installations, there is no need for a water pump or flow loop. This arrangement also eliminates energy loss from the flow loop piping or the need for freeze protection.

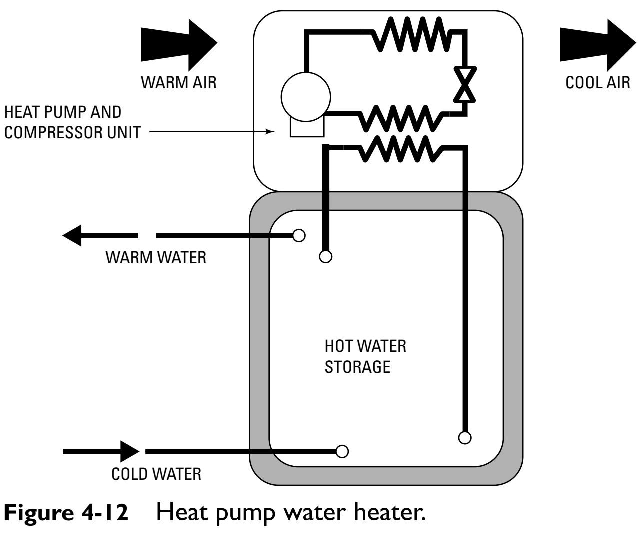


Figure 4-12 Heat pump water heater.

Heat pump water heaters are more expensive to purchase and install than conventional electric resistance water heaters. On the other hand, they use 50 percent less energy than conventional electric resistance heaters.

Combination Water Heaters

Many of the earlier combination water/space heaters used in hydronic systems did not keep the domestic hot water separated from the hot water used for space heating. This feature resulted in scale buildup in the water tank and oxygen-induced damage to the tubing in the radiant heating panel. A combination water heater in which the domestic hot water is separated from the space heating water in the same appliance is shown in Figure 4-13. Two separate corrugated stainless steel tanks are used in this design. The outer tank contains the primary fluid (water) and is connected to the space-heating circuit. The inner tank contains the domestic hot water and is connected directly to the utility water supply and a separate domestic hot-water circuit. The primary water in the outer tank is heated by a gas or oil burner and does not exceed a temperature of 180°F, which significantly reduces scale buildup in the domestic (that is, inner) hot-water tank. The domestic hot-water supply in the inner tank absorbs heat from the hot water in the outer tank. There is no direct heating of the inner tank.

The two water circulation circuits supplied by this type of combination water heater are completely independent of one another.

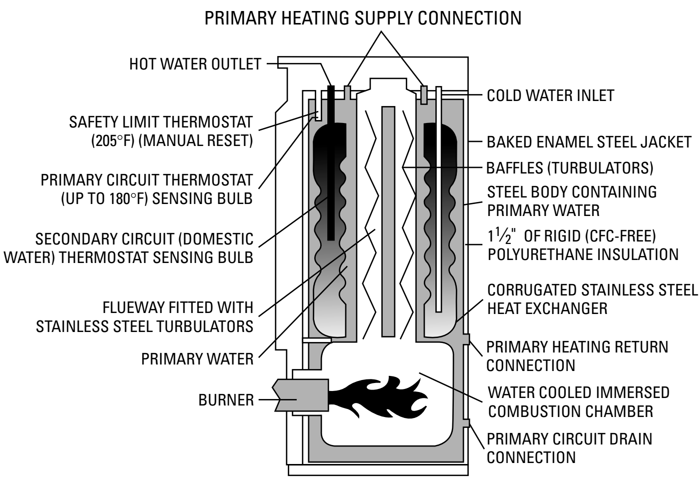


Figure 4-13 Combination water heater.

This arrangement eliminates the problem of oxygen from hot domestic water mingling with the space-heating water, thereby reducing the possibility of oxygen production, which can damage tubing or cause scale buildup in the tank.

Note

> The primary water in the outer tank is never changed. Changing the water can lead to the introduction of oxygen into the system.

The space-heating water in the outer tank is circulated in a closed loop through baseboards, tubing or panels, and heat exchangers. The only point of contact between the inner and outer tanks is where the cold-water inlet pipe and the hot-water flow pipe extend through the top of the combination water heater. The heater is equipped with two separate built-in control systems, one for the outer tank and one for the inner tank.

Some combination water heater installations consist of an indirect water heater connected to a high efficiency furnace or a boiler. Liquid heat (from the hot water) is transferred to the air and then distributed through a duct system by a blower.

Note

> Combination water heaters are practical mostly in new construction or where a boiler or furnace must be replaced.

Water Heater Construction Details

The automatic controls, fuel-burning equipment (gas burners, oil burner, and so on), and venting system found on a water heater will depend on the type of fuel used and certain other variables. These components are described in detail in appropriate sections of this chapter and elsewhere in the book.

The direct-fired automatic storage water heater is the most commonly used heater in residences. Certain construction details of these heaters remain essentially the same regardless of the type of controls or fuel-burning equipment.

Principal among these are the following:

1. Water storage tanks
2. Tank fittings
3. Dip tubes
4. Anodes
5. Valves

Water Storage Tanks

The tank of a water heater provides storage space for the hot water and also serves as a heat transfer surface. The design and construction of the tank must be strong enough to withstand at least 300 pounds per square inch without leakage or structural deformation.

Corrosion is a major problem in water heater storage tanks. One successful method of reducing corrosion has been to provide steel tanks with glass linings. Older water heater tanks will be found with copper or stone (Portland cement) linings, but these are becoming increasingly rare.

Glass-lined tanks are also equipped with a sacrificial magnesium anode rod, as shown in Figure 4-14. The corrosion process attacks the metal anode rod first, rather than the metal of the tank walls. The anode rod should be removed and replaced before decomposition occurs.

The operating life of a storage tank is directly related to the temperature of the stored water when it is over 140°F. The rule-of-thumb is that each 20° rise above 140°F will reduce tank life by 40 percent.

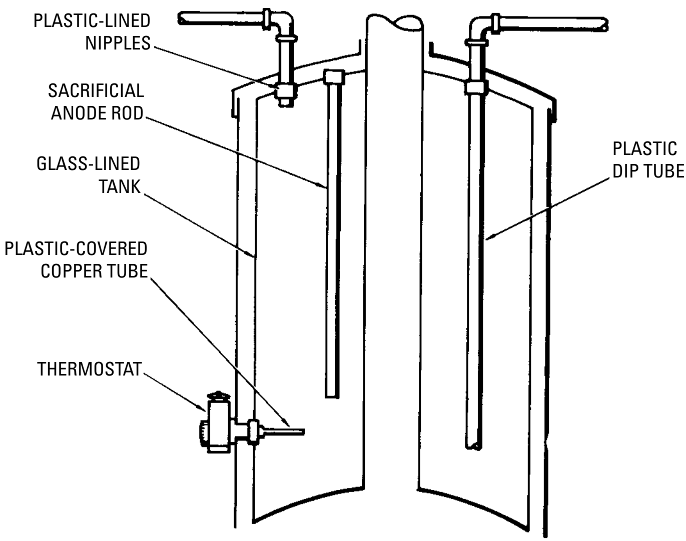


Figure 4-14 Sacrificial anode installation in a residential water heater tank. *(Courtesy Robertshaw Controls Co.)*

Tank Fittings

Figures 4-15 and 4-16 illustrate the various fittings required on both domestic and commercial water heaters.

Each tank should have fittings for hot-water outlet and cold-water inlet connections. These water connections generally consist of threaded spuds welded into openings in the tank.

A fitting is also provided in the top of most tanks for the insertion of the sacrificial anode. Other fittings provide for the use of immersion thermostats, immersion automatic gas shutoff devices, drain cocks, pressure and temperature relief valves, and dip tubes.

Dip Tubes

Some water heaters are designed so that the cold-water inlet is at the top of the tank. Because this is also the location of the hot-water supply outlet, there will be an excessive mixing of the cold water with the hot water unless provisions are made to keep the two separated. A *dip tube* is used for this purpose.

As shown in Figure 4-17, a dip tube is an extension of the cold-water supply pipe and is used to direct the cold water to the bottom

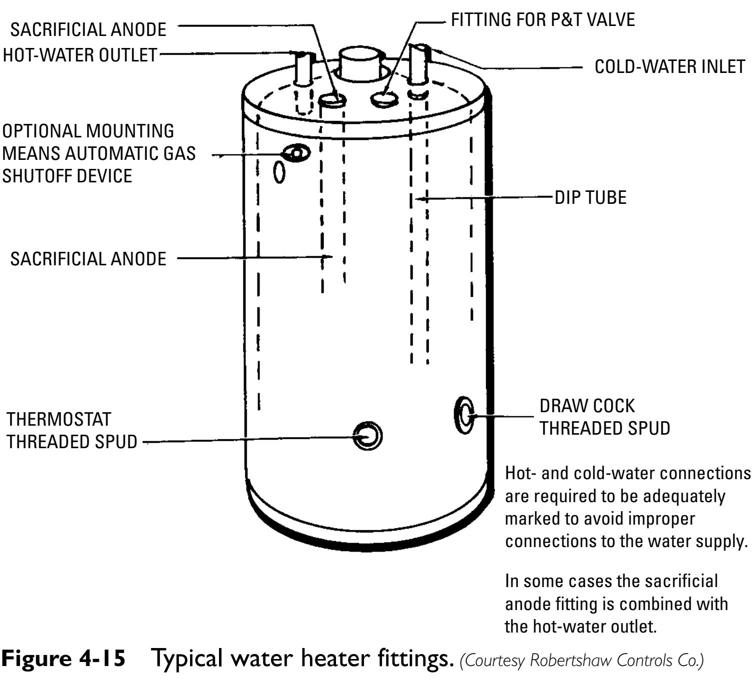


Figure 4-15 Typical water heater fittings. *(Courtesy Robertshaw Controls Co.)*

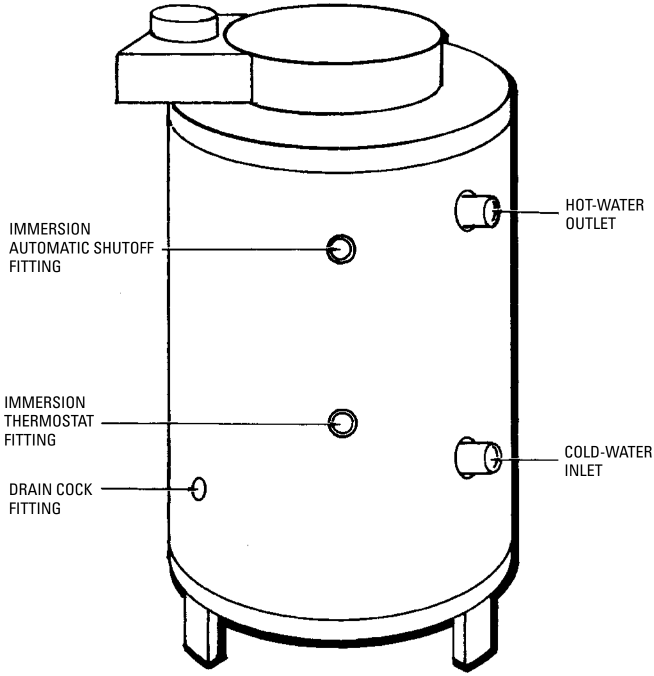


Figure 4-16 Commercial water heater fittings with low-level cold-water inlets. *(Courtesy Robertshaw Controls Co.)*

of the tank. On older water heaters, dip tubes were made of metal. Now they are generally made from a high-density, temperature-resistant plastic. In all water heaters, the water at the top of the tank during cycling and intermittent standby conditions is always warmer than the water at the bottom of the tank. If the dip tube is too short, the cold water will mix with the water at the top of the tank and reduce the temperature of the hot-water supply to an unacceptable level. On the other hand, a dip tube that is too long will create an excessive water variation between the top of the tank and the lower thermostat control level. The dip tube must be of sufficient length to avoid both these conditions.

Each dip tube is provided with a small hole near the top of the tank, which functions as an antisiphon device. Sometimes it is possible for a malfunction to close off the cold-water supply while the hot water continues to be removed from the tank. Were it not for the antisiphon hole, the water would be drawn to the bottom

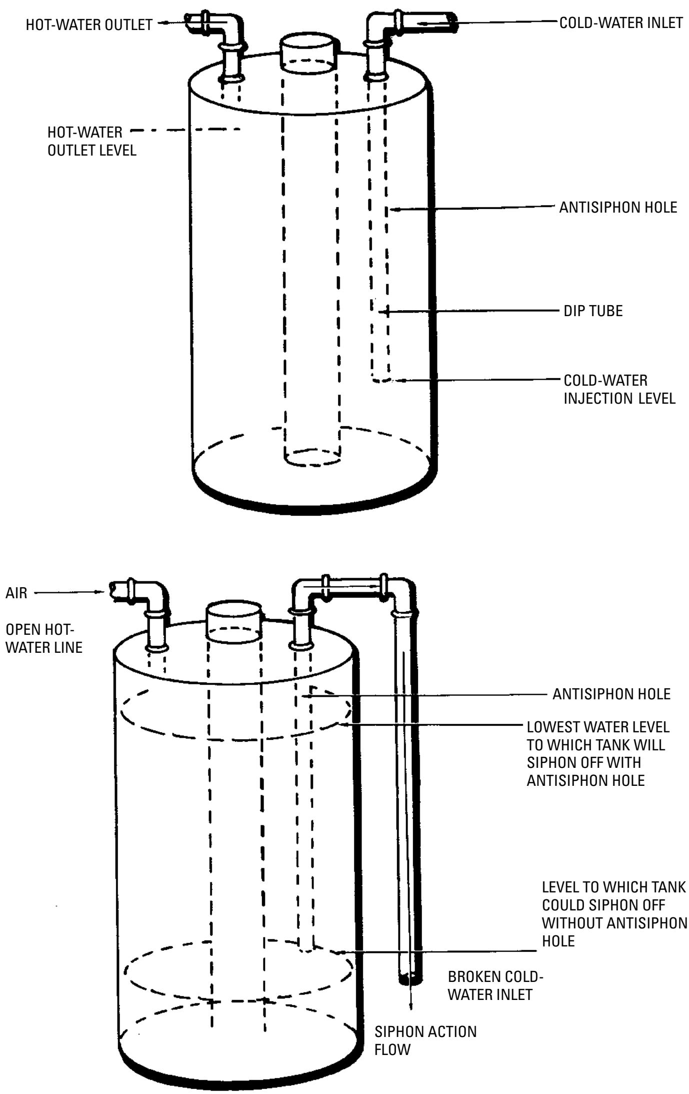


Figure 4-17 Dip tube and antisiphon hole. *(Courtesy Robertshaw Controls Co.)*

of the dip tube, a dangerously low water level for the tank. The siphon action is broken when the water reaches the level of the antisiphon hole, and the hot water will not be drawn below this level.

Anodes

The inside surface of a domestic hot-water tank is covered with a coating to protect the steel from corrosion. Sometimes, because of a production error, a very small part of the surface may remain uncoated and subject to corrosion. If another metal with less resistance to corrosion than steel is inserted into the tank, the corrosion will attack it instead of the exposed steel surface on the tank wall.

Metal rods called *anodes* are used to protect the walls of the water storage tank from corrosion. They are made from either magnesium or aluminum formed around a steel wire core. Because both of these metals have less resistance to corrosion than steel, corrosion will attack them instead of the exposed steel. In other words, they sacrifice themselves to the electrolytic process. For this reason, anodes are sometimes called *sacrificial anodes*.

An anode rod is installed by screwing it into the top of the water storage tank. It can be unscrewed, removed, inspected, and replaced by a new rod. A residential water tank will have one or two anode rods depending on the life of the warranty. Two rods are used in tanks with 12-year warranties. One rod is used if the warranty is half as long. Water storage tanks used in commercial systems will have anywhere from one to six anode rods.

Note

All the anode rods used in a tank must be made of the same metal. Otherwise, some will corrode faster than others.

Valves

Three types of valves are used with domestic hot-water heaters: temperature and pressure relief valves, vacuum relief valves, and water-tempering valves. These valves are used to prevent damage to the water heater from excessively high pressures, temperatures, or vacuum conditions. They also protect the user from personal injury.

Safety Relief Valves

A relief valve for a domestic hot-water supply heater is an emergency safety device. If properly installed, it allows water to escape and spill out when excessive pressure, dangerously high temperature, or both conditions are present in the water storage tank.

It is important to understand the relationship between excessive pressure and high temperature for the safe operation of a hot-water heater. Ignorance of this relationship may result in an explosion severe enough to cause tragic loss of life and extensive property damage. The two principal causes of hot-water storage tank explosions are (1) water in the tank at an excessively high temperature, and (2) a physical weakness of the tank caused by a defect, age, corrosion, or general deterioration.

Water under pressure (greater than atmospheric pressure) can be heated above 212°F and still not boil (see Figure 4-18). As shown in Figure 4-18, the pressure in the tank will rise as it is heated because of thermal expansion. Such pressure cannot be relieved by backing into the main if the cold water is blocked by a check valve or other devices. If there is a failure in the heating-control device, the water in the tank will continue to heat beyond 212°F, and the superheated water will immediately flash into steam when a rupture occurs in the storage tank. Such action instantaneously converts 1 cubic inch of water into 1 cubic foot of steam with explosive force. This tremendous steam-flash explosive force can shoot water heaters, much like a jet-propelled rocket, through floors and roofs, burst foundations, destroy property, and cause serious or fatal injuries (see Figure 4-19).

Tests have shown that even though water pressure is raised above the normal safe tank limit, the worst that can happen is for the tank to rupture and cause water damage. When heat is applied, however, the tank becomes a potential hazard because of the steam-flash explosive possibilities. Protection against this danger can be obtained by the proper installation of suitable pressure and temperature relief valves. No water heater can operate safely without these safety relief valves.

A pressure relief valve is designed to prevent excessive pressure from developing in the hot-water heater storage tank (see Figure 4-20). This is exclusively a safety device and is not intended for use as a regulating valve to control or regulate the flow pressure. This type of valve starts to open at the set pressure and requires a certain

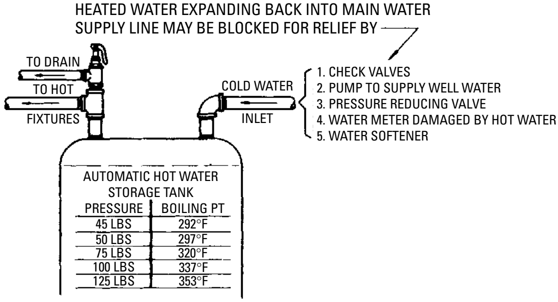


Figure 4-18 Boiling points of water at various pressures.
(Courtesy A. W. Cash Valve Manufacturing Co.)

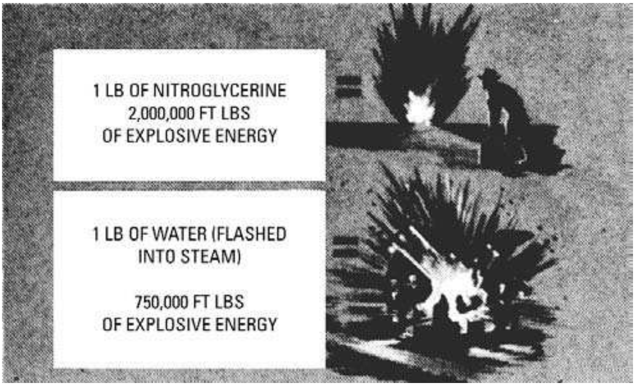


Figure 4-19 Explosive power of superheated water.
(Courtesy A. W. Cash Valve Manufacturing Co.)

percentage of overpressure to open fully. As the pressure drops, it starts to close and shuts at approximately the set pressure.

A temperature relief valve is used to prevent excessively high water temperature from developing in the hot-water heater storage tank. A temperature relief valve may be a separate unit or combined in the same housing with a pressure relief valve to form a combination temperature and pressure relief valve (see Figure 4-21).

Water heater pressure and temperature relief valves must be installed in accordance with AGA, UL, or FHA standard safety requirements. Furthermore, the pressure and temperature relief valve should be constructed and located in conformance with current American National Standard (Z21.22) listing requirements. The manufacturer's recommendations for locating the valve on the storage tank should also be followed. *Never* reuse a relief valve if the water heater is being replaced. Always be sure to use the capacity relief valve recommended by the manufacturer for the installation.

A pressure and temperature relief valve is basically a pressure relief valve with an added temperature-sensing element thermostat located at the inlet of the valve to prevent overheating or explosive dangers. The temperature-sensing element must be immersed in the water within the top 6 inches of the tank (see Figures 4-22, 4-23, and 4-24). This location is required for the immersion element because the hottest water will occupy this portion of the tank.

The basic components of both a pressure relief valve and a combination pressure and temperature relief valve are shown in Figures 4-25 and 4-26. Note the position of the temperature-sensing element

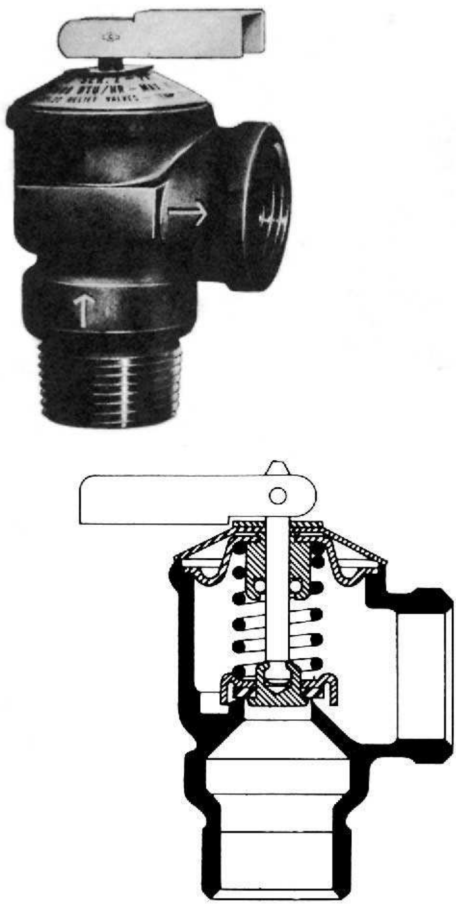


Figure 4-20 Pressure relief (only) valve used to protect hot-water supply systems from excessive pressure. *(Courtesy A. W. Cash Valve Manufacturing Co.)*

thermostat. When the water in the top of the tank approaches the danger zone (210°F), the thermostat expands and lifts the valve disc from the seat, allowing hot water to escape and cooler water to replace it in the tank. A decrease of less than 10° in the water temperature causes the thermostat to contract and allows the loading spring to reseat the valve, thus maintaining a supply of hot water at all times.

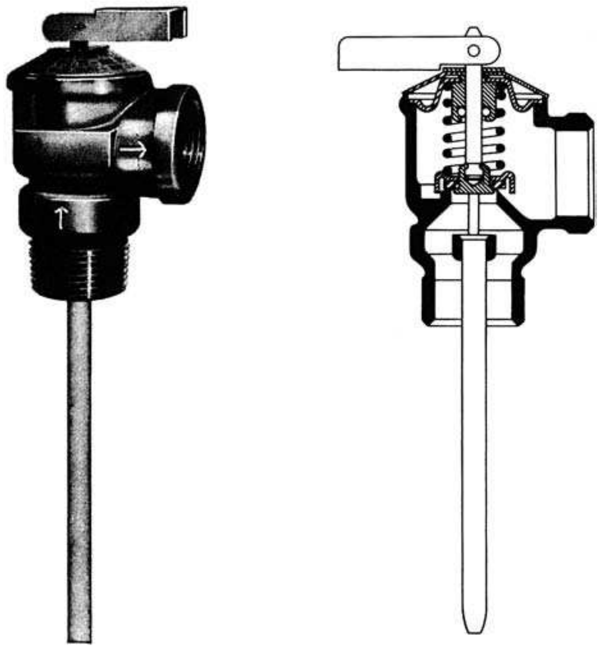


Figure 4-21 Combination pressure and temperature relief valve. *(Courtesy A. W. Cash Valve Manufacturing Co.)*

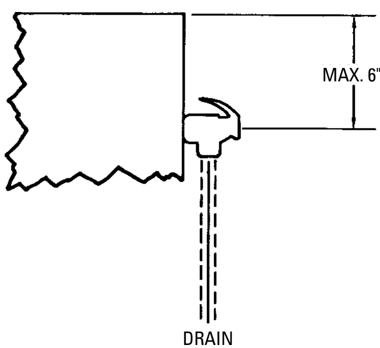


Figure 4-22 Direct side tapping. *(Courtesy Watts Regulator Co.)*

If a combination pressure and temperature relief valve is used, it should be installed in a separate tapping in the top of the hot-water storage tank (see Figure 4-24). If a separate tapping is not available, then the valve should be installed in the hot-water discharge line to

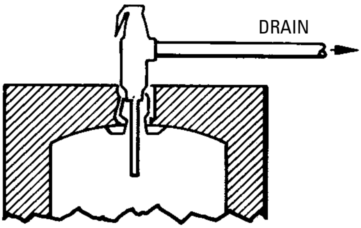


Figure 4-23 Direct top tapping.
(Courtesy Watts Regulator Co.)

the fixture outlets at a point as close to the tank as possible (see Figure 4-24).

The relief valve should be installed in the upper end of a tee, the lower end of which is connected to the tapping in the top of the hot-water storage tank by means of a closed nipple. The hot-water supply line to the fixture outlets is then connected to the branch of the tee as shown in Figure 4-24. If the relief valve is located in the hot-water supply line to the fixtures at a distance greater than 4 inches from the storage tank, excessive temperatures generated within the tank may result in serious damage before the excessive temperature is communicated through the water and piping to the relief valve. The possibility of this situation arising can be avoided by selecting a valve with a temperature-sensing element that is long enough to extend into the top 6 inches of the tank.

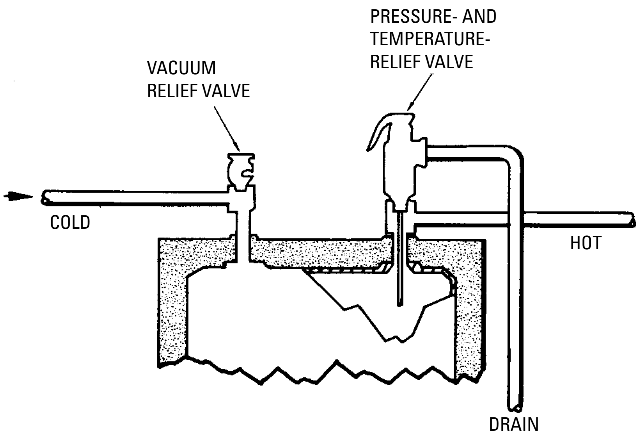


Figure 4-24 Relief valve installed in hot-water discharge line.
(Courtesy Watts Regulator Co.)

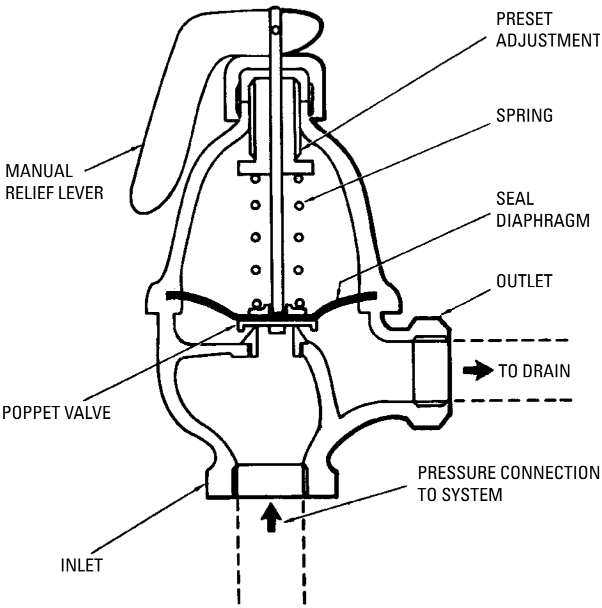


Figure 4-25 Principal components of a pressure relief valve.
(Courtesy Robertshaw Controls Co.)

A temperature relief valve must be installed so that the temperature-sensing element is in contact with hot water in the top 6 inches of the tank. This is a necessary safety precaution because of a condition called *temperature lag*, that is, the condition of temperature variation between the hottest water in the top of the tank and water temperature at varying distances away from the actual tank tapping (see Figure 4-27). When the average temperature in the top 6 to 8 inches is 210°F, there will be a considerable temperature lag (under no-flow conditions) at varying distances away from the tank. For example, a temperature of 191°F can be found at a point even with the top of the tank. At 4 inches above the top of the tank, the temperature has dropped off to 170°F. Taking these conditions into account, then, it becomes clear why relief valves with extension-type temperature-sensing elements are recommended. The temperature-sensing element must reach down to the point at which the highest water temperature occurs.

Where *separate* pressure and temperature relief valves are used, the temperature relief valve should be installed in the top of the

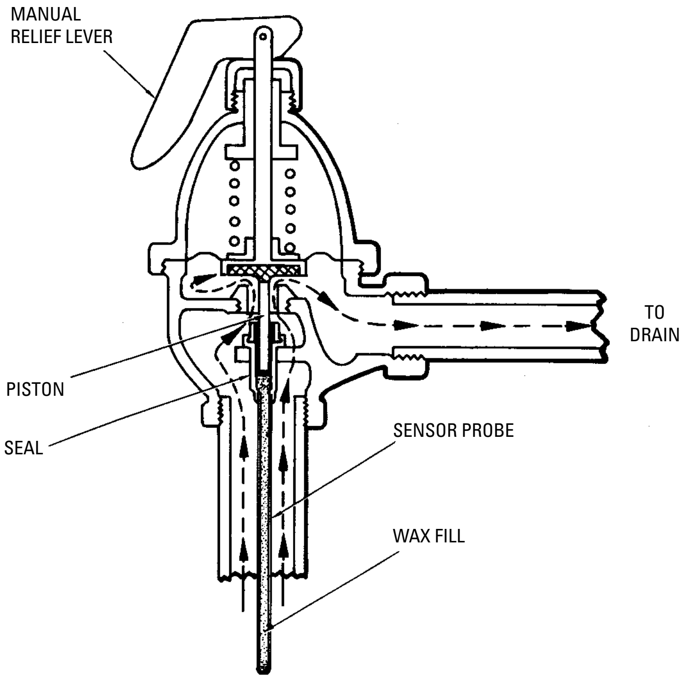


Figure 4-26 Principal components of a pressure and temperature relief valve. *(Courtesy Robertshaw Controls Co.)*

hot-water storage tank or as close as possible to the tank in the hot-water supply line to the fixtures as previously described, and the pressure relief valve should be installed in the cold-water supply line at a point as close to the hot-water storage tank as possible.

The rated capacity of temperature relief valves (in Btu/h) should equal or exceed the input capacity of the hot-water heater (also expressed in Btu/h). Both the pressure and temperature steam ratings should be listed on the side of the valve (see Figure 4-28).

Typical piping connections for an automatic storage water heater are shown in Figure 4-29. A two-temperature capability is provided by feeding the hot water directly to the appliances. A balancing valve is installed in the cold-water line to the tempering valve to compensate for pressure drop through the heater. Because the tempering valve cannot compensate for rapid pressure fluctuations, a pressure equalizing valve should be installed where the system is subjected to water-pressure fluctuations.

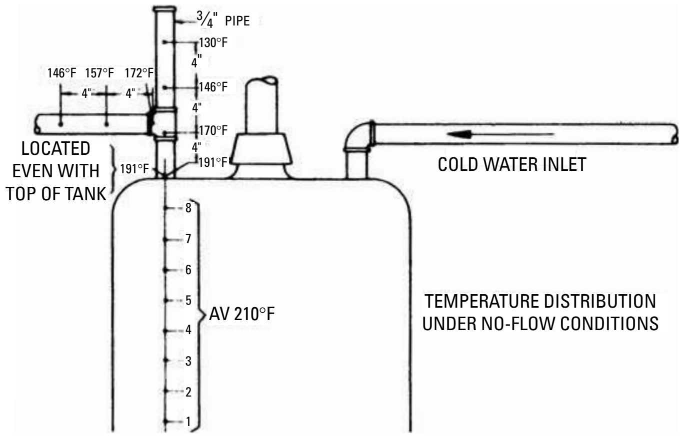


Figure 4-27 Temperature distribution under no-flow conditions (temperature lag). *(Courtesy A. W. Cash Valve Manufacturing Co)*

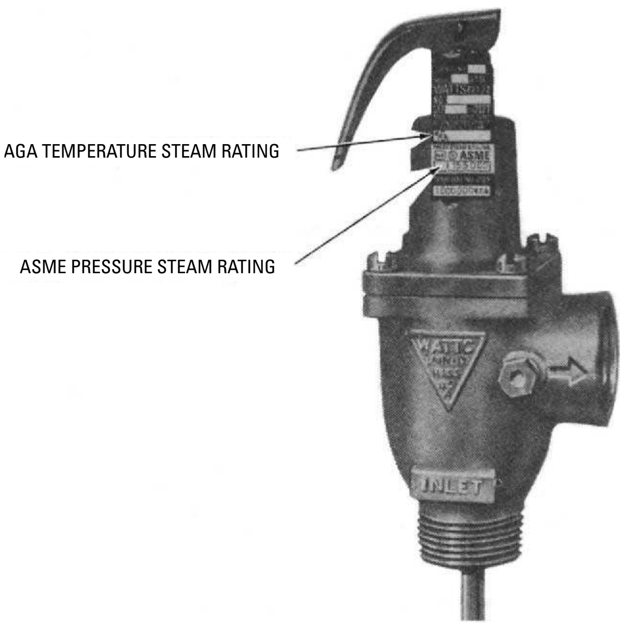


Figure 4-28 Rating of a typical pressure and temperature relief valve. *(Courtesy Watts Regulator Co.)*

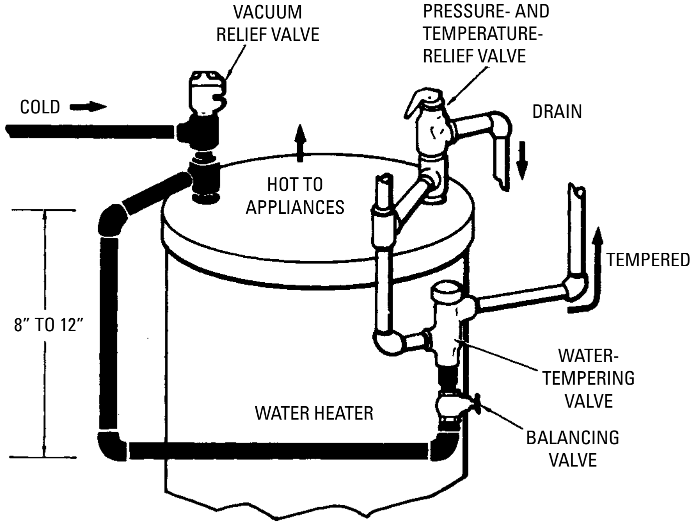


Figure 4-29 Automatic storage water heater piping connections.
(Courtesy Watts Regulator Co.)

Figure 4-30 illustrates the piping connections for large-size instantaneous heat exchanger or converter heater applications. If either leg of the circulator is valved off from the heater, an ASME pressure relief valve must be installed.

Tankless heater piping connections are shown in Figure 4-31. As in other installations, a balancing valve has been installed in the cold-water line to the tempering valve to compensate for pressure drop.

Vacuum Relief Valve

A vacuum relief valve is used to protect a hot-water supply system by preventing vacuum conditions that could drain the system by siphonage, burn out the water heater, or cause the storage tank to collapse (see Figure 4-32).

The vacuum relief valve is installed in the cold-water supply line. It closes tightly under system pressure and opens quickly in case of emergency at less than ½-inch vacuum. When the valve opens, atmosphere is admitted and breaks the vacuum, preventing siphonage of the system and the possible collapse of the storage tank.

Water-Tempering Valves

A *water-tempering valve* (see Figure 4-33) is used in a hot-water supply system to provide domestic hot water at temperatures

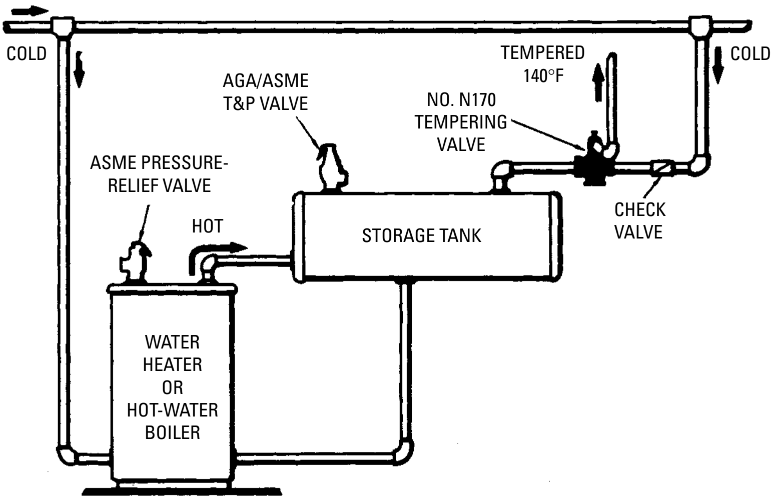


Figure 4-30 Typical piping connections for large instantaneous heat exchanger or converter-type heater applications. *(Courtesy Watts Regulator Co.)*

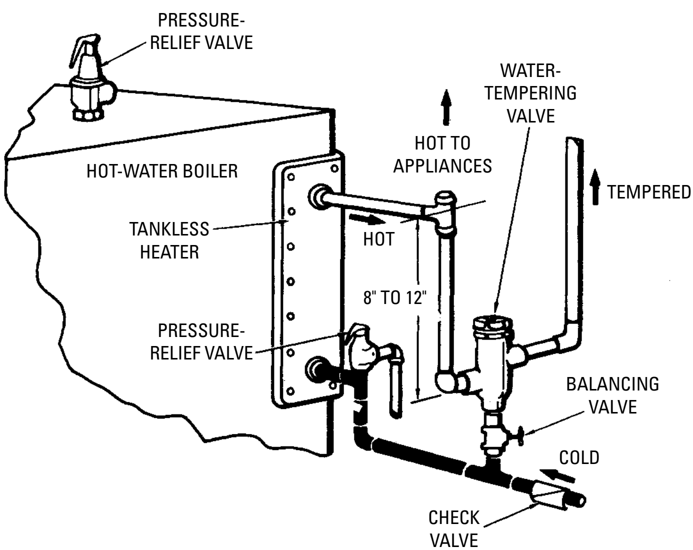


Figure 4-31 Tankless heater piping connections. *(Courtesy Watts Regulator Co.)*

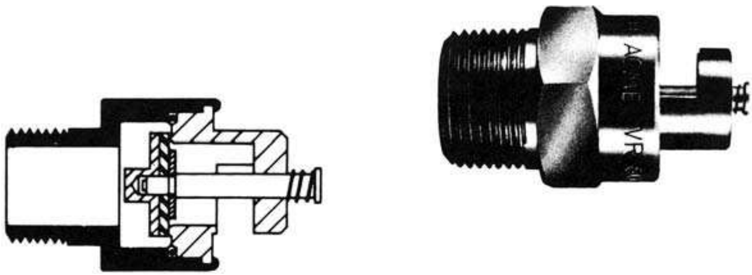


Figure 4-32 Vacuum relief valve used to protect hot-water supply systems from internal vacuum conditions. *(Courtesy A. W. Cash Valve Manufacturing Co.)*

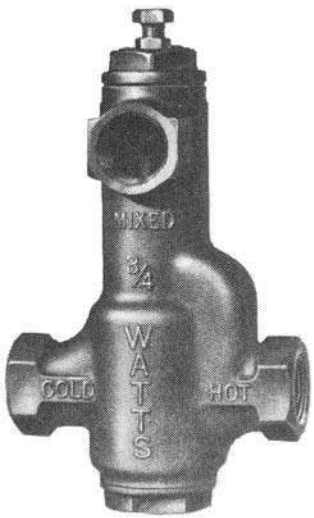


Figure 4-33 Typical water-tempering valve. *(Courtesy Watts Regulator Co.)*

considerably lower than those of the water in the supply mains. These valves are especially recommended for larger hot-water supply systems requiring dependable control of the water temperature at the fixture outlets.

A water-tempering valve is not designed to compensate for system-pressure fluctuations and should never be used where more sophisticated pressure-equalized temperature controls are required to provide antiscald performance. Water-tempering valves are described in greater detail in Chapter 10 of Volume 2 ("Steam and Hydronic Line Controls").

Gas-Fired Water Heaters

Gas-fired automatic storage water heaters are those in which the hot-water storage tank, the gas burner assembly, the combustion chamber and necessary insulation, and the automatic controls are combined in a single self-contained, prefabricated unit or package. Size limitations, resulting from the necessity of such heaters being readily portable, generally restrict the storage tank capacity to approximately 75 gallons.

In this type of water heater, the heat of the gas flame is transmitted to the water by direct conduction through the tank bottom and flue surfaces. Some heaters have multiple central flues, while in other designs the hot exhaust gases pass between the outer surfaces of the tank and the insulating jacket. In either case, these areas become radiating surfaces serving to dissipate the heat of the stored hot water to the flue or chimney when the burner is off. This is particularly true if the flue or chimney has a good natural draft.

The most commonly used gas-fired water heater is the underfeed type. If properly maintained, gas underfeed water heaters will have a long service life. They are generally inexpensive to purchase and install. The older gas underfeed models were not especially efficient, but design improvements, such as greater tank insulation and improved heat transfer surfaces, have improved their efficiency. Locating the gas burner and flue outside the storage tank has resulted in still another type of gas-fired water heater. These units (sometimes called *sidearm heaters*) provide indirect heating of the water, which allows the use of plastic-lined storage tanks and reduces standby losses.

Storage Capacity

The average ratio of hourly gas input to the storage capacity in gallons of water (for gas-fired automatic storage water heaters of the so-called rapid-recovery type) is such that the recovery (heating) capacity in gallons of water raised 100°F in one hour, in most instances, approximately equals the storage capacity of the tank in gallons.

Where the water must be raised 120°F, the recovery (heating) capacity in gallons per hour will be approximately 83 percent of the storage capacity in gallons.

Where the water must be raised 140°F, the recovery (heating) capacity in gallons per hour will be approximately 71 percent of the storage capacity in gallons.

Gas Burners

The burners used in gas-fired water heaters must be provided with inlet gas orifices and some means of air intake. These conditions are necessary to provide the required air-gas mixture for the flame. Beyond these two basic requirements, gas burners will vary widely in both design and construction. These variations in design and construction are generally concerned with providing good flame pattern and ignition. Flame characteristics are affected not only by the design of the ports (raised, drilled, ribbon, slotted, or flush) but also by their number, distribution, depth, and spacing. The gas input rating is an important factor in determining the number, distribution, and size of the ports. Proper spacing is generally determined by observation. Some common types of gas burners used on water heaters are shown in Figure 4-34.

The purpose of the gas orifice is to provide the proper input for the type of gas (for example, natural, LP) and the normal range of gas pressures. The gas passes into the mixing tube of the burner where it mixes with the air. Air is generally admitted through adjustable air shutters located around the gas orifice. The design and arrangement of the burner ports control the burning characteristics and distribution of the flame.

The size of the ports and their distribution affects the flame characteristics. If the ports are too large (both individually and in their distribution), the flame may flash back to the burner orifice. On the other hand, blowing flames can result from porting that is too small. As can be readily understood, good flame patterns are in part determined by proper porting. The number and size of ports necessary to give proper flame characteristics must be calculated.

Automatic Controls on Gas-Fired Water Heaters

The principal automatic controls used to govern the operation of a *gas-fired* water heater are as follows:

1. Thermostatic valve
2. Automatic pilot valve
3. Manual gas valves
4. Main gas–pressure regulator
5. Pilot gas–pressure regulator
6. Temperature and pressure relief valves
7. Automatic gas shutoff device
8. Pilot burner

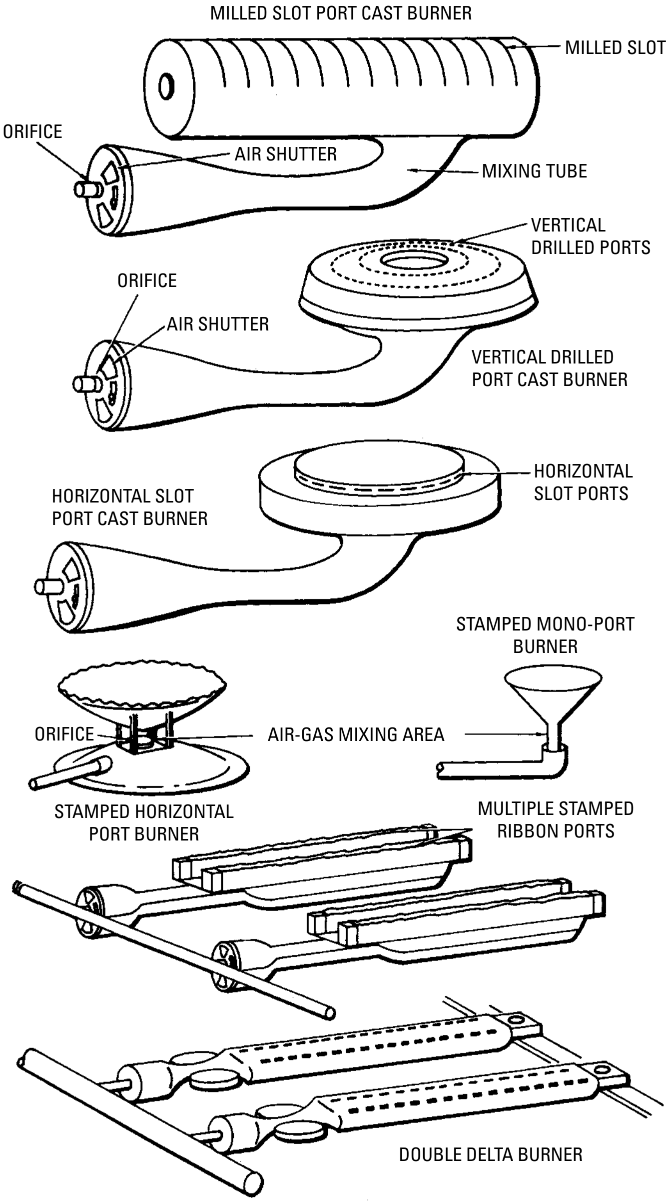


Figure 4-34 Common types of gas burners used in water heaters.

(Courtesy Robertshaw Controls Co.)

A *thermostatic valve* (see Figures 4-35 and 4-36) is used to control the gas input to the burners in relation to the water temperature in the storage tank. Thermostatic water temperature controls are usually direct, snap-action bimetallic devices that react to a drop in the temperature of the water in the storage tank. This drop in temperature causes a thermal element immersed in the stored hot water to contract and, through mechanical linkage, to open the main gas valve on the unit. When the water in the tank reaches a selected, predetermined setting, the thermal element expands and closes the main gas valve. These thermostatic valves normally operate at a temperature differential of approximately 12°F. In other words, if set to shut off the gas to the main burner when the tank water temperature reaches 140°F, they will react to open the valve when the temperature drops to 128°F.

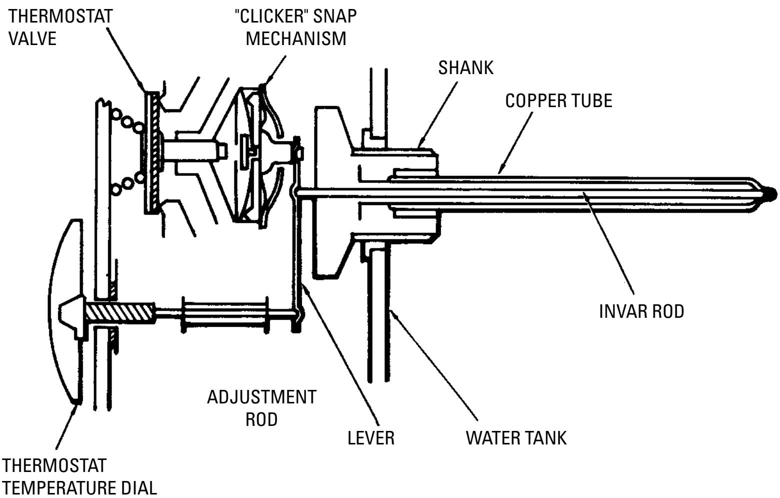


Figure 4-35 Principal thermostatic valve components.
(Courtesy Robertshaw Controls Co.)

Another important control on a *gas-fired* water heater is the *automatic pilot valve*, which operates on the thermocouple principle (see Figures 4-37 and 4-38). This control automatically shuts off the gas when pilot outage or improper ignition conditions occur. When the electromagnet is deenergized, the magnet allows the return spring to close the automatic pilot valve and shut off the gas supply to *both* the main burner and the pilot. The 100 percent automatic pilot shutoff condition is shown in Figure 4-39. As

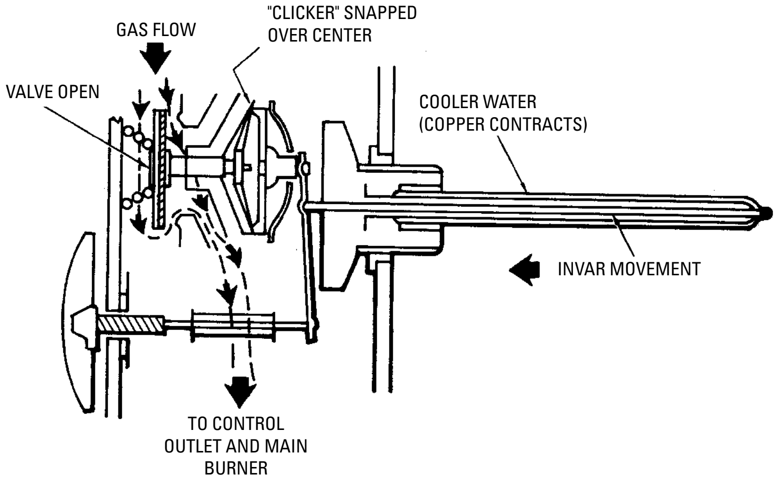


Figure 4-36 Thermostatic valve operating principles.
(Courtesy Robertshaw Controls Co.)

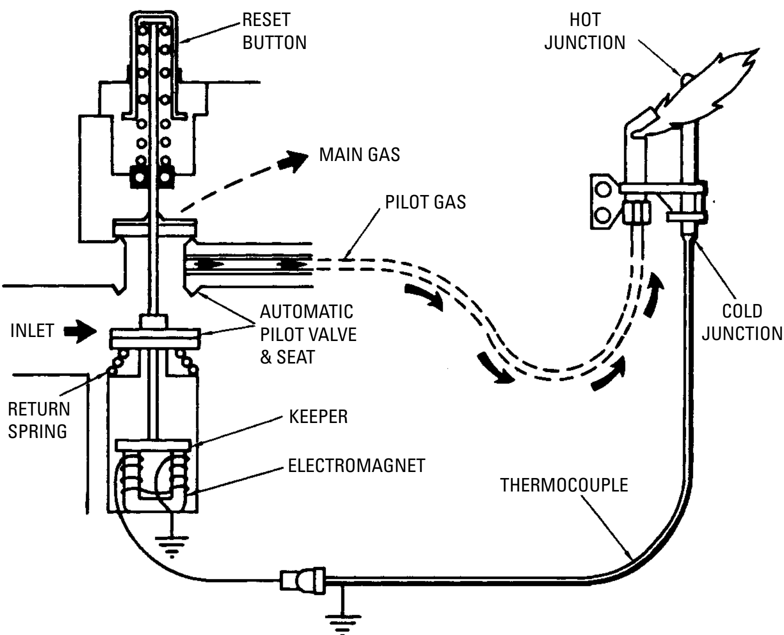


Figure 4-37 Principal components of an automatic pilot system.
(Courtesy Robertshaw Controls Co.)

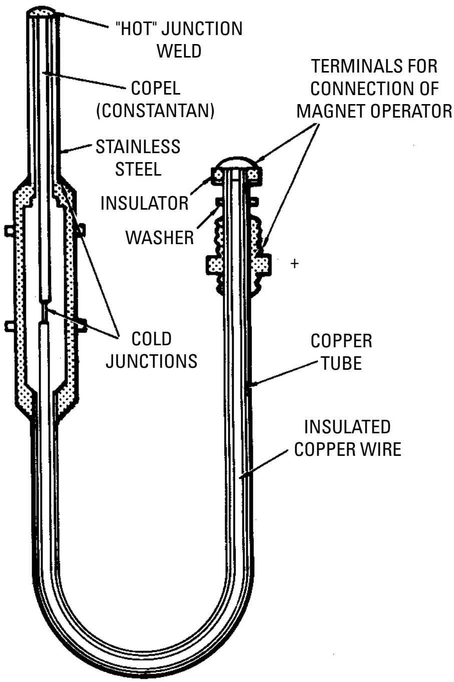


Figure 4-38 Typical thermocouple construction. *(Courtesy Robertshaw Controls Co.)*

shown in Figure 4-40, the reset button must be depressed while the pilot is being relit. If the flame is established, the pilot will continue to burn after the reset button is released (see Figure 4-41).

Manual gas valves (gas cocks) function as a backup safety system to the automatic pilot valve by providing manual control of the main burner and pilot burner gas supply (see Figure 4-42). The manual gas valve is also used with the automatic pilot valve to provide safe pilot lighting by ensuring that *only* pilot gas is flowing during the pilot lighting operation.

Both pilot gas– and main gas–pressure regulators are used on gas-fired water heaters. The *pilot gas–pressure regulator* is used to regulate the pressure of the gas flowing to the pilot. The *main gas–pressure regulator* performs the same function for gas flowing to the main burners. These gas-pressure controls have been mandatory on gas-fired water heaters since 1972.

Schematics of several types of pressure regulators used on water heaters are shown in Figures 4-42, 4-43, and 4-44. These devices

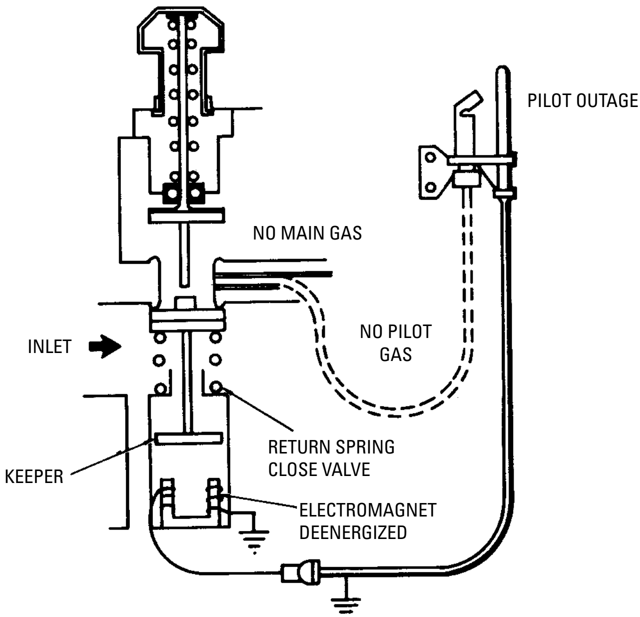


Figure 4-39 Automatic (100 percent) pilot shutoff condition.
(Courtesy Robertshaw Controls Co.)

operate on the balanced-pressure principle; that is to say, a main pressure diaphragm and a balancing diaphragm act to balance out or cancel the differences in inlet and outlet pressures caused by pressure variations.

Domestic gas water heater combination controls provide for main gas–pressure regulation by incorporating a pressure regulator in the control. Independent pilot gas–pressure regulation is optional (see *Combination Gas Controls* in this chapter).

The schematic of a Robertshaw pilot gas–pressure regulator is shown in Figure 4-45. This particular pressure regulator has the approximate diameter of a penny and is inserted downstream from the pilot filter.

The following three types of safety controls (individually or in combination) are also found on water heaters:

1. Automatic gas shutoff device
2. Pressure relief valve
3. Temperature relief valve

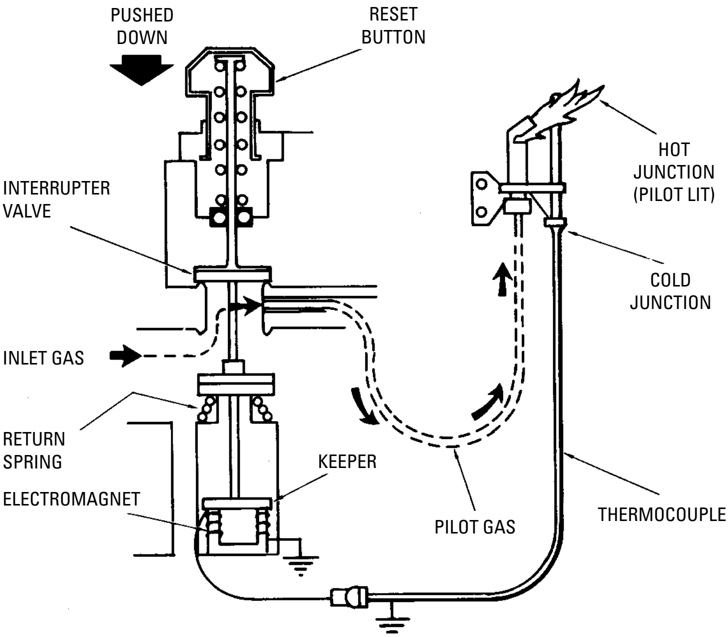


Figure 4-40 Automatic pilot valve reset button depressed while pilot is being lit. *(Courtesy Robertshaw Controls Co.)*

An *automatic gas shutoff device* is designed to shut off *all* gas to the water heater when excessively high water temperature conditions occur. In most automatic gas shutoff systems, this device operates in conjunction with the automatic pilot valve in the pilot safety shutoff circuit. The automatic shutoff device is generally set to shut off the automatic pilot valve when the water temperature in the storage tank approaches 210°F.

A typical automatic shutoff device, such as the one shown in Figure 4-46, is mounted on the tank surface so as to sense the water temperature through the tank wall. These devices are normally closed electrical switches connected in series in the automatic pilot millivolt circuit. When the switch reaches its preset temperature limit, it snaps open and deenergizes the electromagnet of the automatic pilot valve. This allows the closure spring of the automatic pilot valve to close the valve. As a result, all gas is shut off to all burners (including the pilot burner).

When the water temperature becomes too high, the volume of water in the tank tends to expand. A *temperature relief valve* is

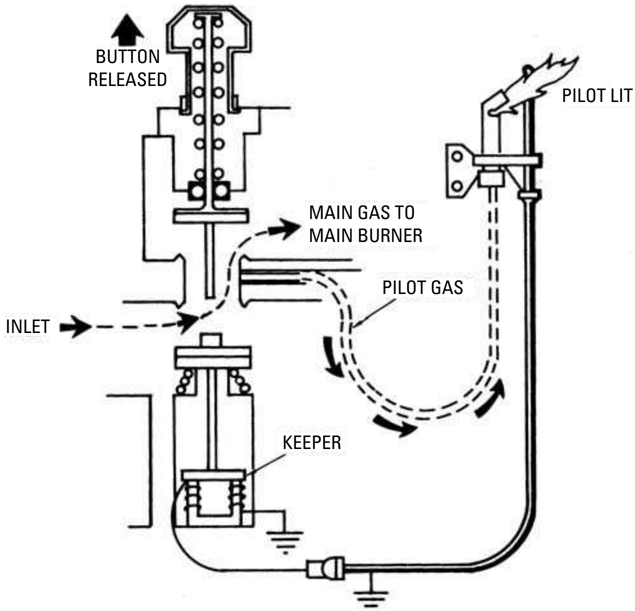


Figure 4-41 Pilot continues to burn after reset button is released. *(Courtesy Robertshaw Controls Co.)*

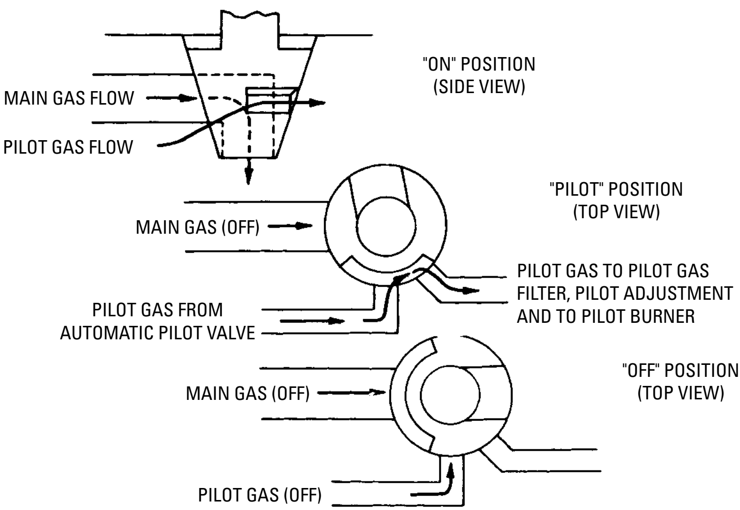


Figure 4-42 Diagram of a gas-cock parting. *(Courtesy Robertshaw Controls Co.)*

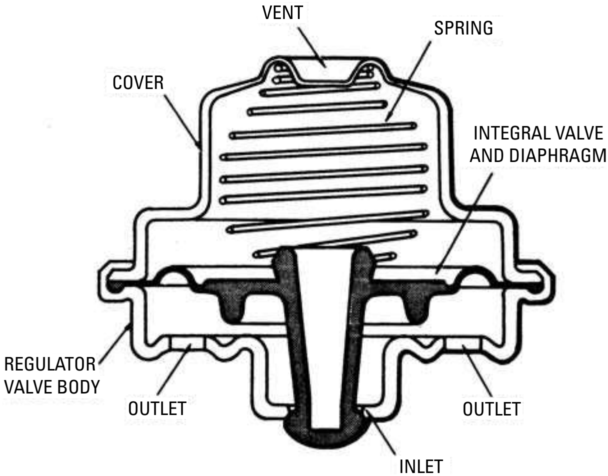


Figure 4-43 Principal components of a pilot gas–pressure regulator. *(Courtesy Robertshaw Controls Co.)*

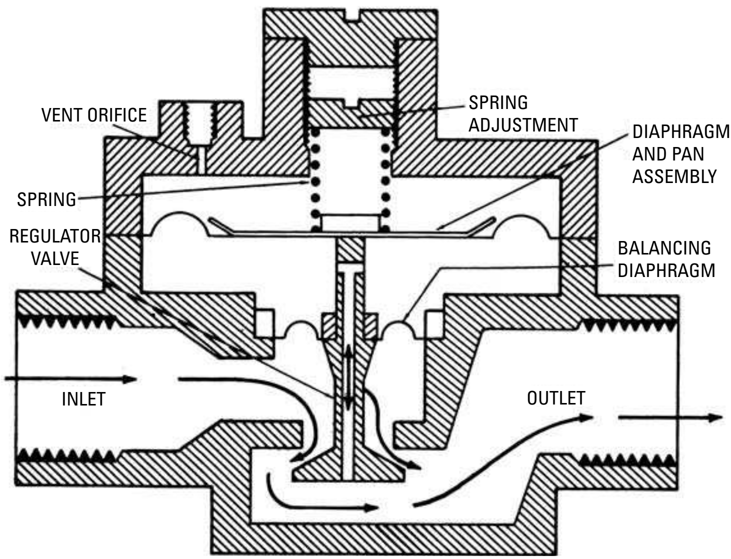


Figure 4-44 Operating principles of a balanced-pressure regulator. *(Courtesy Robertshaw Controls Co.)*

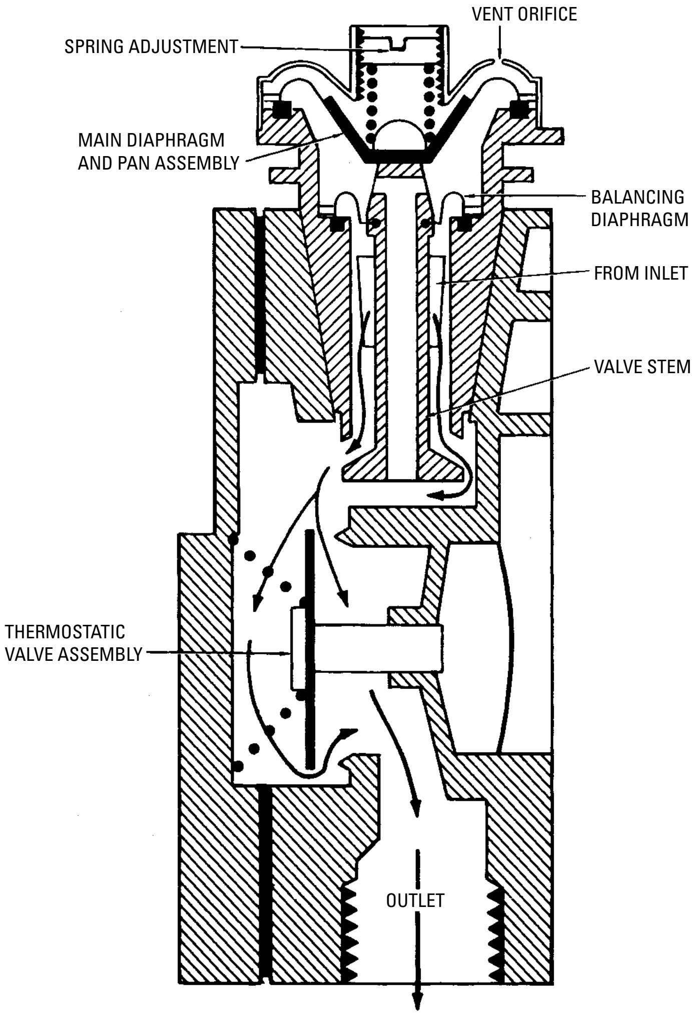


Figure 4-45 Diagram of a Robertshaw Unitrol R110R series water heater control incorporating a balanced-pressure regulator.

(Courtesy Robertshaw Controls Co.)

designed to release a portion of the water and at the same time introduce cold water to reduce the temperature of the remaining water. The temperature relief function must occur at or below 210°F on residential and commercial water heaters.

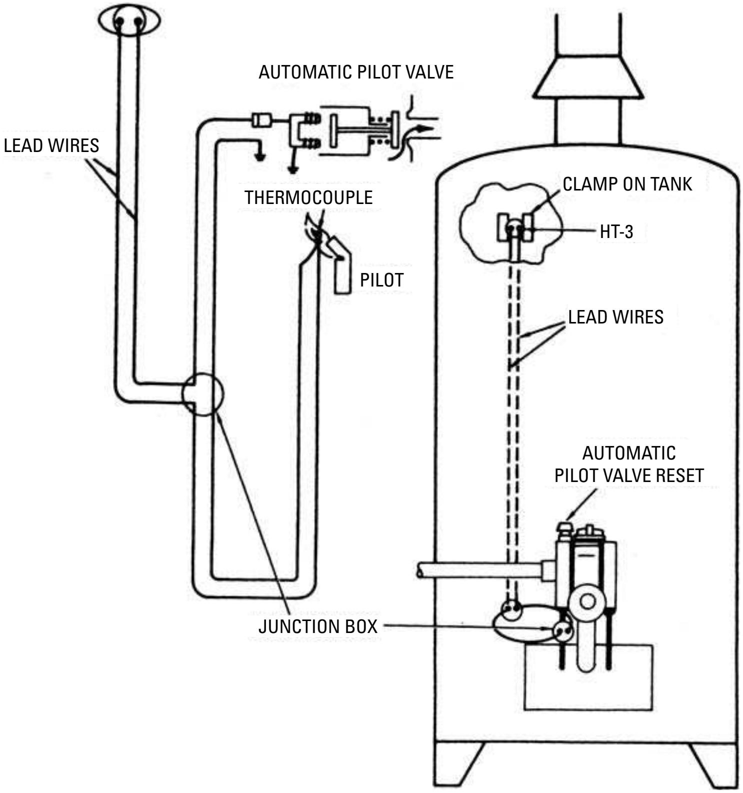


Figure 4-46 Automatic gas shutoff device installation.
(Courtesy Robertshaw Controls Co.)

The purpose of a *pressure relief valve* is to release a portion of the water from the heater or hot-water heating system when excessive pressure conditions occur. Pressure and temperature relief valves are used on *all* types of tank water heaters *regardless* of the fuel used to heat the water. See *Relief Valves* in this chapter.

The pilot burner gas supply is taken off ahead of the gas valve in the thermostatic control. Pilots are usually of the safety type, functioning to shut off the gas supply if the pilot burner flame is extinguished.

Most of the control functions described in the preceding paragraphs can be combined in a single unit or combination gas control (see next section).

Combination Gas Valve

A *combination gas valve* (or *combination gas control*) combines in a single unit all the automatic and manual control functions necessary to govern the operation of a gas-fired water heater.

A typical combination gas valve is shown in Figures 4-47 and 4-48. This particular unit contains a water heater thermostat (thermostatic valve), automatic pilot valve, automatic gas shutoff device, main gas–pressure regulator, pilot gas–pressure regulator, and manual valve (gas cock).

The installation instructions included with most combination gas valves are usually very complete and should cover the following points:

1. Disassembly and assembly instructions
2. Automatic shutoff valve and magnet replacement
3. Gas-cock lubrication
4. Thermostatic valve cleaning instructions
5. Pressure-regulator adjustment
6. Thermostat calibration
7. Lighting procedure
8. Test procedure

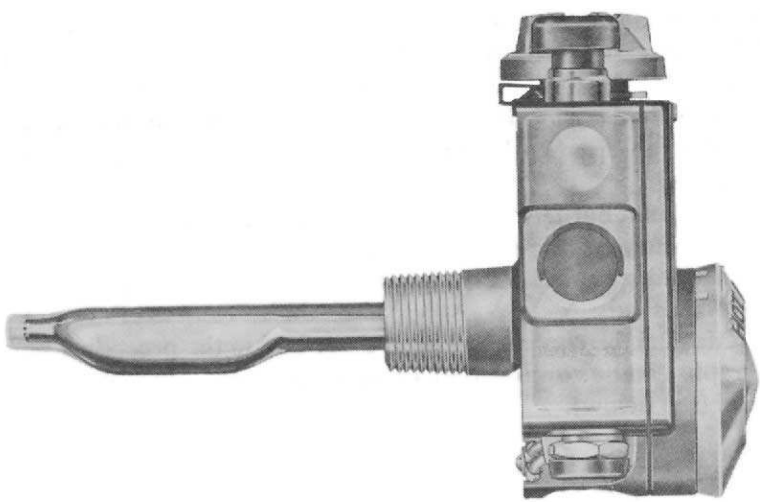


Figure 4-47 Robertshaw Unitrol R11ORTP combination gas valve.
(Courtesy Robertshaw Controls Co.)

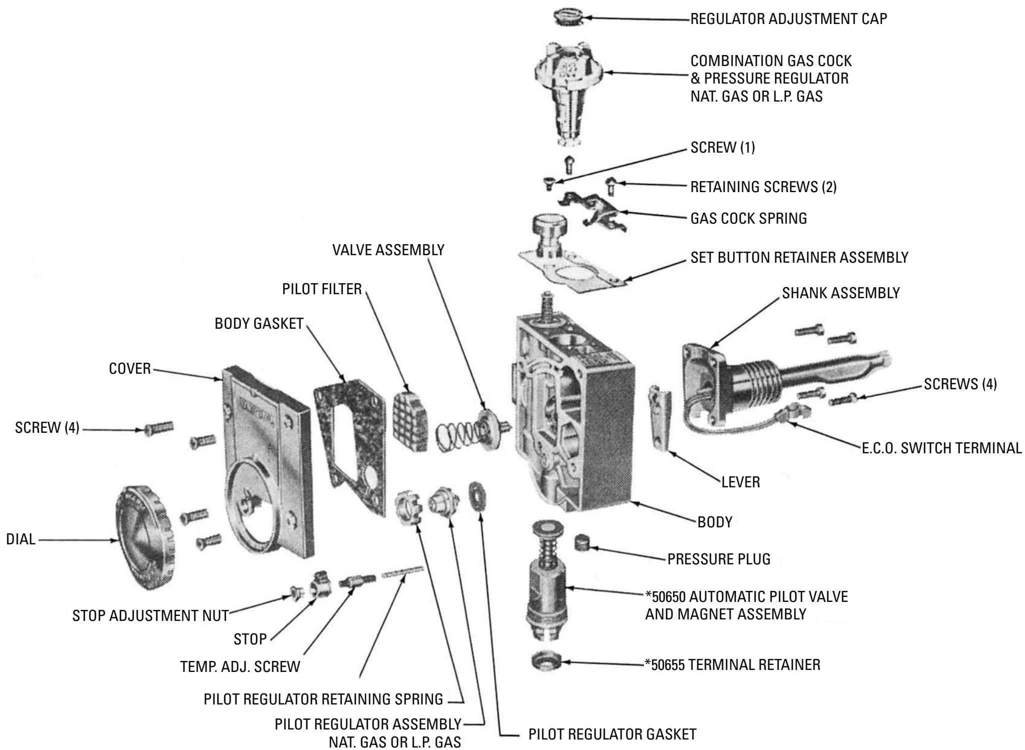


Figure 4-48 Exploded view of a Robertshaw Unitrol R110RTP combination gas valve.

(Courtesy Robertshaw Controls Co.)

Most control manufacturers provide test kits to test the operation of the thermocouple, thermomagnet, and automatic safety shutoff device. The test kit consists of a millivolt meter and an adapter for testing the thermomagnet (see Figure 4-49).

As shown in Figure 4-50, the manual valve (gas cock) is used when lighting the pilot. The gas-cock dial (1) is turned to the *off* position and at least 5 minutes is allowed to pass. This should be sufficient time for any gas that has accumulated in the burner compartment to escape. The gas-cock dial is then turned to the *start* position, and the set button (2) is depressed while the burner is being lit (see Figure 4-51). The standby flame is allowed to burn for approximately ½ minute before the reset button is released (see Figure 4-52). Unless there is a problem, the burner should stay lit after the reset button has been released. After releasing the reset button, turn the gas-cock dial to the *on* position and turn the temperature dial (3) to the desired setting.

The combination valve shown in Figure 4-53 does not use a reset button in the lighting procedure. The upper dial is turned counterclockwise to the *pilot* position and held against the spring-loaded stop until the pilot burner lights. After the pilot burner burns for about 30 to 60 seconds, the upper dial is turned clockwise to *on* for automatic control. The lower dial is then set for the desired water temperature.

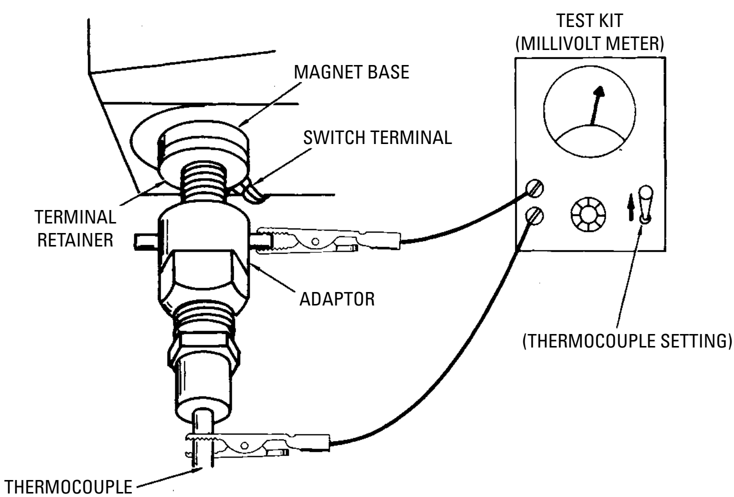


Figure 4-49 Typical testing procedure with millivolt meter and adapter. *(Courtesy Robertshaw Controls Co.)*

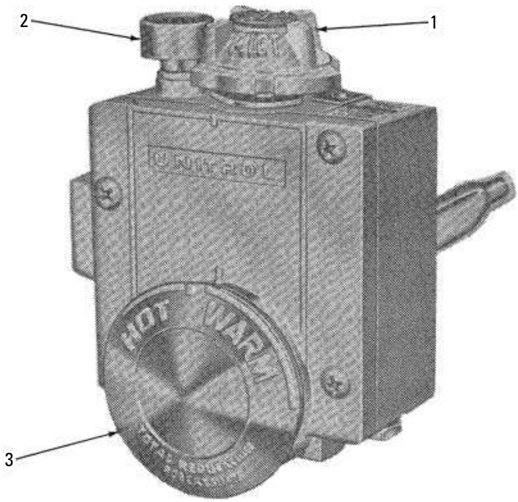


Figure 4-50 Pilot lighting procedure. *(Courtesy Robertshaw Controls Co.)*

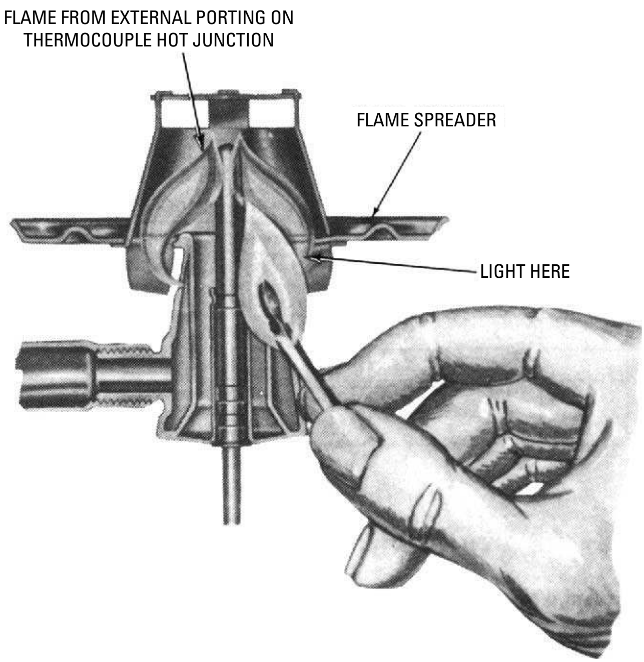


Figure 4-51 Standby flame pattern. *(Courtesy Robertshaw Controls Co.)*

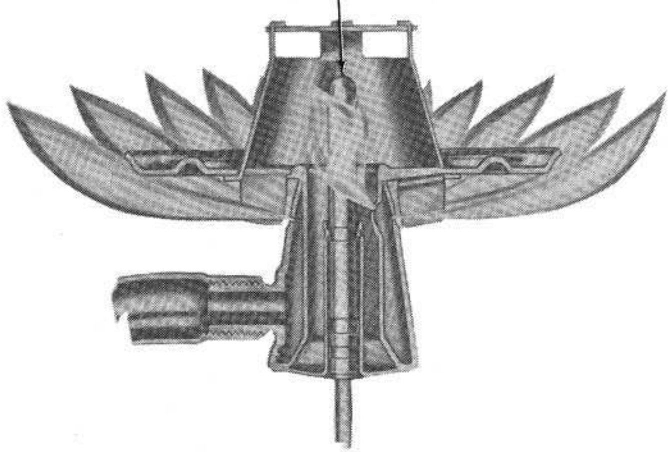
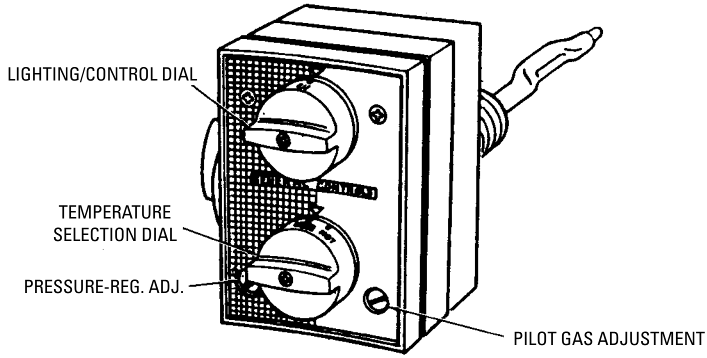


Figure 4-52 Full-input flame pattern. *(Courtesy Robertshaw Controls Co.)*

Installation and Operation of Gas-Fired Water Heaters

The installation and operation of a gas-fired automatic storage water heater involves little possibility of error if the instructions of the manufacturer are strictly followed and due consideration is given to the following factors:

1. Location
2. Venting regulations
3. Water heater venting system
4. Size of flue pipe
5. Runs of flue pipe
6. Gas meter
7. Gas supply line
8. Hot-water circulation methods
9. Safety relief valves
10. Building and safety code provisions
11. Lighting and operating instructions



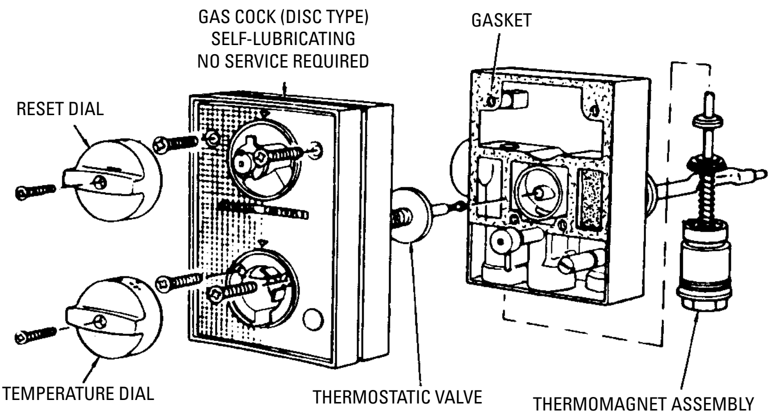


Figure 4-53 ITT General Controls water heater control.
(Courtesy ITT General Controls)

Location

The heater should be located at a point convenient to the flue or chimney and, if possible, at a point approximately equidistant from all hot-water outlets.

Venting Regulations

Many building codes prohibit connecting appliances to a common flue or chimney with coal- or oil-fired equipment. Where regulations do not require venting of gas-fired equipment to a separate flue and it is vented to a common flue with coal- or oil-fired units, the flue pipe of the gas-fired water heater or other appliance should be connected to the chimney at a point *above* the flue pipe from the coal- or oil-fired equipment.

When possible, a separate hole in the chimney should be used for the water heater flue. If this is not possible, join the flue from the water heater and the flue from the heating boiler (or furnace) with a Y connection (*never* a T connection) and install a separate draft regulator for each unit.

When the chimney cannot handle the combined input of both the water heater and the heating plant, wire the two so that they do not operate simultaneously.

Water Heater Venting Systems

The venting system of a fuel-fired water heater is designed to transfer the products of combustion to the outdoors. By transferring these potentially harmful gases outside the structure, the living spaces are maintained free of any possible air contamination. Electric water heaters do not require venting systems.

A typical venting system for a fuel-fired water heater consists of the following basic components:

1. Heater flues or heat exchangers
2. Draft diverter
3. Vent pipe connections

The design and arrangement of a venting system should take advantage of the natural tendency of hot gases to rise. These flue gases are a waste by-product of the combustion process. Because they are hot gases, they are lighter than the surrounding ambient air, and they tend to rise in a vertical path. The venting system should provide essentially a vertical path to take advantage of this natural vertical flow of the gases. The vent pipes should be of sufficient diameter to carry the volume of gas without restricting its natural flow rate.

Excessive cooling of the flue gases can be avoided by providing a controlled mixture of dilutant air from the draft diverter. If the flue gases cool, condensation will occur, the gases will grow heavier, and it will be impossible to maintain draft. The same condition (that is, excessive cooling) will occur if the vents are unusually long or high. This can be minimized by insulating the vent pipes.

Fans are used on some high-input water heaters to supplement natural venting. The use of a fan is sometimes referred to as *power venting*, and the water heaters are referred to as *power-vent water heaters*. In most cases where a fan is used, proper venting can generally be obtained from a smaller-diameter vent pipe. However, some provision should be made to automatically shut off the water heater in case of a fan failure. Fan-assisted venting allows the use of much longer horizontal or vertical flue pipes than would ordinarily be the case. As a result, the water heater can be located anywhere in the structure. On the downside, the fan and water heater are electrically operated, and a power failure will shut down the unit.

Vent pipe connections are often made directly to the outdoors or through a chimney wall. When direct venting is the case, the vent pipe connects to a vent outlet hood.

Draft hoods are used on all water heaters that rely on natural vent action to eliminate contaminating flue gases. The draft hood should contain an inlet and outlet opening for the flue gases, and an air dilutant intake and relief opening to relieve downdraft conditions.

Examples of common types of draft hoods used on gas-fired water heaters are shown in Figure 4-54. The vertical draft hood is usually the most efficient for venting.

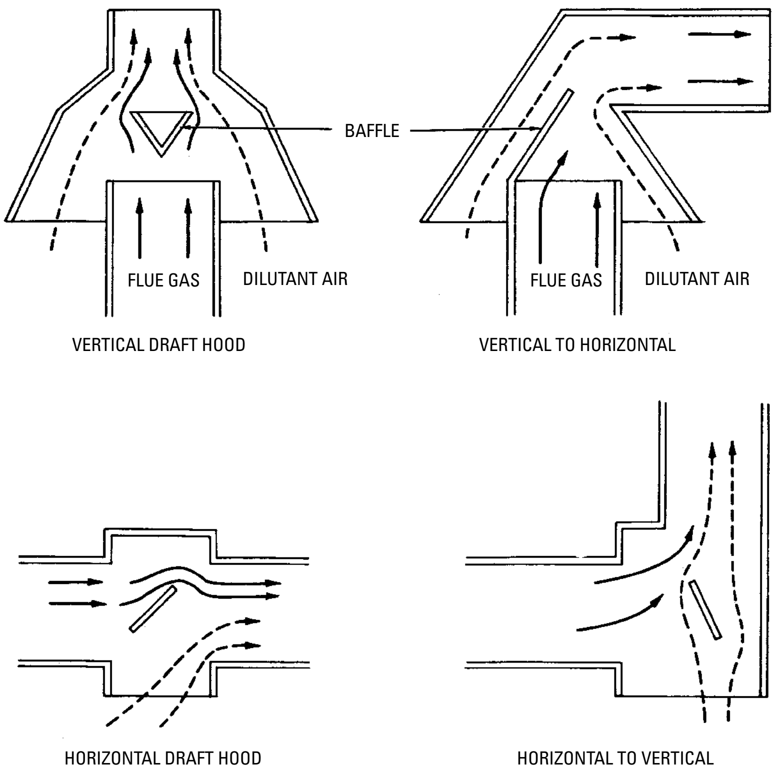


Figure 4-54 Draft hoods commonly used on water heaters.
(Courtesy Robertshaw Controls Co.)

A well-designed draft hood should be able to prevent excessive updraft in the burner compartment and momentary excessive downdraft conditions. Sometimes the flow rate of flue gases suddenly increases and results in an excessive updraft condition in the burner compartment. The amount of air flowing into the flue through the air dilutant intake is clearly insufficient to control the condition. The diverter should be designed to allow an increase in air intake during excessive updraft conditions so that the weight of the flue gases is increased and the flow rate slowed.

When downdraft conditions occur, the baffles and relief opening in the draft hood allow the downdraft to be relieved *outside* the flue so that the burner flame is unaffected. This expulsion of the combustion by-products through the air intake is only a *momentary* condition.

Size of Flue Pipe

The size of the flue pipe should not be less than that specified by the manufacturer or that shown in available tables for the rated gas input.

Flue Pipe Run

Horizontal runs of the flue pipe should pitch upward toward the chimney connection and should run as directly as possible, avoiding unnecessary bends or elbows. The backdraft diverter supplied by the manufacturer or other approved draft hood of adequate size should be employed.

Gas Meter

The gas meter must be of adequate size or capacity to supply not only the requirements of the water heater but also the requirements of all other gas-fired equipment.

Gas Supply Line

The gas supply line to the water heater should be adequate in size to supply the full rated gas input of the heater at the available pressure, taking into consideration the pressure drop through the supply line. A separate gas supply line from the meter to the water heater should be employed if the existing line from the meter is too small to supply the combined requirements of the water heater and other equipment or appliances that may be connected to it.

Safety Relief Valves

Both a pressure relief valve and a temperature relief valve are used to ensure the safe operation of a water heater. The operating characteristics of these two safety relief valves have already been described (see *Safety Relief Valves* in this chapter).

Hot-Water Circulating Methods

If a building circulation loop is employed to maintain circulation of the hot-water supply throughout the building for the purpose of making the hot water more readily available at each fixture, the return line from the circulating loop should be connected to the cold-water supply line of the heater. A swing-check valve *must* be installed in a horizontal section of the return line at a point as close to its connection to the cold-water supply line as possible to prevent the possibility of backflow of cold water to the hot-water outlets of fixtures that may be connected to the circulation loop at a location that may be closer to the cold-water supply line than to the water heater.

If a check valve were not employed, and the pressure drop in the line between the cold-water supply line and the hot-water outlet were less than the pressure drop in the line between the heater and the hot-water outlet, cold water could flow to the hot-water outlet.

Where a circulating pump is employed to accelerate the circulation in a building hot-water supply loop, it should be installed in the return water line at a point as close to its connection to the cold-water supply line as possible. To eliminate the unnecessary wear and expense incidental to operating a circulating pump continuously, it should be controlled by a direct aquastat installed in the return circulating line at a point conveniently close to the pump.

It is suggested that this aquastat be adjusted to close the pump circuit when the water in the return line drops to (or below) 100° to 110°F and break the pump circuit when the water temperature at that point rises to approximately 120° to 130°F if the desired hot-water temperature at the fixture is approximately 130° to 140°F.

Building and Safety Code Requirements

The building and safety codes of certain states require the use of dip tubes in the hot-water storage tanks of automatic storage water heaters or recovery water heating systems, while other codes prohibit their use.

The apparent purpose of code provisions prohibiting the use of cold-water supply dip tubes in the tanks of underfired storage water heaters is to prevent the possibility of developing dangerously excessive temperatures and pressures in the tank of the gas supply to a *manually* controlled heater (if not turned off) or the safety control of an automatic water heater that fails to function.

Under such circumstances, the water in the tank would drain to the levels of the holes drilled in the dip tubes close to the top of the dip tube before the siphon action would be broken.

The water remaining in the tank, being practically at zero pressure, would vaporize rapidly if automatic temperature and safety controls failed to function or the gas supply were not shut off. The steam thus generated in the remaining space in the upper portion of the tank would create a personal scalding hazard if communicated to the hot-water supply piping and outlets, or could attain sufficient pressure to rupture the tank or piping.

An equally hazardous condition would be created if the tank of a storage heater not equipped with a cold-water supply dip tube were completely drained.

Under this condition, if the gas supply to a manually controlled heater were not shut off, or the thermostatic and safety controls of an automatic heater failed to function with the gas valve in the thermostat in the open position, explosive pressures would be almost instantaneously developed if cold water were introduced into the empty heater tank.

To avoid such hazards, the gas supply to either a manually controlled or automatic storage water heater should always be shut off before draining the tank of the heater or the entire hot-water supply system.

Where the use of a cold-water dip tube installed in a tapping in the top and extending to a point close to the bottom of the hot-water storage tank is prohibited, the cold-water supply line should be connected to a tapping as close to the bottom as possible.

If the cold water enters the tank at a point considerably above the bottom, the water below that point will be in a more or less static state, which may be conducive to more rapid deposition of lime or other scale on the tank bottom.

Lime or other scale on the tank bottom retards the transfer of heat to the water if the heater is of the underfired type, which impairs its efficiency.

Lighting and Operating Instructions

Lighting and operating instructions are supplied by the manufacturer and should be read and thoroughly understood before attempting to adjust the rate of gas input and the thermostat or other automatic controls, particularly if the serviceperson is not completely familiar with the design and construction of such controls.

Before leaving the premises, it is imperative that the serviceperson hang the operating instructions at a point convenient to the heater where it will be available for ready reference whenever needed by the owner or operating personnel.

The return warranty registration card, if provided, should also be properly filled in by the serviceperson and handed to the owner for mailing to the manufacturer. In many instances, warranty provisions are invalidated if the registration card is not returned to the manufacturer.

Installation and Maintenance Checklist

The water temperature control in a residential water heater should be set as low as possible and still provide satisfactory hot water at the faucets. This adjustment for low water temperature prolongs

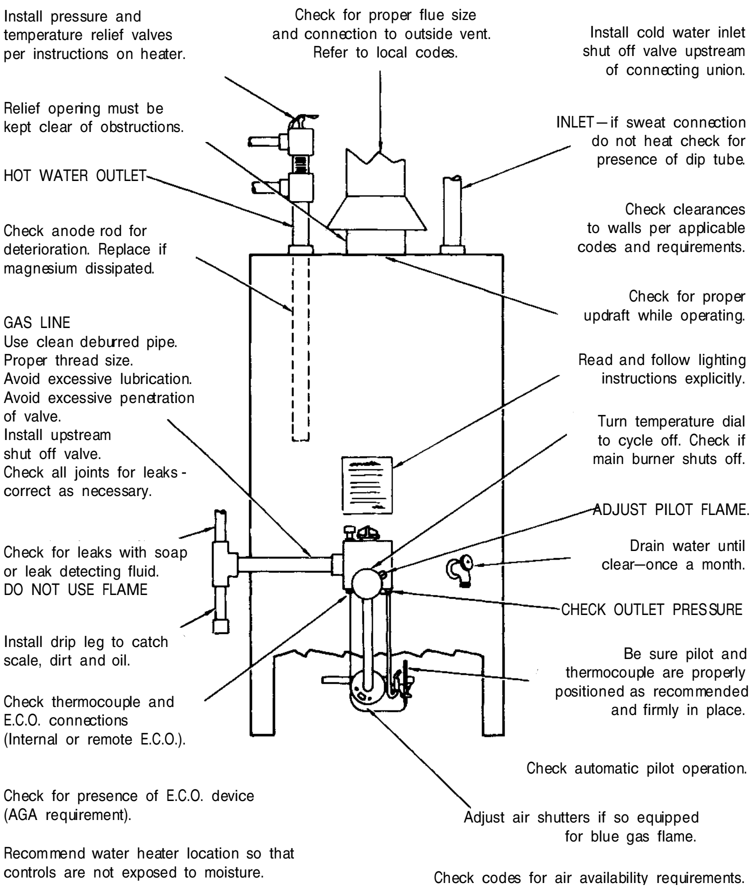


Figure 4-55 Water heater service guide. *(Courtesy Robertshaw Controls Co.)*

the life of the tank and prevents stacking. The temperature dial is adjustable and should be used to meet varying conditions and requirements. For control maintenance, it is best to call a qualified serviceperson. Instructions in the manufacturer's field information bulletin should be followed when servicing or repairing water heater controls. Figure 4-55 provides a general checklist for water heater installation and maintenance.

Troubleshooting Gas-Fired Water Heaters

Table 4-1 covers many of the more common symptoms and possible causes of operating problems associated with gas-fired water heaters.

Table 4-1 Troubleshooting Gas-Fired Water Heaters

Symptom and Possible Cause	***Possible Remedy***
Water too hot.	
(a) Thermostat setting too high.	(a) Set thermostat lower.
(b) Leaking thermostat valve.	(b) Clean valve or replace.
(c) Pilot too high.	(c) Adjust pilot lower.
(d) Thermostat out of calibration.	(d) Recalibrate or replace thermostat.
(e) Pilot outage.	(e) Set thermostat lower and reignite pilot.
Not enough hot water or water temperature too low.	
(a) Thermostat setting too low.	(a) Set thermostat higher. Caution: Do not set thermostat higher than 120°F.
(b) Thermostat out of calibration.	(b) Recalibrate or replace thermostat.
(c) Undersized heater for hot-water demand.	(c) Replace with larger heater.
(d) Clogged burner orifice.	(d) Inspect and clean.
(e) Undersized burner orifice.	(e) Change orifice to correct size.
(f) Gas pressure too low.	(f) Readjust regulator (if so equipped); check gas supply pressure and manifold pressure.
(g) Clogged flue.	(g) Inspect and clean.

(continued)

Table 4-1 *(continued)*

Symptom and Possible Cause	***Possible Remedy***
(h) Draft venting problem.	(h) Check for downdraft and updraft venting and correct as required; check for any drafts blowing out pilot light.
(i) Defective thermostat.	(i) Replace thermostat.
(j) Gas control problem.	(j) Inspect and replace.
(k) Defective dip tube.	(k) Replace dip tube.
No hot water.	
(a) No gas supply to burner.	(a) Turn on gas supply.
(b) Pilot out.	(b) See *Failure to Ignite* and *Pilot Will Not Stay Lit*.
Delayed or slow hot-water recovery.	
(a) Clogged flue.	(a) Clean flue chamber.
(b) Incorrect gas pressure.	(b) Check gas pressure and adjust.
(c) Clogged burner orifice.	(c) Inspect, clean, or replace as necessary.
(d) Excessive drafts.	(d) Locate and eliminate drafts.
Burner flame too high.	
(a) Pressure regulator set too high.	(a) Reset.
(b) Defective regulator.	(b) Replace.
(c) Burner orifice too large.	(c) Replace with correct size.
Noisy burner flame.	
(a) Too much primary air.	(a) Check and adjust.
(b) Noisy pilot.	(b) Reduce pilot gas.
(c) Burr in orifice.	(c) Remove burr or replace orifice.
(d) Dirty burner orifice.	(d) Inspect and clean.
Yellow-tipped burner flame.	
(a) Too little primary air.	(a) Check and adjust.
(b) Dirty burner orifice.	(b) Inspect and clean.
(c) Misaligned burner orifices.	(c) Realign.
(d) Clogged draft hood.	(d) Clean.

Table 4-1 *(continued)*

Symptom and Possible Cause	*Possible Remedy*
Floating burner flame.	
(a) Blocked venting or clogged flue.	(a) Inspect and clean.
(b) Insufficient primary or secondary air.	(b) Increase air supply; adjust air shutters.
(c) Incorrect orifice.	(c) Install correct orifice.
Delayed ignition.	
(a) Improper pilot location.	(a) Reposition pilot.
(b) Pilot flame too small.	(b) Check orifices; clean; increase pilot gas.
(c) Burner ports clogged near pilot.	(c) Clean ports.
(d) Low pressure.	(d) Adjust pressure regulator.
Unable to ignite pilot.	
(a) Gas supply off.	(a) Open manual valve to turn on gas supply.
(b) Thermostat out of calibration.	(b) Recalibrate, repair, or replace.
(c) Defective thermocouple and/or automatic pilot valve.	(c) Check and replace.
(d) Loose thermocouple connection.	(d) Check and tighten connection.
(e) Defective safety magnet assembly.	(e) Check magnet and replace gas valve.
(f) Gas-cock knob dial set incorrectly.	(f) Check lighting instructions and set gas-cock knob to correct position.
(g) Clogged pilot burner orifice.	(g) Clean or replace.
(h) Air in gas line.	(h) Purge air from line.
(i) Defective gas valve.	(i) Replace gas valve.
(j) Clogged pilot tube.	(j) Clean or replace.
(k) Pinched pilot tube.	(k) Repair or replace.
Burner will not turn off.	
(a) Thermostat set too high.	(a) Lower setting.
(b) Thermostat out of calibration.	(b) Recalibrate or replace.
(c) Dirt on thermostat valve seat.	(c) Clean or replace.
(d) Defective thermostat.	(d) Replace thermostat.

(continued)

Table 4-1 (continued)

Symptom and Possible Cause	*Possible Remedy*
Pilot will not stay lit.	
(a) Too much primary air.	(a) Check and adjust pilot shutter.
(b) Dirt in pilot orifice.	(b) Open orifice.
(c) Clogged flue.	(c) Clean flue way.
(d) Draft venting problem.	(d) Check downdraft and updraft venting and correct as required; check for any drafts blowing out pilot light.
(e) Too much draft.	(e) Provide shielding or reduce draft.
(f) Defective safety magnet assembly.	(f) Check magnet and replace gas valve.
(g) Automatic pilot magnet valve defective.	(g) Replace.
(h) Loose thermocouple connection.	(h) Tighten connection.
(i) Defective thermocouple.	(i) Replace.
(j) Thermocouple tip out of pilot flame.	(j) Move tip into flame.
(k) Incorrect pilot-gas adjustment.	(k) Adjust pilot gas.
(l) Incorrect pilot orifice size.	(l) Replace with correct size.
(m) Pilot burner orifice or supply tube partly clogged.	(m) Inspect and clean pilot burner and supply tube.
Main burner will not stay lit.	
(a) Clogged orifice.	(a) Clean or replace.
(b) Low gas pressure.	(b) Check gas supply pressure and correct.
(c) Pinched or damaged main burner gas supply tube.	(c) Repair or replace.
(d) Clogged main burner gas supply tube.	(d) Clean or replace.
(e) Defective magnetic assembly.	(e) Check and replace gas control valve.
(f) Defective thermocouple.	(f) Check and replace thermocouple.
(g) Loose thermocouple connection.	(g) Check and tighten connection or replace if connection damaged.

Table 4-1 *(continued)*

Symptom and Possible Cause	***Possible Remedy***
(h) Defective main valve.	(h) Replace gas control valve.
(i) Venting downdraft problem.	(i) Check and correct.
(j) Venting sizing problem.	(j) Check and correct.
Noisy water heater operation.	
(a) Scale or sediment at bottom of tank.	(a) Clean tank.
(b) Loose baffles.	(b) Reset and tighten.
Excessive temperature/pressure relief valve operation.	
(a) Excessive temperature.	(a) Lower temperature setting. If problem continues, check for grounded element and correct as necessary; replace defective thermostat.
(b) Excessive water pressure.	(b) Install specified pressure-reducing valve on cold intake side.
Rusty, black, or brown water.	
(a) Excessive sediment accumulation in tank.	(a) Drain and clean tank, or replace if necessary.
(b) Elements covered with scale.	(b) Clean or replace elements.
(c) Dissolved anode rod.	(c) Replace anode rod.
Water below gas water heater (drops of water or puddles on floor).	
(a) Normal condition for gas water heaters if drops of water or small puddles dry up.	(a) Ignore.
(b) Small pinhole leak in inner tank.	(b) Replace water heater.
(c) Loose immersion thermostat or anode rod.	(c) Tighten or replace.
(d) Defective joint at cold intake or hot outlet on tank.	(d) Inspect and repair as necessary.
(e) Defective temperature/pressure relief valve.	(e) Check and replace.

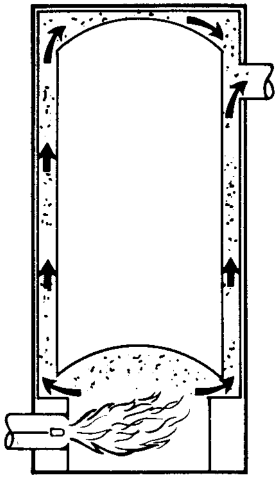


Figure 4-56 External (floating) tank oil-fired water heater.

(Courtesy National Oil Fuel Institute)

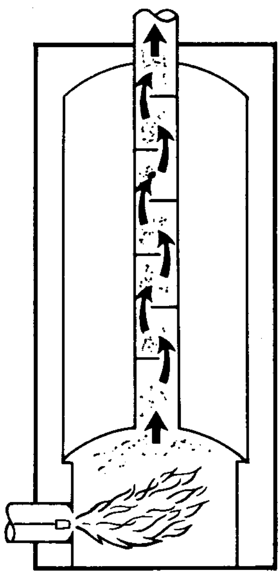


Figure 4-57 Internal flue oil-fired water heater.

(Courtesy National Oil Fuel Institute)

Oil-Fired Water Heaters

Most of the oil-fired heaters used in residences and small buildings are of the external, or floating, tank design (see Figure 4-56). The products of the combustion process pass upward through the flue passages located between the suspended hot-water storage tank and the outer walls of the water heater. Multiflue and internal flue oil-fired water heaters, though less common, are also used (see Figure 4-57).

As with gas-fired water heaters, an oil heater must have an adequate draft for proper combustion. Sometimes it is necessary to vent two oil-fired appliances (for example, furnace and water heater) into the same flue. When this situation occurs, the two can be connected to the flue either with a "Y" connection or in such a way that both feed directly into the flue (see Figure 4-58). When two oil-fired appliances, such as a furnace and a water heater, are connected to a single vent, the controls can be wired to prevent simultaneous operations and give priority to the water heater (see Figure 4-59).

Oil-fired water heater controls are similar to those used to control hot-water space-heating boilers. They are also designed to regulate the temperature of the water in the water heater storage tank. For example, the primary control shown in Figures 4-60 and 4-61 is used in conjunction with an immersion aquastat and a remote sensor (cadmium detection cell) to simultaneously regulate the water temperature and provide oil burner control. Both oil burner malfunctions and water temperatures that fall outside the rated temperature range of the heater will cause the primary control to start or stop the oil burner as conditions require.

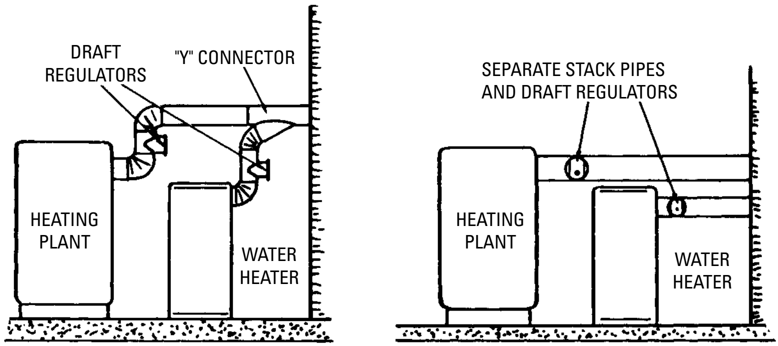


Figure 4-58 Connecting the boiler and water heater flues to chimney. *(Courtesy National Oil Fuel Institute)*

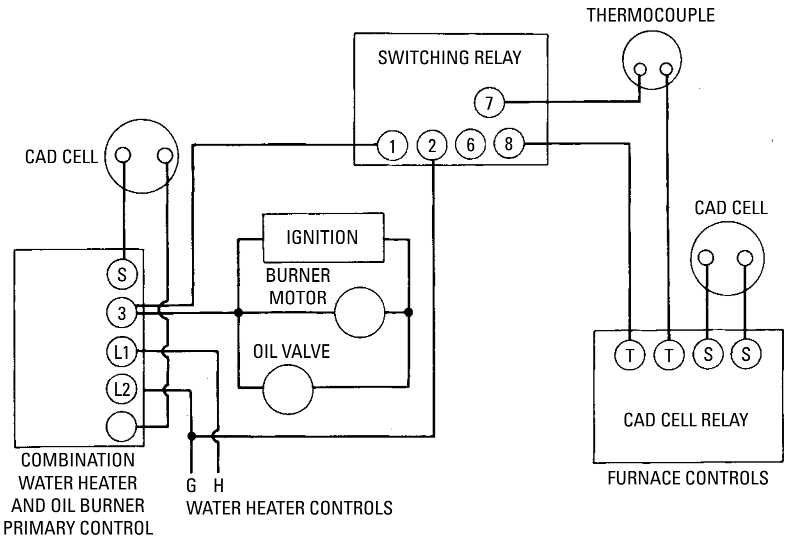


Figure 4-59 Wiring the water heater and heating plant so that they do not operate simultaneously. *(Courtesy National Oil Fuel Institute)*

Pressure and temperature relief valves are vital for the protection of the hot-water storage tank. These valves are described elsewhere in this chapter (see *Relief Valves*).

When adjusting an oil-fired water heater, always adjust for a smoke-free fire first, and then make the necessary adjustment for efficient operation.

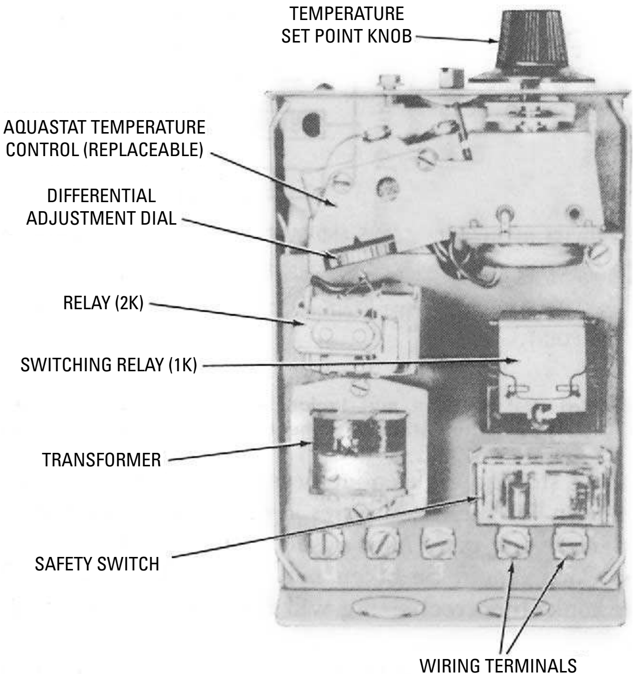


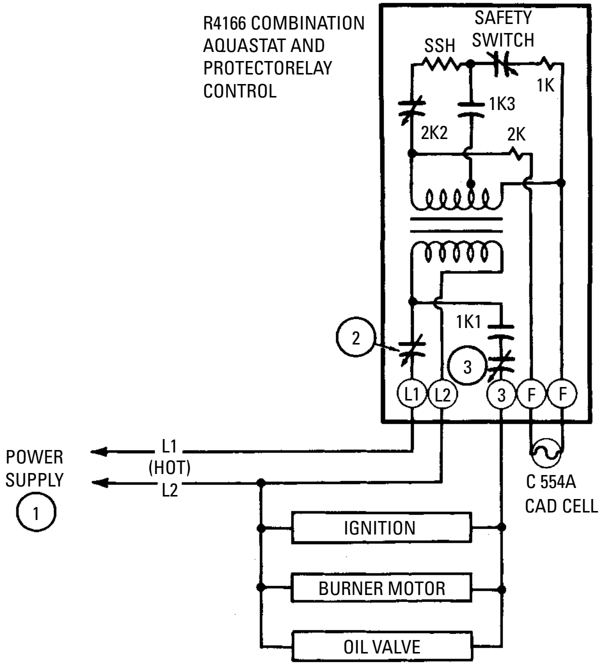
Figure 4-60 Honeywell R4166 combination water heater and oil burner primary control. *(Courtesy Honeywell Tradeline Controls)*

Electric Water Heaters

Most electric water heaters used in residences are the automatic storage type. Although some instantaneous heaters are in use, the high electric power input required makes them uneconomical to operate when compared with fuel-fired types.

An electric water heater generally consists of a vertical tank with a primary heating element or resistor inserted near the bottom of the tank. Some water heaters have a secondary heating element located in the upper one-fourth of the tank (see Figure 4-62). The number of heating elements used in the heater will depend on the size of the storage tank. Large-capacity storage tanks will require two heating elements.

The manual and thermostatic (automatic) controls are located inside the storage tank. A water heater thermostat is designed to automatically open or close the electrical circuit to the heating element(s) whenever the hot-water temperatures exceed or fall below



1 Provide disconnect means and overload protection as required.

2 Aquastat control breaks on temperature rise to set point.

3 R4166b only—high limit control breaks on temperature rise to set point.

Figure 4-61 Internal diagram and typical wiring hookup of a Honeywell R4166 combination water heater and oil burner primary control. *(Courtesy Honeywell Tradeline Controls)*

the temperature range of the water heater. Depending on the size of the storage tank, the water heater will be equipped with either one or two thermostats.

The rated voltage for electric water heaters is 240 volts. The thermostats controlling the primary and secondary heating elements are generally set at 150°F.

Several types of heating units are available for electric water heaters, but the two most popular are probably the immersion element and the strap-on unit. The immersion element is inserted

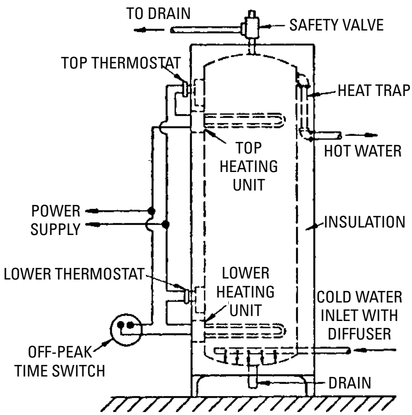


Figure 4-62 Components of an electric-fired water heater. *(Courtesy 1965 ASHRAE Guide)*

through an opening in the side of the tank. The strap-on unit is externally mounted on the surface of the tank.

A larger storage tank capacity is required for electric water heaters than for fuel-fired types in order to compensate for the limited recovery rate. As a result, initial equipment costs are higher. Care should be taken not to oversize or undersize the storage tank. Incorrect sizing will result in an inefficient water heater.

Electric water heaters of the automatic storage type are generally available in storage tank capacities ranging from 30 to 140 gallons. The electric power input requirement will range from 1600 to 7000 watts.

Troubleshooting Electric Water Heaters

The troubleshooting list in Table 4-2 covers most of the problems commonly encountered when operating electric water heaters.

Table 4-2 Troubleshooting Electric Water Heaters

Problem and Possible Cause	***Suggested Remedy***
No hot water.	
(a) Blown fuse.	(a) Replace fuse.
(b) Tripped circuit breaker.	(b) Reset circuit breaker. Call electrician if problem continues.
(c) Tripped high-limit switch.	(c) Manually reset switch.
(d) Grounded thermostat.	(d) Check and replace.

Table 4-2 (continued)

Problem and Possible Cause	*Suggested Remedy*
(e) Upper thermostat defective.	(e) Replace.
(f) Thermostat out of calibration.	(f) Tighten/replace as necessary.
(g) Upper element defective.	(g) Replace.
(h) Loose wiring.	(h) Check, tighten, and replace.
(i) Defective or damage wiring.	(i) Replace.
(j) Undersized service wire.	(j) Replace.
Hot-water temperature too high.	
(a) Thermostat setting too high.	(a) Lower thermostat setting to desired temperature.
(b) Thermostat out of calibration.	(b) Check and replace.
(c) Grounded or defective element.	(c) Check and replace.
(d) Water heater thermostat not flush with tank.	(d) Reposition thermostat with its back touching the tank.
Water slow to heat.	
(a) Undersized heating elements.	(a) Check wattage and replace.
(b) Defective lower thermostat.	(b) Replace.
Not enough hot water or temperature of water too low.	
(a) Thermostat set too low.	(a) Increase thermostat setting. Caution: Do not set the thermostat above 120°F.
(b) Incorrect wiring.	(b) Check manufacturer's wiring diagram and rewire.
(c) Loose wiring.	(c) Check; tighten or replace as necessary.
(d) Lower element defective.	(d) Replace.
(e) Lower thermostat defective.	(e) Replace.
(f) Incorrectly wired thermostat.	(f) Replace.
(g) Grounded thermostat.	(g) Replace.
(h) Incorrect heating element wattage.	(h) Check wattage and replace.
(i) Water heater thermostat not flush with tank.	(i) Reposition thermostat with its back touching the tank.
(j) Scale of heating element.	(j) Clean or replace.
(k) Damaged dip tube.	(k) Replace dip tube.

(continued)

Table 4-2 *(continued)*

Problem and Possible Cause	*Suggested Remedy*
(l) Water tank poorly grounded.	(l) Check grounding and tighten.
(m) Undersized water heater.	(m) Resize for residence. Replace if necessary.
Leaking water heater.	
(a) Damaged or loose joints at cold-water inlet and/or hot-water outlet.	(a) Check joints and repair.
(b) Defective temperature/pressure relief valve.	(b) Replace.
(c) Defective heating elements.	(c) Replace.
(d) Defective anode rod or gaskets.	(d) Replace.
(e) Hole in inner tank.	(e) Replace water heater.
Excessive temperature/pressure relief valve operation.	
(a) Excessive temperature.	(a) Lower temperature setting. If problem continues, check for grounded element and correct as necessary; replace defective thermostat.
(b) Excessive water pressure.	(b) Install specified pressure-reducing valve on cold intake side.
Rusty, black, or brown water.	
(a) Excessive sediment accumulation in tank.	(a) Drain and clean tank, or replace if necessary.
(b) Elements covered with scale.	(b) Clean or replace elements.
(c) Dissolved anode rod.	(c) Replace anode rod.
Strong unpleasant odor.	
(a) Dirty tank.	(a) Drain and clean tank with chlorine bleach to remove bacteria.
(b) Dissolved anode rod.	(b) Drain and clean tank; replace anode rod.

Manual Water Heaters

Manual water heaters, also referred to as *circulating tank* or *side arm heaters*, are of the conventional design with the gas burner and accompanying heating coils mounted on the side of the hot-water storage tank as shown in Figure 4-63.

Manual water heaters are generally equipped with copper coils 16½ to 20 feet in length and with either ¾ - or 1-inch outside diameter. The coils are usually made of copper tubing of No. 20 Stubbs gauge. Other designs are occasionally employed—for example, the internal or underfired units intended to overcome liming in hard-water areas.

These heaters usually have between 20,000 and 30,000 Btu capacity, although the maximum sizes run up to 85,000 Btu capacity. The

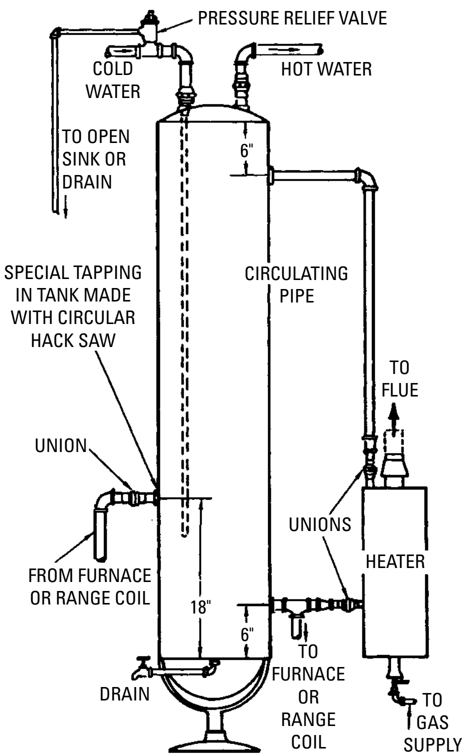


Figure 4-63 Connection of a manual gas water heater where interconnected with a waterback or range coil.

smallest-size manual heater will deliver about 19 gallons of hot water per hour. This size heater is generally ample for most homes in which the conventional 30-gallon tank is used for storing the hot water.

The manual water heater was formerly widely employed because of its comparatively low cost and economy in operation. As the name implies, manual water heaters are nonautomatic and supply hot water quickly by turning on and lighting the gas shortly before the warm water is required. Automatic water heaters have largely replaced the manual type because the former require little or no attention when in operation.

Assembly and Installation of Manual Water Heaters

A great many installations of manual water heaters have given poor service, not because of any fault in the heater, but mainly due to the improper method of connecting the heater to the storage tank. This lack of good service can be largely overcome if a few simple installation rules are followed.

All recently manufactured range boilers have tappings provided in them for hot- and cold-water connections, specifically two tappings in the side of the tank 6 inches from the top and bottom as shown in Figure 4-63 to accommodate the circulating water connections, which should be made of ¾-inch or larger pipe. The bottom of the tank has a tapping for connection to the drain or blow-off, which is used to drain water or sediment from the boiler. Circulating pipes between the heater and tank should be made as free from fittings and bends as possible.

The use of brass pipe on the hot-water circulating line from the heater to the tank is recommended, particularly for high-temperature circulation.

When required, unions should be placed as close to the heater as possible on the hot-water and cold-water circulating lines.

The placement of hot- and cold-water tappings 6 inches from the top and bottom of the tank allows free circulation, which results in relatively large-volume storage without overheating. It also eliminates short-circuiting of the water through the heater and provides ample sediment storage below the circulating line, thus preventing sediment from getting into the heating element.

Solar Water Heaters

Many of the valves and heating controls used with gas, oil, and electric water heaters can also be used in solar water heating systems. These components are designed to protect and control a solar water heating installation from a single source. A typical system is

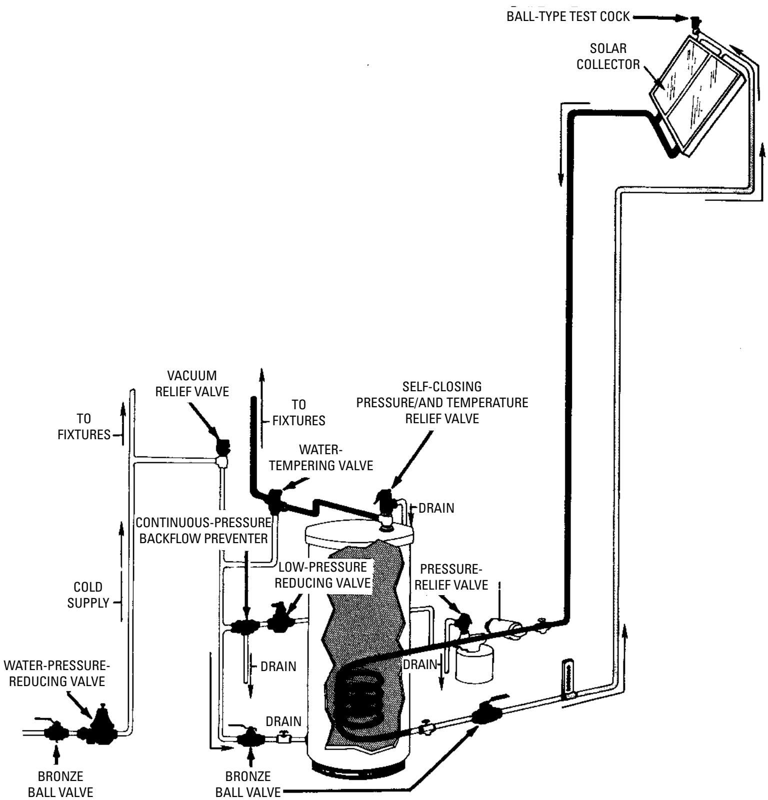


Figure 4-64 Typical solar water heating installation.
(Courtesy Watts Regulator Co.)

shown in Figure 4-64. A specially designed thermostatic element (for 210°F to 250°F service) in a thermal bypass control should be included in the system to divert high-temperature water to a cooling section (see Figure 4-65). This prevents structural damage to the solar panels and improves system efficiency.

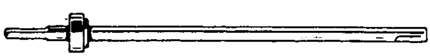


Figure 4-65 Thermostatic element for 210°F to 250°F service.
(Courtesy Watts Regulator Co.)

Chapter 5

Heating Swimming Pools

Heating systems have been added to both private and commercial swimming pools for a variety of reasons, ranging from the simple desire to increase body comfort with warmer water temperatures to the more practical reason of extending the swimming season.

In many commercial buildings and larger residences equipped with hot-water (hydronic) heating systems, the central boiler provides the heat for space heating, domestic hot water, and pool water. In structures equipped with other heating systems (for example, forced warm-air), a pool heater operating independently of the central heating unit is necessary to heat the pool water. The water in a swimming pool may be heated in one of the three following ways:

1. Solar heating
2. Radiant heating
3. Recycling

Solar heating relies on the use of solar panels to collect the heat from the sun. The pool water is circulated through the panels where it collects the heat from the sun and then carries it back down to the pool. Many solar pool-heating systems have an auxiliary gas or electric heater to augment the heat from the panels on days where there is insufficient sunlight.

Pools can also be heated with a radiant heating system, but such a system *must* be installed when the pool is constructed because it entails embedding tubing (commonly ½-inch diameter) in the pool itself. As shown in Figure 5-1, the tubing is buried close to the surface in the walls and floor of the pool. The hot water is fed through a supply pipe from the boiler. The water returns to the boiler through a return line. Water temperature in the pipes is controlled by a thermostat, which usually is located on the return line.

Radiant heating systems for swimming pools are the most expensive types to install because they require more pipe than other heating systems. Furthermore, the construction feature of having the copper tubing embedded in the walls and floor of the pool adds to the installation cost.

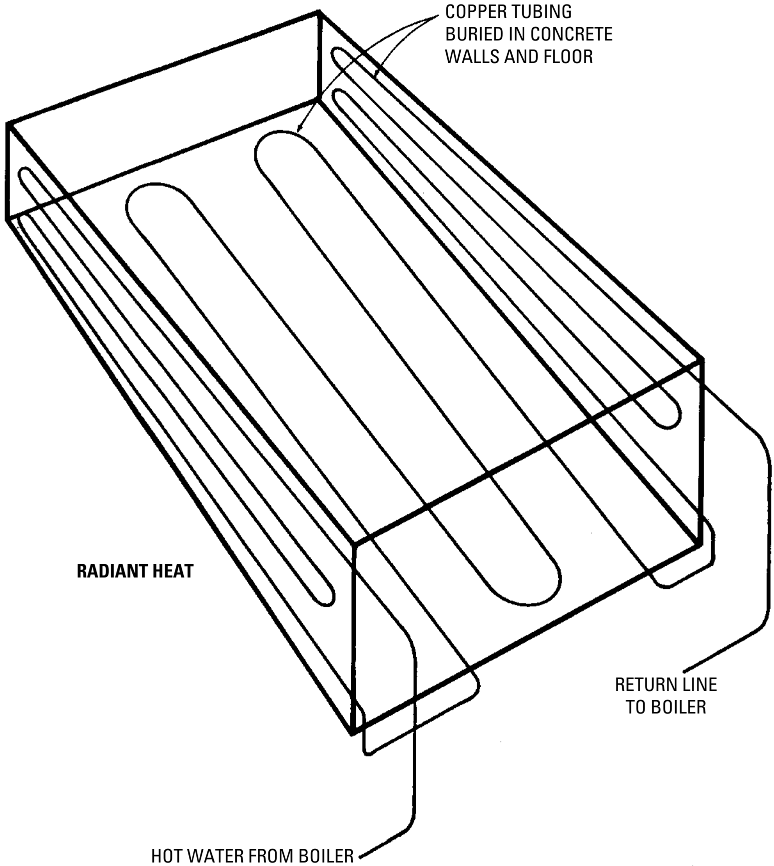


Figure 5-1 Heating a swimming pool by the radiant heating method.

Most modern pool heating systems are based on the recycling principle. The water is drawn from the pool by a pump, passed to the heat exchanger in the boiler or pool heater, heated to the desired temperature, and returned to the swimming pool.

When both a pool and its heating system are installed during the original construction of the house or building, it is possible (and advisable) to install a single boiler with more than one heat exchanger. As a result, the boiler will have the capacity to provide hot water not only for the pool but also for space heating and domestic hot-water needs. Three such systems for commercial buildings are illustrated in Figures 5-2, 5-3, and 5-4. In these systems, the primary boiler water is maintained at the desired space-heating water temperature by the operating aquastat in the boiler. The temperature of the pool water is maintained by the opening and closing of a pool temperature-control valve located in the circulation line between the filter and heater. This valve is controlled by a pool temperature-control aquastat, which senses the temperature of the water being returned from the pool.

Pool heaters can also be installed independent of space heating and domestic hot-water heating systems. This is usually the case when a heating unit is installed at an existing pool.

A pool heater operates on the same principle as the domestic hot-water heater, but the two differ considerably in their functions. The hot-water heater is required to heat only 30 to 40 gallons of water in a closed tank. The pool heater must heat thousands of gallons of water with a surface *exposed* to the outside air. Because there is a high degree of heat loss from the large surface area of the water to the colder air above it, a pool heater uses a considerable amount of fuel to replace the lost heat and to maintain the pool water at the desired temperature. The fact that water has a high heat capacity contributes to the problem. As a result, it generally takes a pool heater 20 to 24 hours to warm the water to the desired temperature.

Classifying Pool Heaters

Pool heaters can be classified in a number of different ways. If they are classified according to their basic operating principle, the following two types are recognized:

1. Direct-type pool heaters
2. Indirect-type pool heaters

In a *direct-type pool heater* (see Figure 5-5), the water from the pool passes through the heating unit in pipes that are heated directly by a gas or oil burner. In an *indirect-type pool heater* (see Figure 5-6), the pipes containing the pool water pass through a compartment in the heating unit, which also contains water. The water in the compartment of the heating unit is heated by a gas or oil burner located outside the water compartment. The heat of the water is then transferred to the water in the pipes from the pool,

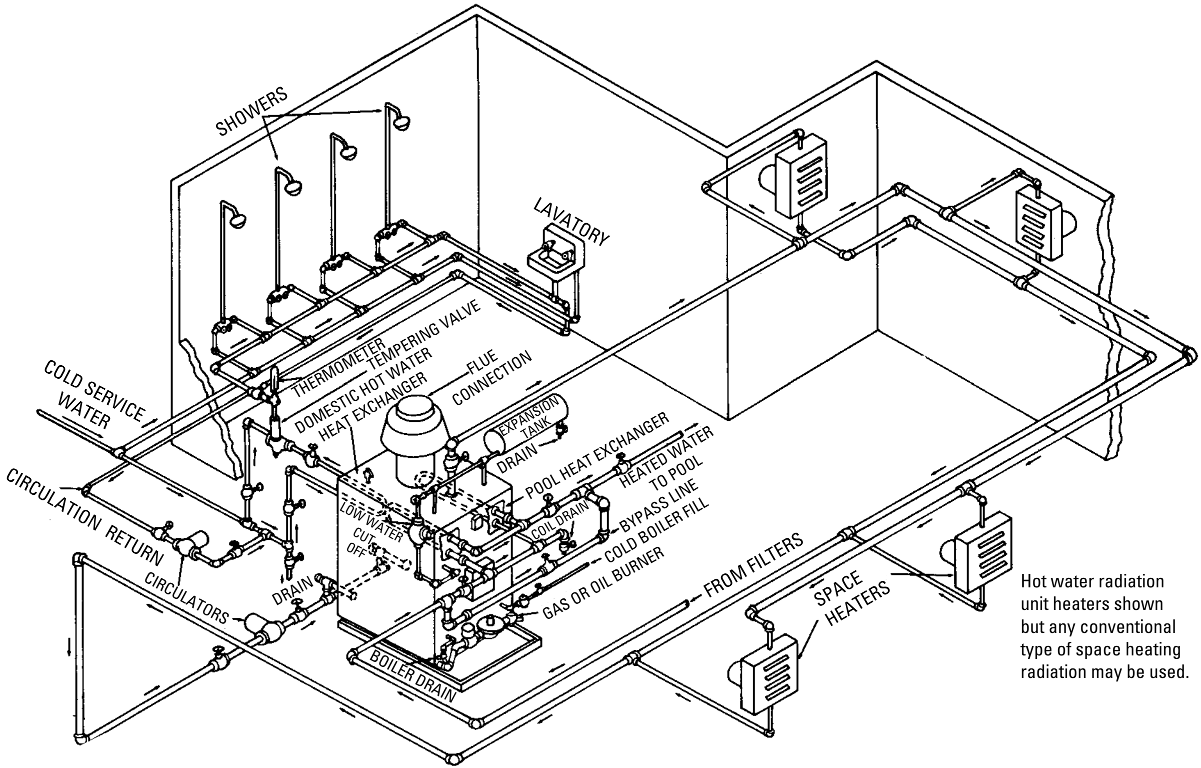


Figure 5-2 Typical multipurpose water-heating system for pool heating, space heating, and hot-water service.
(Courtesy Bryan Steam Corp.)

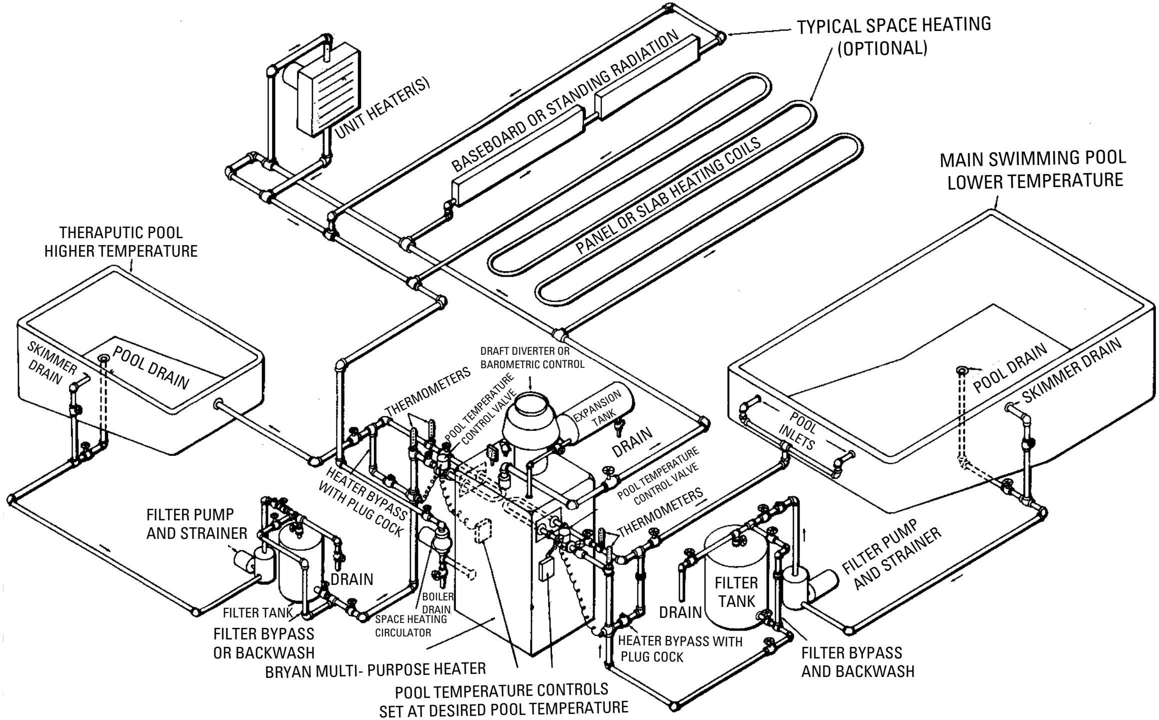


Figure 5-3 Typical multipurpose water-heating system for two pools of different temperatures and space heating. *(Courtesy Bryan Steam Corp.)*

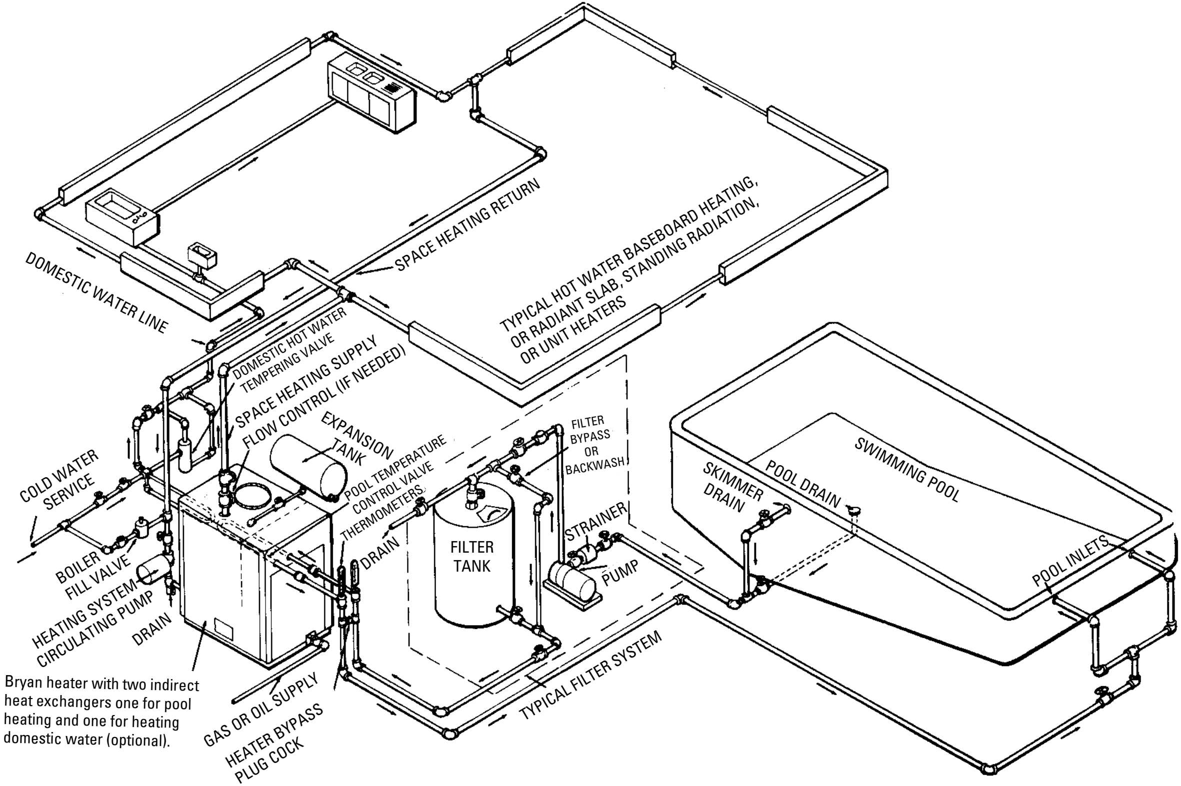


Figure 5-4 Typical multipurpose water-heating system for pool heating, space heating, and domestic hot water.
(Courtesy Bryan Steam Corp.)

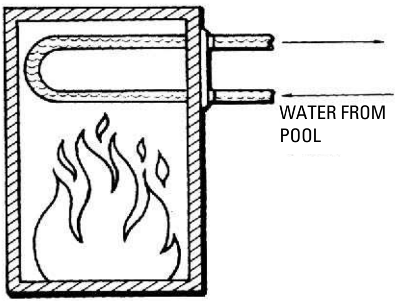


Figure 5-5 Operating principle of a direct-type pool heater.

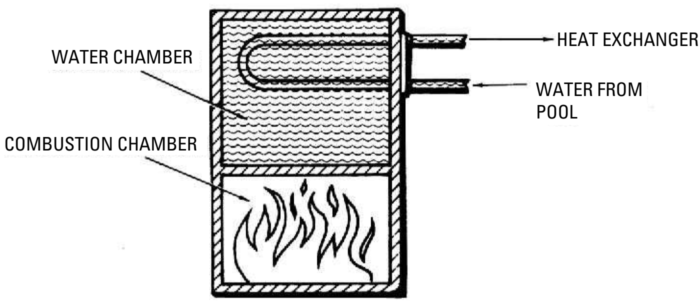


Figure 5-6 Operating principle of an indirect-type pool heater.

hence the name *indirect* pool heater. Because the coils of the heat exchanger never come in direct contact with the combustion heat (as is the case with direct-type pool heaters), scale and corrosion are virtually eliminated.

Another means of classifying pool heaters is by the type of fuel or energy source used to heat the water. The pool water can be heated by natural gas or propane, oil, electricity, or solar radiation.

Note

When installing a conventional pool heating system, purchase a heater with a high efficiency rating. It will save energy and result in significantly lower fuel costs.

Gas-Fired Pool Heaters

Gas-fired indirect pool heaters (see Figure 5-7) are available in the same Btu input/output ratings as the oil-fired types. They differ only in certain items of standard equipment that relate directly to

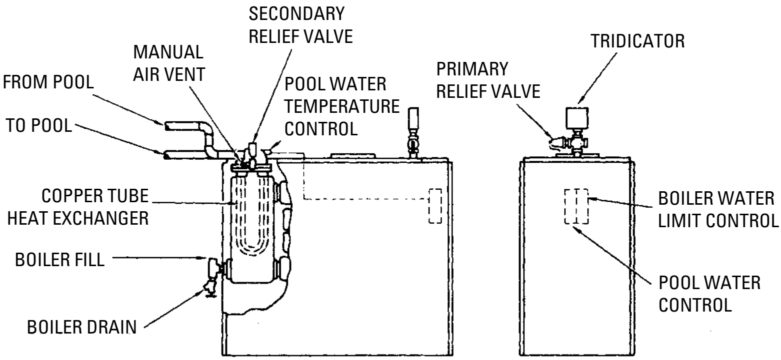


Figure 5-7 Hydrotherm gas-fired indirect pool heater. *(Courtesy Hydrotherm, Inc.)*

the type of fuel used. Gas-fired pool heaters will also differ according to the type of ignition system. There are two types of ignition systems used in gas-fired pool heaters:

- Millivolt (or standing pilot) ignition systems
- Automatic spark ignition systems

A *millivolt ignition system* is one in which the pilot light is continuously burning. The heat from the pilot light is used to generate a low-voltage electrical current. The electrical current produced by the pilot light is strong enough to open and close the main gas valve (also sometimes called a *combination gas valve*) as well as the controls and safety devices on the heater.

Note

A pilot light that is continuously lit is sometimes called a *standing pilot* or *standing pilot light.*

An *automatic spark ignition system* (also sometimes called an *intermittent ignition system* or simply an *IID system*) has a pilot light that is lit *only* when the heater is operating. An external electrical source is used to spark the pilot and operate the controls and safety devices on the heater.

In addition to the pilot light, a gas-fired pool heater also will include a number of different components, safety devices, and controls. Those included in the heater will depend on the type of ignition system used as well as its make and model. They include the following:

- **Pilot generator.** A pilot generator (also sometimes called a *thermocouple*) is the device in a millivolt ignition system that converts the heat energy of the pilot flame to the electrical energy required to operate the main gas valve. Pilot generators are not used in the automatic spark ignition systems.
- **Control circuit.** The control circuit consists of a series of safety devices used to control the flow of electricity to the main gas valve. If there is a malfunction somewhere in the heater, one or more of these safety devices in the control circuit will interrupt the flow of electricity to the main gas valve and prevent the burners from operating. The devices in the control circuit include safety switches (see *safety switches*), a fusible link (see *gas burner tray*), and a remote on-off switch.
- **Safety switches.** A variety of different types of switches are used in gas-fired pool heaters for safety and operational control purposes.
  - *Pressure switch*. A device that prevents the heater from starting until there is sufficient water pressure in the system.
  - *High-limit switch*. A device that prevents the water temperature in the pool heater from exceeding a preset upper limit (commonly 140°F).
  - *Flow switch*. A device that prevents the heater from starting if there is not enough water flowing through the system.
  - *Fireman switch*. A device that allows the circulator (pump) to continue operating up to 15 minutes after the heater has shut off. The additional pump running time allows the system to cool down.
- **Bypass valve.** The bypass valve is used to maintain a constant flow of water through the heat exchanger. The cool water protects the heat exchanger surfaces and other heater components from excessively high and potentially damaging temperatures. The bypass valve and the fireman switch provide similar functions in a pool heater.
- **Automatic gas valve.** The automatic gas valve (also sometimes called the *main gas valve* or *combination valve*) regulates the flow of gas to the burner tray and pilot. It is controlled by the heater control circuit.
- **Gas-pressure regulator.** A device that regulates the gas pressure. It is commonly combined with the main gas valve in the same unit (hence the name *combination gas valve*).

- **Gas shutoff valve.** A valve used to shut off the supply of gas to the burners when a heater malfunction occurs.
- **Thermostat.** As in other heating systems, a thermostat is used to control operation within a preset temperature range. When the pool water temperature drops below a preset low-temperature limit setting, the thermostat switches on the pool heater. When the temperature of the pool water reaches the upper preset limit, it shuts off the pool heater.

Other gas-fired pool heater components, many of which are also found on oil-fired, electric, and solar heaters, include the following:

- **Heat exchanger.** A device used to transfer heat from air, fluid, or water contained in one circulating system to the air, fluid, or water contained in an adjacent one *without* any intermixing. Heat exchangers are available in the form of flat plates or fins, coils, or tubes and are made of a metal that easily absorbs heat. Copper-finned heat exchangers are the type most commonly used in pool heaters. These consist of closely spaced flat fins attached to copper tubing.
- **Header.** The header (also called a *manifold*) is the component that directs the flow of water in and out of the heat exchanger. There is a header at each end of the heat exchanger. The front header, through which the water flows into the heat exchanger, contains a flow control assembly that is used to mix the cool incoming water with the hot outgoing water as it leaves the heat exchanger through the back header. This ensures a temperature differential of 25°F or less between the temperatures of the incoming and outgoing water. This reduced temperature differential prevents condensation, mineral deposits, and other problems associated with excessively high temperature differentials.
- **Gas burner assembly.** A pool heater may have as many as 16 and as few as 6 burners, depending on the make and model. The burner tubes are arranged in a parallel array and connected by a manifold pipe. A pilot light is mounted on the last burner tube. The gas burner tray beneath the burners can be removed from the cabinet for cleaning.
- **Pool heater aquastat.** A pool heater aquastat is used to control pool water temperatures and provide high-limit boiler control. The high-limit control provides shutdown protection to prevent boiler overheating. Some models are equipped with automatic reset, while others are equipped with manual.

A typical wiring diagram for a gas-fired indirect pool heater is shown in Figure 5-8. The pool water control on the dual aquastat is set at the desired pool temperature. The cold water from the pool starts the boiler, which continues to produce heat until the pool water temperature reaches the setting on the pool control. When this point is reached, the boiler shuts off. The boiler water temperature is controlled by the water-limit control.

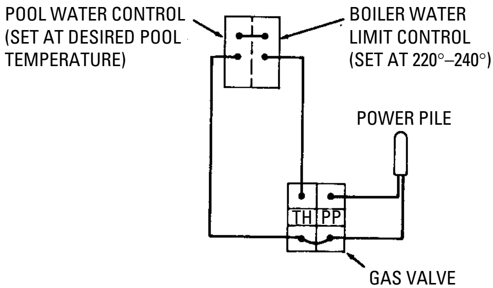


Figure 5-8 Typical wiring diagram for a gas-fired indirect pool heater. *(Courtesy Hydrotherm, Inc.)*

Oil-Fired Pool Heaters

The oil-fired indirect pool heater illustrated in Figure 5-9 is available in several input ratings ranging from 175,000 Btu/h (1.25 gph firing rate) to 280,000 Btu/h (2.00 gph firing rate) with No. 2 fuel oil. The corresponding *output* ratings range from 133,000 Btu/h to 208,000 Btu/h, which gives this pool heater the capacity to heat swimming pools containing 16,000 to 25,000 gallons of water.

These pool heaters have a 100-psi ASME pressure rating, which makes possible their direct connection to city water lines without the use of pressure-reducing valves. The heat exchanger consists of multiple-pass finned copper tubes, which are designed for low-pressure drop and which can be removed for cleaning.

Figure 5-10 illustrates the recommended piping arrangement for this particular pool heater. Note that the filter is installed on the line from the pool between the pump (circulator) and the shutoff valve. No provision for bypass piping is made between the pipes leading to and from the pool. An example of bypass piping in a pool heating installation for a similar oil-fired indirect heater is shown in Figure 5-11.

The aforementioned pool heater is suitable for small residential pools. A typical 25,000-gallon pool is approximately 18 feet wide by 36 feet long if a rectangular-shaped pool is used as an example.

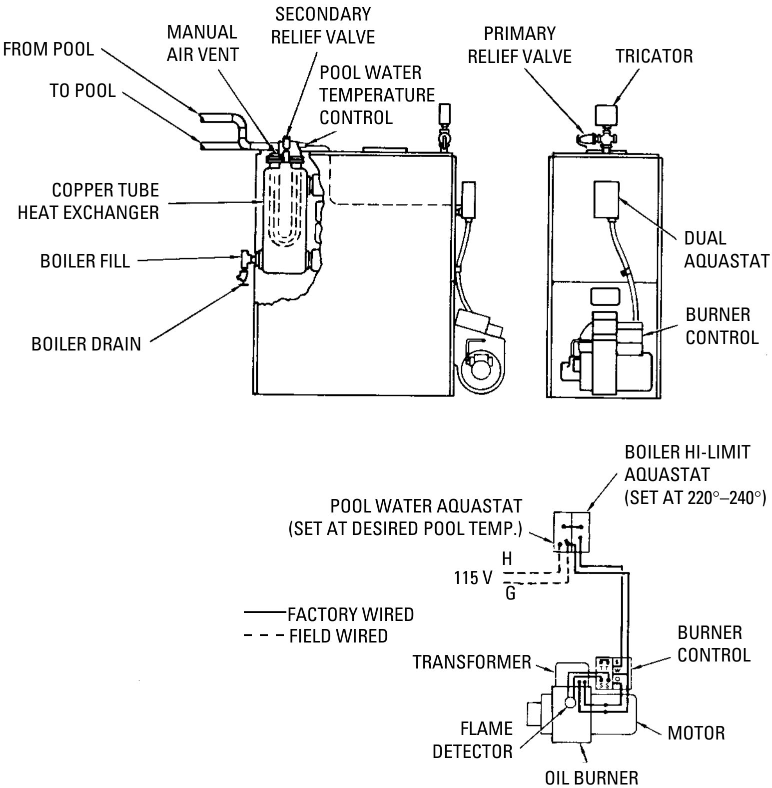


Figure 5-9 Oil-fired indirect-type pool heater with wiring diagram.
(Courtesy Hydrotherm, Inc.)

Pool heaters, whether oil-, gas-, or electric-fired, are available for almost any size pool. It is simply a matter of matching the pool size with the capacity of the pool heater. For example, Figure 5-9 shows an indirect oil-fired pool heater used for commercial applications, which is capable of heating a 105,000-gallon swimming pool. It has an input rating of 1,155,000 Btu per hour with 8.25 gph firing rate. This pool heater actually represents the combination of three heating modules; each has its own oil burner and modulating aquastat.

Electric Pool Heaters

An electric pool heater produces heat by forcing water to flow around a submerged electric coil. Most of the components are

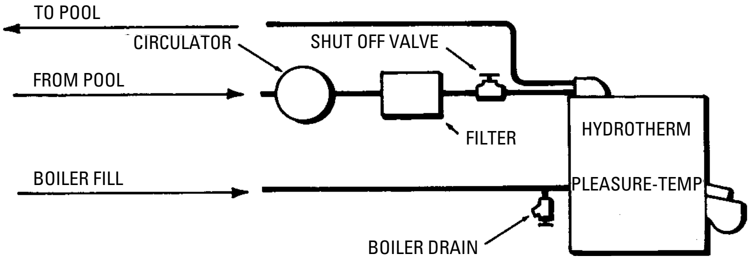


Figure 5-10 Recommended piping arrangement for heater in Figure 5-7. *(Courtesy Hydrotherm, Inc.)*

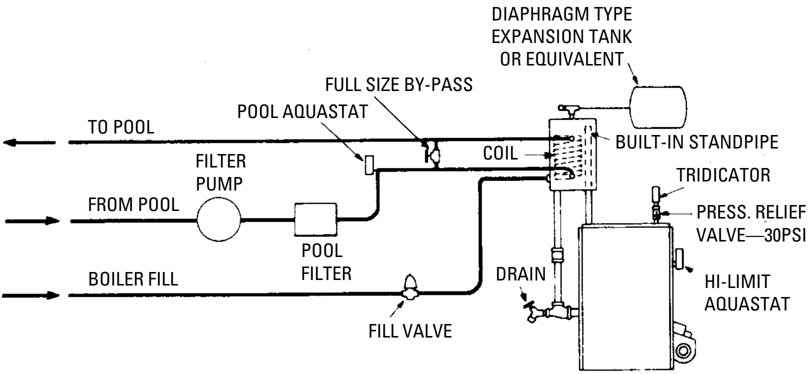


Figure 5-11 Piping diagram with bypass arrangement. *(Courtesy Hydrotherm, Inc.)*

similar to a gas or oil pool heater. The controls of an electric pool heater are usually built into the unit. Some models have a separately mounted thermostat to control water temperature.

Electric pool heaters are used where space is too restricted for a gas or oil heater, or where it is not possible to provide sufficient ventilation. They are used more frequently to heat small spas or hot tubs than pools.

The input of an electric-fired indirect pool heater is measured in kilowatts; its output is measured in Btu. The pool heater shown in Figure 5-12 is available in 11 different models ranging in input capacity from 15 kW to 300 kW with a corresponding output of 50,000 Btu per hour to 1,000,000 Btu per hour. These pool heaters are also available with 240 volts (single-phase) or 240/480 volts (three-phase). A wiring diagram for an electric-fired indirect pool heater is shown in Figure 5-13.

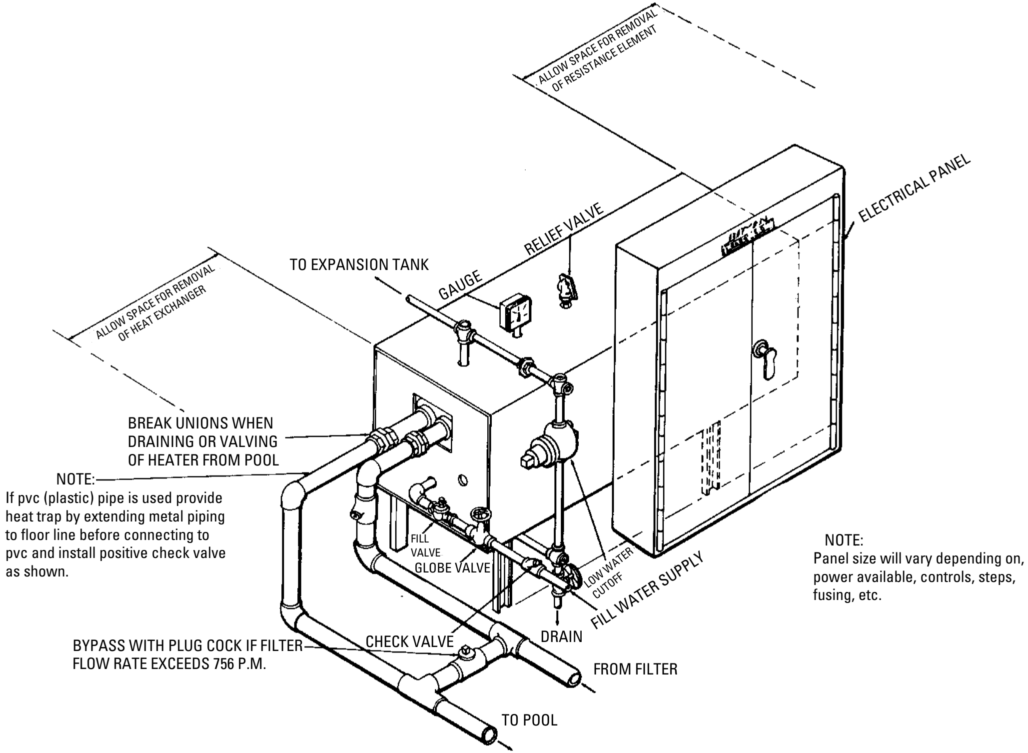


Figure 5-12 Electric-fired pool heater. *(Courtesy Bryan Steam Corp.)*

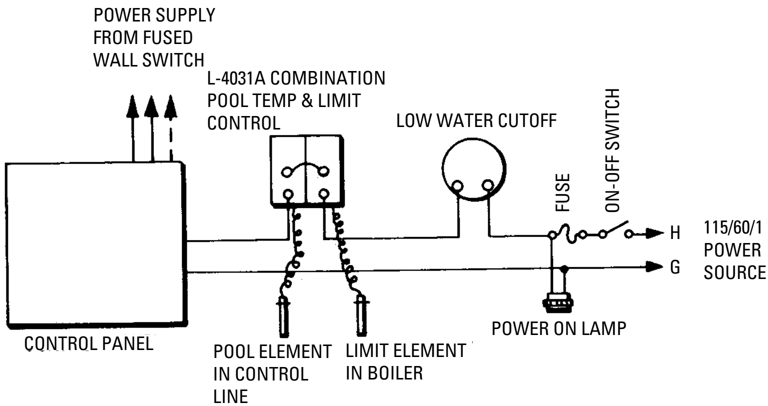


Figure 5-13 Wiring diagram for an electric-fired pool heater.
(Courtesy Bryan Steam Corp.)

Heat-Exchanger Pool Heaters

The heat-exchanger pool heater illustrated in Figure 5-14 is designed for use in either steam or hot-water heating systems. It is essentially a steel shell enclosing the copper tubes of the heat exchanger. The hot water or steam is taken from the heating main and circulated *around* the copper tubes inside the steel shell. The pool water enters the heat exchanger in a pipe leading from the pool filter and circulates *inside* the copper tubes. As it circulates, it is heated by the hot water or steam circulating around the copper tubes. The heated water eventually leaves the heat exchanger through a second exit point and is returned to the pool.

Figures 5-15 and 5-16 illustrate the modifications necessary for use with either steam or hot water as the heat source. Basic construction is essentially the same in both cases, with the pool water circulating through copper tubes (the heat exchanger) enclosed in a steel shell. You will probably notice that different types of steel are used in constructing the shell: 125-psi ASME steel for heat exchangers using hot water as a heat source, and 15-psi ASME steel for those using steam.

Both types of heat exchangers have temperature-control aquastats activated by the temperature of the pool water entering the heat exchanger. In heat exchangers that use water as a heat source, the aquastat is connected to a circulating pump (see Figure 5-16). If steam is the heat source, the aquastat is connected to a steam-control valve. Both the circulating pump and the steam-control valve control the *rate of flow* of the hot water or steam from the heating unit.

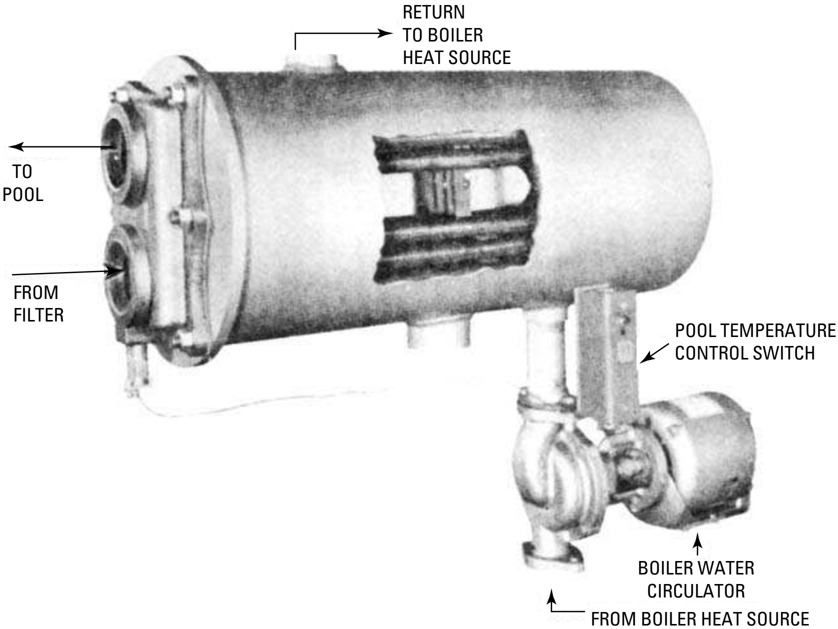


Figure 5-14 Heat-exchanger pool heater. *(Courtesy Bryan Steam Corp.)*

When steam is used as the heat source, the heat exchanger should also be equipped with a steam trap and a line running to the condensation main. The steam valve sizing is based on 2-psi minimum steam pressure and 0-psi return pressure. A steam strainer should be placed in the steam supply line just before it reaches the control valve.

Circulating pump sizing in units that use water as a heat source should be based on a maximum temperature drop through the heat exchanger of 30°F and a maximum head loss in piping between the hot-water boiler and the heater of 10 feet H_2O.

The Btu/h output for heat-exchanger pool heaters using water as a heat source ranges from 200,000 to 4,200,000 Btu per hour. The amount will depend on water temperature (180°F or 210°F) and the size of the unit. Heaters using steam as a heat source are capable of generating an output of 400,000 to 3,600,000 Btu per hour. Here the difference depends on the steam pressure used (2 lbs or 10 lbs) and the size of the unit.

Solar Pool Heaters

The principal components of a solar pool heating system are illustrated in Figure 5-17. In this system, the solar panels or collectors

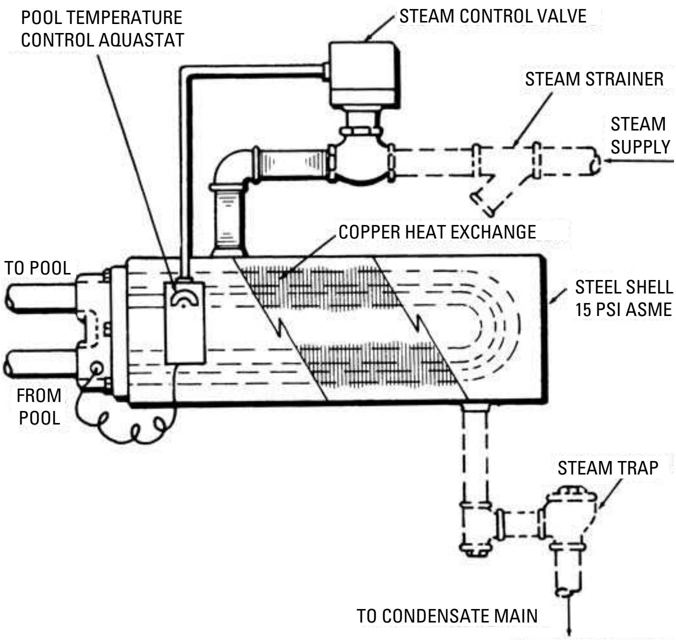


Figure 5-15 Heat-exchanger pool heater using steam as a heat source. *(Courtesy Bryan Steam Corp.)*

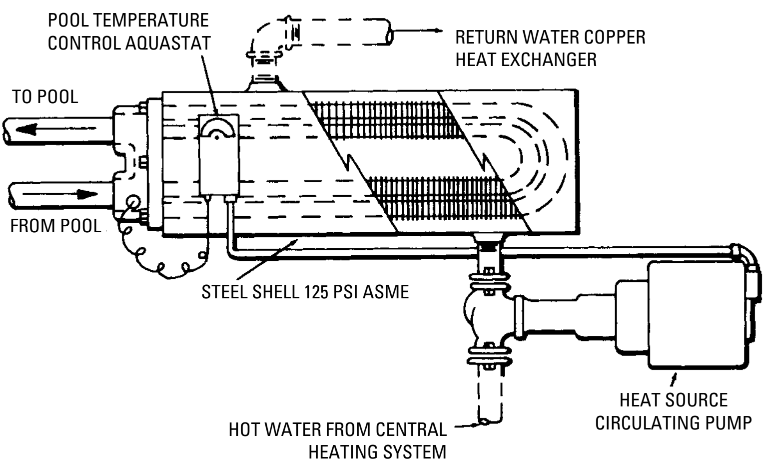


Figure 5-16 Heat-exchanger pool heater using water as a heat source. *(Courtesy Bryan Steam Corp.)*

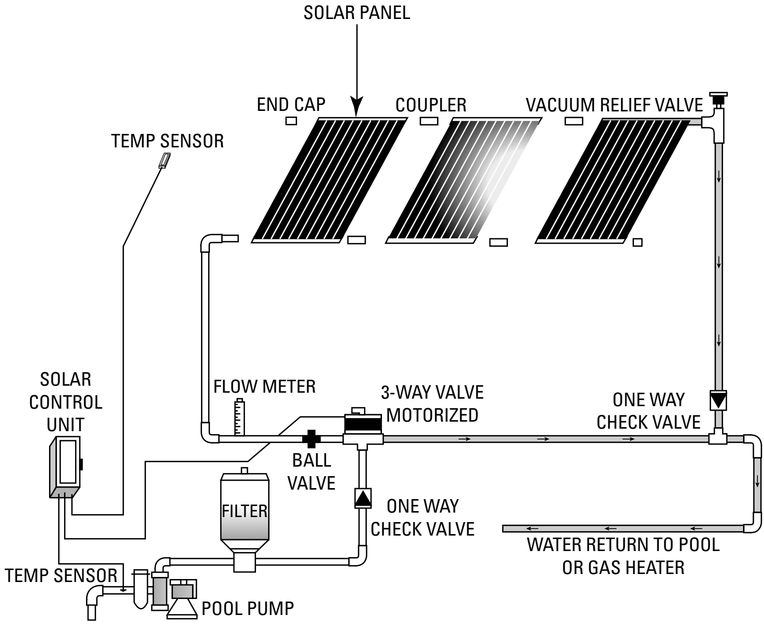


Figure 5-17 Solar pool schematic. *(Courtesy GO Solar Company)*

function as the heater. There is no component similar to the heaters used in the more conventional pool heating systems. Note, however, that an auxiliary heater may be included in the system as a backup to the solar collectors when there is not enough sunlight to warm the water.

In operation, water is automatically pumped through the solar collectors where it picks up the heat from the sun. A solar sensor is used to measure the heat on the panel. If the panels are cold, the solar sensor causes the water to bypass the panels and flow directly to the auxiliary heater (commonly a gas or electric heater) where it is heated and sent to the pool. If the solar sensor detects heat on the panels, it opens a valve to send the water directly to the solar panels where it is heated and then returned to the pool. At the same time, a bypass ball valve closes and isolates the auxiliary heater.

The temperature of the pool water is measured by a water sensor. Both the solar sensor and water sensor are connected to a controller that governs the operation of a three-way valve. A check valve in the piping leading from the three-way valve can be used to isolate the pump, filter, and water sensor from other components in a solar heating system. The isolation valves installed in the solar panel supply and return lines are optional. The former is a ball valve, the latter a check valve.

The solar collectors are made from polypropylene or a similarly formulated material designed to withstand extreme exposure to weather conditions and pollution. The panel material is also unaffected by pool chemicals and will not corrode or rust. Each panel is constructed in a tube and curved web design to trap the heat as the sun moves across the sky.

Heat Pump Pool Heaters

A heat pump also can be used to heat the water in a swimming pool. A heat pump is a much more expensive piece of equipment than a conventional pool heater, but it is more energy efficient, requires less maintenance and repair, and has a longer service life.

Heat is generated when pressure is exerted by the compressor on a nonflammable, noncorrosive gas. The heat in the gas is transferred to water flowing through the heat exchanger. The warm water flows to the pool, and the cooled gas returns to the compressor where it is recompressed and reheated before repeating the cycle.

High-efficiency electric heat pump pool heaters are available with coefficients of performance (COPs) in the 6.0 to 8.0 range. Heat pumps not graded as high-efficiency units will produce a coefficient of performance of approximately 4.0.

Note

> The coefficient of performance may be defined as the ratio of the transferred energy to the electric energy used in the process—in other words, the total useful output (heat energy in the case of a pool heater) divided by the total energy input used to produce the heat.

Sizing Pool Heaters

The two principal methods used for sizing pool heaters are as follows:

1. The surface-area method
2. The time-rise method

Table 5-1 contains all the necessary data for determining the required pool heater size with either method. The listed output ratings are for Bryan pool heaters.

The sizing data in Table 5-2 is based on heat loss from the surface of the heater with an assumed wind velocity of 3½ mph. This

Table 5-1 Sizing the Pool Heater (Ratings Given in 1000 Btu/h)

Surface-Area Method			*Time-Rise Method*							
Pool Size (Rectangular)		***Pool Surface Area***	***Difference between Desired Water Temperature and Average Air Temperature for Recommended Heater Sized on Surface Area***						***Pool Gallonage (approx.)***	***Recommended Heater Sized on Pool Capacity to Raise Temp. 1°F per Hour (approx.)***
Width	***Length***	***(ft²)***	***10°***	***15°***	***20°***	***25°***	***30°***	***40°***		
15	30	450	150	150	150	150	250	250	17,000	250
16	32	512				250			20,000	350
16	36	576						350	23,000	
18	36	648			250				25,000	450
18	40	720					350	450	30,000	
18	42	756							31,000	
20	40	800		250					34,000	
20	42	840							35,000	
20	45	900					450		37,000	650
20	50	1000			350			650	40,000	
25	50	1250	250			450	650		50,000	850
25	60	1500		350	450	650		850	62,000	900
30	60	1800					850	900	79,000	1200
30	70	2100	350	450	650			1200	84,000	
30	75	2250							92,000	1500
35	75	2625		650			1200	1500	107,000	1800

40	75	3000	450		850				123,000	
42	75	3150			900			1800	137,000	2100
42	80	3465		850			1500		143,000	2450
45	90	4050	650		1200	1500		2100	184,000	3200
50	100	5000		1200	1500	1800	2100	2700	217,000	
60	100	6000	850			2100	2450	3200	250,000	3750
60	110	6600	900		1800	2450	2700	3750	275,000	4300
65	120	7800	1200	1500	2100		3200	4300	320,000	
75	130	9750		2100	2450	3200	3750	4850	400,000	Two 2700
75	160	12,000	1500	2450	3200	4300	4850	Two 2700	490,000	Two 3200
80	175	14,000	1800	2700	3750	4850	Two 2700	Two 3200	575,000	Two 3750
80	200	16,000	2100	3200	4300	Two 2700	Two 3200	Two 4300	655,000	Two 4300

(Courtesy Bryan Steam Corporation)

Table 5-2 Wind Velocity and Recommended Pool Heater Capacity

Approximate Pool Gallonage	*Wind Velocity*	*Recommended Pool Heater Capacity*
17,000 gal	3½ mph	250,000 Btu
17,000 gal	5 mph	375,000 Btu
17,000 gal	10 mph	500,000 Btu

is the average wind velocity for a pool protected from direct wind exposure by trees, shrubs, fences, and buildings. An exposed pool will mean that the required pool heater capacity (that is, the input ratings listed in Table 5-1) must be increased. Generally it is recommended that the input rating be increased by 1.25 for a 5-mph wind velocity and 2.0 for a 10-mph wind velocity.

The Surface-Area Method

The *surface-area method* of sizing a pool heater is based on the surface area (in square feet) of the pool and the temperature difference (in degrees Fahrenheit) between the desired water temperature and the average air temperature. The procedure is as follows:

1. Determine the *mean* average air temperature for the coldest month in which the pool is to be used.
2. Determine the desired pool water temperature.
3. Find the difference between the air temperature (step 1) and the water temperature (step 2).
4. Calculate the pool surface area in square feet.
5. In Table 5-1, find the surface area closest to your pool size. Move horizontally in a straight line across to the column that represents the temperature difference for your pool. The point at which the horizontal line and the temperature column intersect will be the required Btu per hour input rating for your pool heater.

The surface-area method can be illustrated with a simple example. Let's suppose that you have a small 15-foot × 30-foot pool with a 17,000-gallon capacity. You want to maintain a pool water temperature of 70°F (step 2), and the mean average air temperature for the coldest month in which the pool is to be used is 50°F (step 1). What will be the required input rating of your pool heater?

Your temperature difference required for sizing the heater is 20° (70° – 50°F). The pool surface area is 450 square feet (15 × 30 feet). Moving horizontally across the top line in Table 5-1, you arrive at the 20° column and learn that the required input rating for a pool heater meeting these criteria is 150,000 Btu per hour.

Another, less precise form of the surface-area method is to multiply the surface area of the pool by 15 and then by the temperature difference between the pool water and the air. Using the same data as before, the following results are obtained:

$$450 \text{ ft}^2 \times 15 \times 20° = 135{,}000 \text{ Btu per hour}$$

The Time-Rise Method

The first step in the time-rise method of sizing a pool heater is to determine the pool capacity in gallons of water (pool gallonage). This only needs to be an approximate figure and is commonly rounded off to the nearest thousand (for example, 17,000 gal, 20,000 gal, 23,000 gal). In Table 5-1, the extreme right-hand column lists pool heaters recommended for different pool capacities. The sizing in this chart is based on the number of Btu required to raise the pool temperature approximately 1°F per hour.

Sizing Indoor Pool Heaters

If the swimming pool is located inside a heated building, the surface temperature of the water is naturally not affected by the colder outdoor air temperatures. A simple rule-of-thumb method for sizing an indoor pool heater is as follows:

1. Determine the surface area of the pool (for example, 30 ft × 40 ft = 1200 ft^2).
2. Multiply the surface area by 125 Btu (1200 ft^2 × 125 Btu = 150,000 Btu per hour input).

Installing Pool Heaters

Installing a pool heater requires knowledge of plumbing, electrical work, gas or oil burner operation, and ventilation. Pool heaters should be installed only by qualified and experienced personnel, and their installation must comply with local codes and ordinances.

Pool heaters are shipped with a complete set of instructions for installing and starting the unit. If the instructions are missing, the manufacturer should be contacted for a replacement set. The following installation recommendations apply to most pool heaters:

1. Install the pool heater on a level concrete slab or a pad of concrete block or brick. The slab or pad must be at least 4 inches high. If concrete blocks are used, align them so that all open cells are pointed in the same direction with the cells at the edge of the pad left open. Cover the top of a concrete block pad with 24-gauge (or thicker) sheet metal.

Note

Never install a pool heater on a combustible material, such as wood boards or plywood.

2. Maintain proper clearances on all sides of an outdoor pool heater. Consult the owner's manual for the clearances specified by the pool heater manufacturer. Maintaining minimum required clearances around the pool heater will ensure efficient combustion and proper ventilation of the combustion gases (gas-fired and oil-fired heaters).

Note

The American National Standards Institute (ANSI) has established a standard set of clearances for outdoor pool heaters based on the external temperature of the heaters (see ANSI 2223.1).

3. Indoor pool heaters must be properly vented to the outdoors. They also must have sufficient intake air for proper combustion. Consult the owner's manual for specific venting requirements.

Warning

Incorrect venting of an indoor pool heater can result in carbon monoxide poisoning. Incorrect venting can also result in fire.

4. An indoor gas-fired pool heater must be equipped with a draft hood to further ensure that potentially harmful combustion gases are expelled outdoors. The vent pipe is directly connected to the draft hood. The diameter of the draft hood is based on recommendations from the National Fuel Gas Code. It may vary among different pool heater makes and models.
5. To provide proper draft, the discharge opening of the flue pipe must extend at least 2 feet above the surface of the roof or its highest point within a 10-foot radius of the point where it extends through the roof.
6. Install a barrier (for example, closed wooden fence, trees and bushes) around a pool if it is subjected to sustained high winds. Sustained winds across the surface of the water will increase the heat loss from the pool. This will require increasing the heater

size to maintain the desired water temperature. The heater itself should be protected from high winds with a windbreak.

Pool Heater Repair and Maintenance

Follow the guidelines in the manufacturer's manual when servicing or repairing a pool heater or related equipment. Some manufacturers also permit the downloading of manuals from their online web site. If a manual is unavailable and you do not have the necessary experience to do the work without one, call the pool heater manufacturer or a local dealer for help.

The following suggestions for servicing and repairing pool heaters apply to all makes and models:

1. Perform a major inspection and servicing of the pool, pool heater, pump, and related components just before putting the pool into operation and just after closing it down if the pool is used only part of the year.
2. Perform periodic inspections and maintenance if the pool is used throughout the year.
3. Replace worn parts with new ones. Do not attempt to reuse them or make temporary repairs.
4. Inspect and clean or replace pool filters on a regular basis.
5. Inspect the pool heater for sooting (a combustion problem).
6. Inspect the pool heater for water leaks (all heaters), gas leaks (gas-fired units), and oil leaks (oil-fired units).
7. Check all pipe connections for tightness and corrosion.
8. Check wiring for damaged wires and loose connections.
9. Check for proper burner flame characteristics on gas-fired and oil-fired heaters. The pilot flame of a gas-fired heater should also be included when making this inspection.
10. Inspect the heat exchanger for scaling.
11. Remove leaves and other debris from the top of the pool heater.

Note

Always shut off the pool heater and allow it time to cool down before servicing it or making repairs.

Caution

To avoid injury from electrical shock, always shut off the electrical power before servicing the line voltage controls. Never leave a jumper wire in place to fix a heater or the operating and safety controls will be bypassed.

Warning

> If gas odors are detected when repairing or servicing a gas-fired pool heater, immediately contact your local utility for instructions. If the pool is located indoors, leave the house and make the call from a neighbor's telephone.

Troubleshooting Pool Heaters and Equipment

Always review the pool heater manufacturer's installation and/or operating manual for recommended troubleshooting procedures. If no manual is available, it may be possible to download one for the specific pool heater or equipment from the manufacturer's online web address. As a last resort, Tables 5-3, 5-4, and 5-5 list frequent problems, their symptoms, and possible remedies.

Table 5-3 Troubleshooting Gas-Fired Pool Heaters

Symptom and Possible Cause	*Possible Remedy*
Heater cycles on and off continuously.	
(a) Low water level in pool.	(a) Raise water level.
(b) Dirty filter.	(b) Backwash or replace filter.
(c) Pressure switch out of adjustment.	(c) Adjust pressure switch.
(d) External bypass setting needs adjustment.	(d) Adjust bypass setting.
(e) Closed valve.	(e) Locate, repair, or replace valve.
(f) Thermostat calibration incorrect.	(f) Recalibrate or replace thermostat.
Heater not producing enough heat.	
(a) Gas cock in wrong position and cutting off gas supply.	(a) Check and change position of gas cock.
(b) Pilot light out.	(b) Relight pilot. If burners still fail to light, call for service.
(c) Pilot light at *off* setting.	(c) Turn to *on* position and relight pilot.
Weak burner flame.	
(a) Burner intake ports clogged.	(a) Remove blockage.
(b) Low gas pressure.	(b) Adjust gas pressure.

Table 5-3 *(continued)*

Symptom and Possible Cause	***Possible Remedy***
Pilot out (millivolt system).	
(a) Restricted pilot.	(a) Clean pilot and restart heater.
(b) Weak or defective pilot generator.	(b) Replace pilot generator.
(c) Low gas pressure.	(c) Adjust gas pressure.
(d) No gas.	(d) Check gas supply. Call local utility.
Pilot will not light.	
(a) No fuel.	(a) Turn on gas.
(b) Fuel tank empty (propane gas).	(b) Fill tank.
(c) Low gas pressure.	(c) Adjust gas pressure or repair as required.
(d) Clogged or damaged pilot tubing.	(d) Clean or replace.
(e) Insufficient air supply.	(e) Correct as necessary.
(f) Improper venting.	(f) Correct as necessary.
Pilot requires frequent relighting.	
(a) Faulty thermocouple/pilot generator.	(a) Replace.
(b) Loose connection between thermocouple and gas valve.	(b) Tighten connection. Replace if damaged.
(c) Loose coil connection.	(c) Tighten connection. Replace if damaged.
(d) Electrical short in wiring between thermocouple and gas valve or coil.	(d) Determine cause of electrical short and repair.
Noisy heater.	
(a) Restriction in system.	(a) Locate restriction and remove.
(b) Blockage in gas line.	(b) Locate and remove blockage.
(c) Scale buildup in heat exchanger.	(c) Remove scale from heat exchanger tubes or replace heat exchanger.
(d) Incorrectly adjusted pressure switch.	(d) Adjust pressure switch.
(e) Low gas pressure.	(e) Adjust gas pressure or repair as required.

(continued)

Table 5-3 (continued)

Symptom and Possible Cause	*Possible Remedy*
Soot forming in combustion chamber.	
(a) Insufficient air supply.	(a) Check clearances and correct (outdoor heater); check for sufficient intake (combustion) air and correct venting and correct (indoor heater). Clean soot from heat exchanger.
(b) Too much water flowing through heater.	(b) Correct water flow. Clean soot from heat exchanger.
(c) Heater run time too short.	(c) Adjust time clock to allow heater to run long enough to heat the water. Clean soot from heat exchanger.
(d) Gas valve regulator adjustment.	(d) Test for correct gas pressure. Adjust regulator or gas valve.
(e) Burner inlet throat or venturi blocked.	(e) Locate blockage and remove.
Heater leaking water.	
(a) Leaking gasket.	(a) Locate and replace gasket.
(b) Loose connection to pressure switch.	(b) Tighten connection.
(c) Oversized pump causing excessive water flow through heater.	(c) Replace with correctly sized pump.
(d) Soot deposits in heat exchange.	(d) Correct problem. Clean heat exchanger tubes.
(e) Damaged bypass valve.	(e) Replace valve.
Scale forming in combustion chamber.	
(a) Problem with water chemistry.	(a) Check pH level, alkalinity, and calcium hardness of water. Bring within levels recommended by heater manufacturer.
(b) Improper bypass valve adjustment.	(b) Adjust bypass valve. If problem persists, repair or replace valve.

Table 5-4 Troubleshooting Oil-Fired Pool Heaters

Symptom and Possible Cause	***Possible Remedy***
Burner will not start (motor and transformer will not start).	
(a) No power to heater.	(a) Check reset buttons on motor and primary control.
(b) Heater control circuit defect.	(b) Connect a jumper wire across the two terminals of the cad cell. If the burner starts, the problem is in either the heater control circuit wiring or one of the controls.
(c) Loose wires or worn insulation in the wire harness of the heater control circuit.	(c) Inspect and correct as necessary.
(d) Defective control (pressure switch, high-limit control, safety switch, thermostat, or time clock switch).	(d) Test each control with a jumper wire. Replace defective control when located.
(e) Restriction in the fuel line.	(e) Check fuel line and repair as necessary.
(f) Binding fuel pump.	(f) Repair or replace fuel pump.
(g) Defective high-limit switch.	(g) Turn off power to the heater and short out the high-limit switch in the line voltage circuit. Try to restart the burner. If it starts, the high-limit switch is defective and must be replaced.
(h) Dirty or defective cad cell.	(h) Remove one cad cell wire from the primary control. If burner starts, replace defective cad cell.
(i) Loose wiring below primary control and ignition transformer.	(i) Locate and repair.
Burner shuts off but restarts when primary control button is pressed.	
(a) Dirty or defective cad cell.	(a) Clean or replace as necessary.
(b) Poor combustion caused by fouled nozzle.	(b) Clean or replace nozzle.

(continued)

Table 5-4 (continued)

Symptom and Possible Cause	*Possible Remedy*
(c) Oil level in storage tank too low.	(c) Fill tank to appropriate level.
(d) Fuel line oil leaks.	(d) Locate and repair leaks.
(e) Nozzle pressure less than 100 psig.	(e) Determine cause and correct nozzle pressure.

Table 5-5 Troubleshooting Pool Pumps and Filters

Symptom and Possible Cause	*Possible Remedy*
Pump does not run.	
(a) Tripped circuit breaker.	(a) Rest circuit breaker.
(b) Blown fuse.	(b) Replace fuse.
(c) Incorrect timer setting.	(c) Check and reset for correct time.
(d) Pump motor binding.	(d) Oil motor.
Pump will not prime.	
(a) Damaged impeller or motor shaft.	(a) Repair or replace pump.
(b) Water leaks in suction line.	(b) Repair or replace suction line.
(c) Valves in wrong position.	(c) Change position of valves.
Excessive high or low filter water pressure.	
(a) Water leak.	(a) Find leak and repair.
(b) Dirty or clogged filter.	(b) Back-flush filter or replace it.
(c) Valves in wrong position.	(c) Change position of valves.

Caution

These troubleshooting procedures may require connections to electrical terminals and jumper wires to check and determine the cause of an operating problem. To avoid injury from electrical shock, always shut off the electrical power before servicing the line voltage controls. Never leave a jumper wire in place to fix a heater or the operating and safety controls will be bypassed.

Caution

Never attempt to troubleshoot or service a pump or pump motor if you are standing on a wet or damp surface or if your hands are wet. The electrical connection can cause serious shock, injury, or even death.

Note

A pump may start unexpectedly if it is equipped with an automatic resetting thermal protector.

Chapter 6

Ventilation Principles

Ventilation is the process of moving air from one space to an entirely separate space and is primarily a matter of air volume. It should not be confused with *circulation*, which is the moving of air *around and within* a confined space. In contrast to ventilation, circulation is a matter of air velocity. Ventilated air may or may not have been conditioned, and it may be supplied to or removed from the spaces by either natural or mechanical means.

The ventilation of a structure is important not only for the health of its occupants but for their comfort as well. The proper ventilation of a structure will replace stale, warm air in the interior with fresh cooler air from the outdoors. It will reduce or eliminate odors, remove excess moisture, and lower humidity levels, especially in the basement, attic, and crawl spaces.

For many years, proper ventilation was not considered as important as it is today. Houses were not very well insulated, and outside air could be easily drawn into the structure not only through open windows and doors but also through the walls themselves. Older houses were said to breathe because air could move in and out of them without much difficulty.

The fuel crisis of the 1970s and the rapid increase in energy costs made the public aware that we had to have more efficient combustion appliances (for example, furnaces, boilers, water heaters) and that structures had to be more tightly constructed and insulated. Although the latter move did result in a reduction in heat loss and gain, it also produced new problems such as trapped moisture, stale air, and even health problems. For example, in tightly constructed and insulated houses, vent fans, clothes dryers, and kitchen exhaust fans can create a negative pressure, drawing air into the house through holes in the framing, chimneys, and even exhaust flues. This can cause backdrafting in combustion appliances, which can be a serious health hazard.

If ventilation is inadequate and more air is exhausted from the house than can be drawn in through natural ventilation, the result is depressurization, which causes toxic combustion gases to be released through cracks or poorly connected ducts in the heating and cooling system. It is important that a balance be maintained between air being exhausted and air being drawn into the house.

There are two types of ventilation: passive ventilation and mechanical ventilation. The former only uses openings (vents) in the roof and walls to allow heat to escape. The latter uses mechanical ventilators, such as exhaust fans, attic fans, and whole-house fans in combination with vents to remove the air from the house. Exhaust and attic fans are covered in Chapter 7 ("Ventilation and Exhaust Fans").

The Motive Force

The force that moves the air in a room or building may be due to natural causes or mechanical means. In the first case, the ventilation is called *natural ventilation*. This kind of ventilation finds application in industrial plants, public buildings, schools, garages, dwellings, and farm buildings. The two natural forces available for moving air into, through, and out of buildings are (1) induction and (2) thermal effect. The inductive action is due to the wind force, whereas the thermal effect is due to the difference in temperature inside and outside a building (this being in fact the same as the *chimney effect*). The air movement may be caused by either of these forces acting alone or by a combination of the two, depending on atmospheric conditions, building design, and location.

The nature of the ventilating results obtained by natural means will vary from time to time because of variation in the velocity and direction of the wind and the temperature difference.

The wind ventilating effect depends on its velocity. In almost all localities, summer wind velocities are lower than those in the winter. There are relatively few places where the wind velocity falls below one-half of the average for many hours per month. Accordingly, if a natural ventilating system is proportioned for wind velocities of one-half the average seasonal velocity, it should prove satisfactory in almost every case.

When considering the use of natural wind forces for producing ventilation, three conditions must be considered:

1. The average wind velocity.
2. The prevailing wind direction.
3. Local wind interference by buildings, halls, or other obstructions.

Inductive Action of the Wind

When the wind blows without encountering any obstruction to change its direction, its movement may be represented by a series of parallel arrows, as in Figure 6-1. The arrows indicate the direction

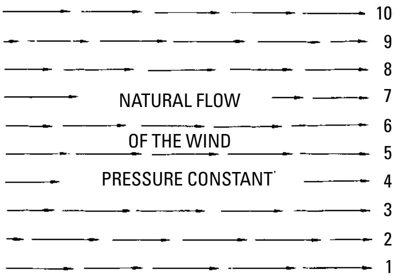


Figure 6-1 Natural flow of wind when there is no obstruction to change its direction.

of flow. Under such conditions, the pressure may be considered as constant throughout the airstream.

If the airstream meets an obstruction of any kind, such as a house or ventilator, these parallel air lines will be pushed aside as in Figure 6-2, crowding each other at points *A* and *B*, curving back on the sides of the obstruction and curving inward past points *C* and *D* to their original parallel positions.

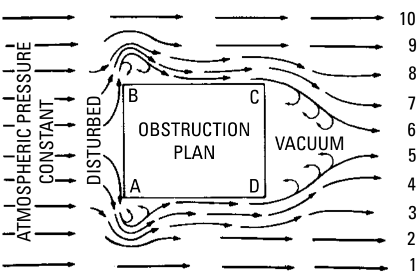


Figure 6-2 The results of an airstream when it meets an obstruction such as a house or ventilator.

A vacuum is formed here as indicated by the suction lines (that is, the arrows that curve back and inward toward the space occupied by the vacuum). This vacuum (or reduction in pressure) is what causes inductive action.

A ventilator can be constructed in such a way as to make this inductive action effective for ventilation. Figure 6-3 shows the two essential parts of a simple ventilator: the head and connecting flue. The head is open at one end and closed at the other and in actual construction is pivoted to rotate, guided by a vane so that the closed end always faces the wind.

As shown in Figure 6-3, the closed end forms an obstruction, which changes the direction of the wind expanding at the closed end and converging at the open end, producing a vacuum inside the

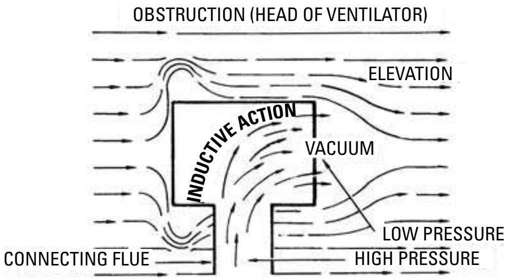


Figure 6-3 Two essential parts of a ventilator showing the results of wind action.

head, which induces an upward flow of the air through the flue and out through the head. This is *inductive* action of the wind.

The *stack* or *flue effect* (see Figure 6-4) produced within a building when the outdoor temperature is lower than the indoor temperature is due to the difference in weight of the warm column of air within the building and the cooler air outside. The flow due to the stack (flue) effect is proportional to the square root of the draft

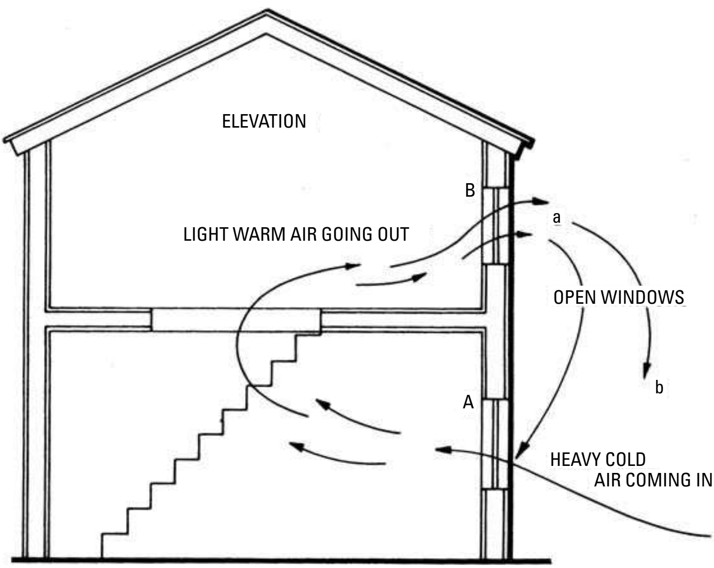


Figure 6-4 Illustrating the stack effect in a two-story structure.

head. The formula for determining the rate of flow is as follows:

$$Q = 9.4A\sqrt{h(t - t_0)}$$

where Q = airflow, cubic feet per minute.
A = free area of inlets or outlets (assumed equal), square feet.
h = height from inlets to outlets, feet.
t = *average* temperature of indoor air at height h, °F.
t_0 = temperature of outdoor air, °F.
9.4 = constant of proportionality, including a value of 65 percent for effectiveness of openings. This should be reduced to 50 percent (constant = 7.2) if conditions are not favorable.

Induced Draft

A closed flue (stack) or chimney will induce a draft or draw air. In other words, it will cause the air to rise from the bottom level (or room level) to the top. Consider the schematic of a stack shown in Figure 6-5. The air is cool at the bottom of the stack and hot at the top. Each unit of air in traversing the stack expands as the temperature increases and becomes lighter. Assuming that cube *A* in Figure 6-5 represents 1 lb of air and that the initial volume undergoes first eight expansions and then sixteen, the corresponding weight of the initial volume (1 lb) decreases to ⅛ lb and then to 1⁄16 lb. Accordingly the sum of the weights of unit volume in ascending is 1 + ⅛ + 1⁄16 or 1 3⁄16 lbs. On the outside of the stack the volume and weight of each unit of air remain the same so that considering three units *a*, *b*, *c* of decreasing weights in the stack, there are three units of *a*′, *b*′, *c*′ of constant weight outside the stack, the total weight outside the stack being 3 lbs and only 1 3⁄16 lbs inside the stack. As a result of the downward force (3 lbs) outside the stack being greater than that in the stack, the heavy units *a*′, *b*′, *c*′ push the lighter units *a*, *b*, *c* up and out of the stack, thus inducing a draft as indicated by the lever scales in Figure 6-5. For purposes of explanation, induced draft may be considered virtually the same as thermal effect.

Combined Force of Wind Effect and Thermal Effect

It should be noted that when the forces of wind effect and thermal effect are acting together (even when both forces are acting together without interference), the resulting airflow is not equal to the sum

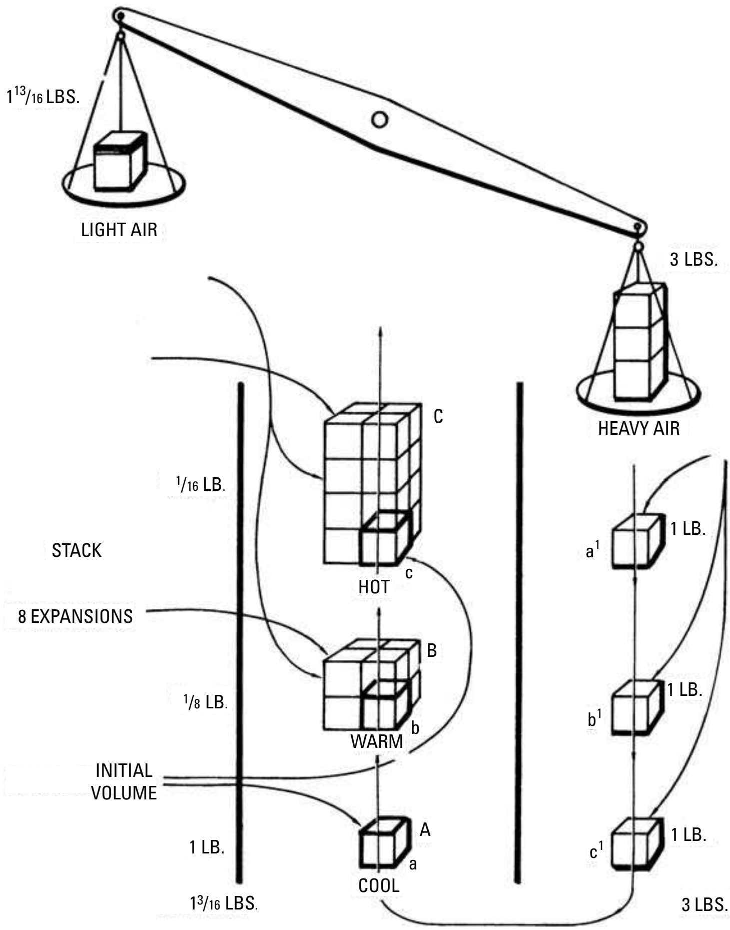


Figure 6-5 The principle of induced draft.

of the two estimated quantities. The flow through any opening is proportional to the square root of the sum of the heads acting upon the opening.

When the two heads are equal in value and the ventilating openings are operated so as to coordinate them, the total airflow through the building is about 10 percent greater than that produced by either head acting independently under conditions ideal to it. This percentage decreases rapidly as one head increases over the other, and the larger will predominate.

The wind velocity and direction, the outdoor temperature, or the indoor distribution cannot be predicted with certainty, and refinement in calculations is not justified; consequently, a simplified method can be used. This may be done by using the equations and calculating the flows produced by each force separately under conditions of openings best suited for coordination of the forces.

Mechanical Ventilation

Mechanical ventilation is the process of supplying or removing air by mechanical means. In other words, it represents a form of *forced* ventilation. Some form of mechanical ventilation is necessary when the volume of air required to ventilate a space cannot be delivered adequately by natural means. As a result, it may be necessary to add a fan (or fans) to the ventilation system in order to obtain the required rate of air change.

Mechanical ventilation involves the use not only of fans but also of ducts in some larger systems. The selection, installation, and operation of fans are described in Chapter 7 ("Fan Selection and Operation"). All aspects of duct sizing, the resistance to airflow, and other related aspects are described in considerable detail in Chapter 7 of Volume 2 ("Ducts and Duct Systems").

Air Ventilation Requirements

The volume of air required for proper ventilation is determined by the size of the space to be ventilated and the number of times per hour that the air in the space is to be changed. Table 6-1 gives some recommended rates of air change for various types of spaces. The volume of air required to ventilate a given space is determined by dividing the volume of the space by the number of minutes shown for that space in the "rate of change" column in Table 6-1.

In many cases, existing local regulations or codes will govern the ventilating requirements. Some of these codes are based on a specified amount of air per person and others on the air required per foot of floor area. The table should thus serve only as a guide to average conditions; where local codes or regulations are involved, they should be taken into consideration.

If the number of persons occupying a given space is larger than would be normal for such a space, the air should be changed more often than shown in the table. It is recommended that an air exchange rate of 40 cubic feet per minute per person be allowed for extremely crowded spaces.

If the cooling effect of rapid air movement is needed in localities that have high temperatures or humidities, the number of air changes shown in Table 6-1 should be doubled.

Table 6-1 Fresh Air Requirements

Type of Building or Room	*Minimum Air Changes per Hour*	*CFA per Minute per Occupant*
Attic spaces (for cooling)	12–15	
Boiler rooms	15–20	
Churches, auditoriums	8	20–30
College classrooms		25–35
Dining rooms (hotel)	5	
Engine rooms	4–6	
Factory buildings (ordinary manufacturing)	2–4	
Factory buildings (extreme fumes or moisture)	10–15	
Foundries	15–20	
Galvanizing plants	20–30*	
Garages (repair)	20–30	
Garages (storage)	4–6	
Homes (night cooling)	9–17	
Hospitals (general)		40–50
Hospitals (children's)		35–40
Hospitals (contagious diseases)		80–90
Kitchens (hotel)	10–20	
Kitchens (restaurant)	10–20	
Libraries (public)	4	
Laundries	10–15	
Mills (paper)	15–20*	
Mills (textile—general buildings)	4	
Mills (textile—dyehouses)	15–20*	
Offices (public)	3	
Offices (private)	4	
Pickling plants	10–15†	
Pump rooms	5	
Restaurants	8–12	
Schools (grade)		15–25
Schools (high)		30–35
Shops (machine)	5	
Shops (paint)	15–20*	
Shops (railroad)	5	

Table 6-1 (continued)

Type of Building or Room	*Minimum Air Changes per Hour*	*CFA per Minute per Occupant*
Shops (woodworking)	5	
Substations (electric)	5–10	
Theatres		10–15
Turbine rooms (electric)	5–10	
Warehouses	2	
Waiting rooms (public)	4	

**Hoods should be installed over vats or machines.*
†Unit heaters should be directed on vats to keep fumes superheated.

Roof Ventilators

The function of a roof ventilator is to provide a storm- and weatherproof air outlet. For maximum flow by induction, the ventilator should be located on that part of the roof where it will receive the full wind without interference.

One must exercise great care when installing ventilators. If the ventilators are installed within the vacuum region created by the wind passing over the building or in a light court, or on a low building between two buildings, their performance will be seriously influenced. Their normal ejector action, if any, may be completely lost.

The base of a ventilator should be a tapering cone shape. This design provides the effect of a bell mouth nozzle, which gives considerably higher flow than that of a square entrance orifice.

Air inlet openings located at low levels in the building should be at least equal to, and preferably larger than, the combined throat areas of all roof ventilators.

The advantages of natural ventilation units are that they may be used to supplement power-driven supply fans, and under favorable conditions it may be possible to shut down the power-driven units.

Types of Roof Ventilators

Roof ventilators are manufactured in a variety of shapes and designs. Because of this variety, it is possible to classify roof ventilators under a number of broad categories, including the following:

1. Stationary head
2. Revolving

3. Turbine
4. Ridge
5. Siphonage

Some of the examples illustrated in the paragraphs that follow are no longer manufactured, but they will be encountered on older buildings. For this reason, they are included in this chapter.

Stationary-Head Ventilators

More ventilators are of this type than any other, and when well designed, it is usually considered the most efficient type of gravity ventilator. The chief advantages of stationary-head ventilators are as follows:

1. Higher exhaustive capacity under all wind conditions.
2. No moving parts.
3. Quiet operation.
4. No upkeep.

A stationary head ventilator is illustrated in Figure 6-6.

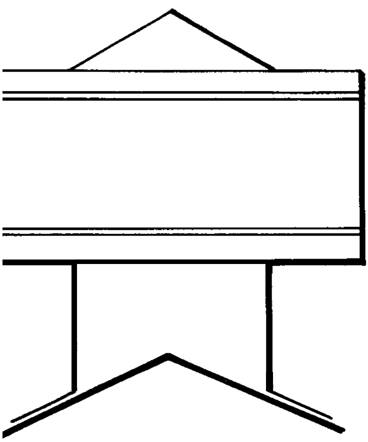


Figure 6-6 Stationary-head ventilator.

Revolving Ventilators

A typical revolving ventilator is shown in Figure 6-7. This type of ventilator swings on a pivot, aided by the wind vane so that its open end points away from the wind. The inductive action of the wind, in passing around the head, draws air out of the building. In

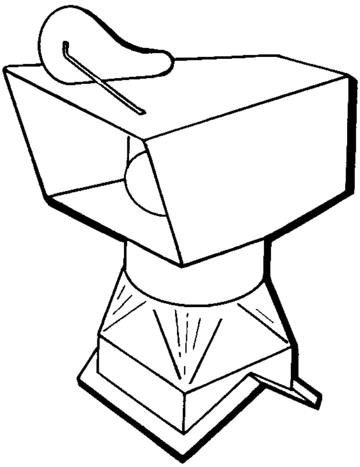


Figure 6-7 Revolving ventilator. The top portion pivots.

general, this is not as efficient as the stationary-head ventilator, although it has general use.

A major disadvantage of the revolving ventilator is its low capacity in still air. Furthermore, if the pivot bearings stick so that the head cannot follow the wind, it fails to exhaust air (in some cases even admitting air, rain, or snow). The revolving ventilator also frequently becomes noisy, creaking when changing direction. Constant attention is required to overcome these disadvantages.

Turbine Ventilators

Figure 6-8 represents one type of turbine ventilator. On its top is a series of vanes that, from the force of the wind, causes the entire top to rotate. Fastened to the top on the inside and placed in the air outlet openings is a series of propeller blades. The wind rotates this head, the blades drawing air up the shaft and exhausting it through the blade opening. The basic limitation of the turbine ventilator is that its blades draw the air outward as the top revolves. Its principal disadvantages include the following:

1. Low capacities in quiet air.
2. Lowered capacity if the pivot bearings do not turn freely.
3. The tendency to become noisy (as does any heavy rotating body that cannot accurately be kept in balance).
4. Required service attention in oiling, cleaning, and eventually replacing bearings.

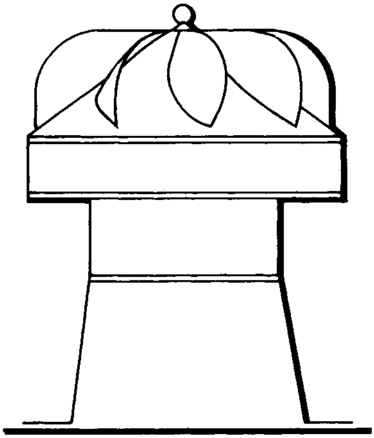


Figure 6-8 Turbine ventilator. The blades draw air outward as the top revolves.

Another type of turbine ventilator (see Figure 6-9) consists of a globe-shaped head containing vane blades. It, too, is designed to draw air out of the structure as the globe-shaped head rotates. The basic components of a globe-head turbine ventilator are shown in Figure 6-10.

Turbine ventilators with globe-shaped heads also have a number of disadvantages. For example, wind impact on the vanes allows outside air to enter the head on the windward side that must be exhausted, together with the air from the building on the leeward

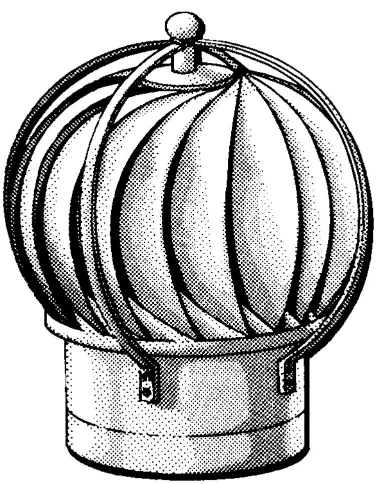


Figure 6-9 Globe-head turbine ventilator.

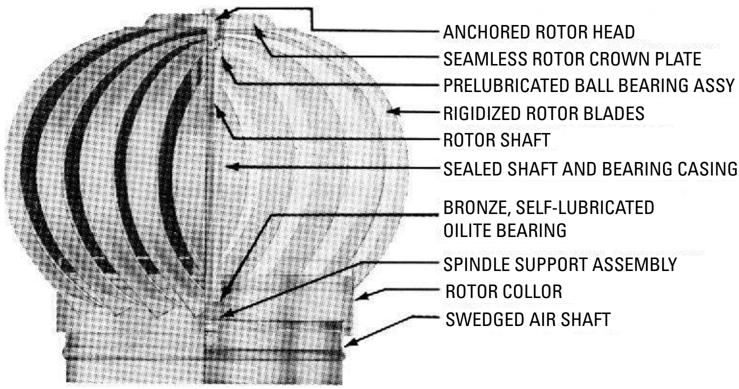


Figure 6-10 Construction details of a turbine ventilator.
(Courtesy Penn Ventilator Co., Inc.)

side. This decreases its efficiency inasmuch as the head must handle both volumes of air. Furthermore, this type of ventilator is apt not to be rainproof when the wind is not turning it. Like all revolving ventilators, its moving parts involve a service problem in oiling, keeping bearings free, and the replacement of worn parts.

Ridge Ventilators

Figure 6-11 shows a sectional view of a ridge ventilator, which is installed along the entire roof ridge of the space to be ventilated. Basically, it consists of a valve in the top of the building, which lets the warm air out as it rises to the roof air outlet distribution along the length of the structure. Then, too, it has a pleasing uniform appearance.

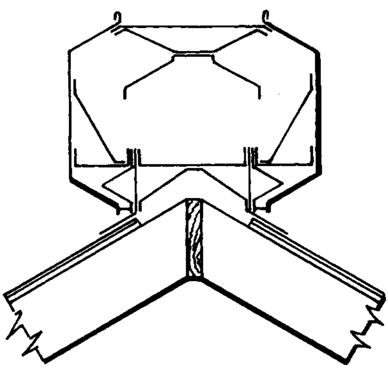


Figure 6-11 Ridge ventilator.

Its major disadvantage is that it does not take full advantage of wind action unless the wind direction is almost directly across it. This type of ventilator also involves a somewhat cumbersome damper and a rather difficult problem in building modernization.

Siphonage Ventilators

The siphonage ventilator (see Figure 6-12) acts by induction, drawing the building air upward. Wind causes a flow of air upward through a duct that is concentric to and parallel with the ventilator shaft extending from the building. Both of these air passages terminate in the ventilator head, and the upward flow of the outside air creates a siphonage action drawing the building airstreams exhausting through the head. This ventilator is simply a stationary unit with an auxiliary air passageway to obtain the siphonage action.

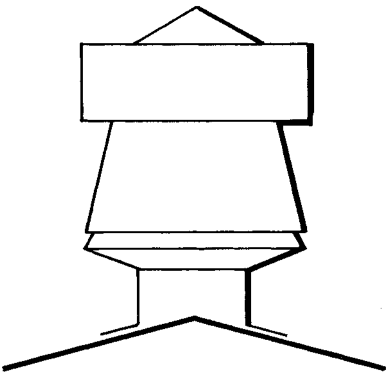


Figure 6-12 Siphonage ventilator.

The head of the siphonage ventilator must be designed to eject not only the building air but also the siphon stream. This tends to retard airflow from the building due to the fact that egress from the head is usually somewhat restricted.

Fan Ventilators

A typical fan ventilator is shown in Figure 6-13. The principal advantage of this type of ventilator is that the fan greatly increases the ventilating capacity when the fan is in operation. Fan ventilators also have a number of other advantages when

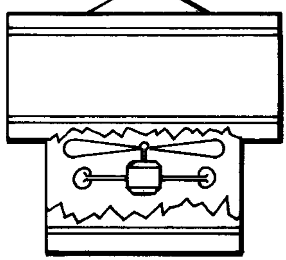


Figure 6-13 Sectional view showing fan ventilator.

the fan is not in use and have great capacity when the fan is operated. Fan ventilators can be used on any building, regardless of access to wind flow, and can be spotted directly over any point at which ventilation is badly needed. These ventilators can also be used on ductwork flues to give greater capacities when friction losses are relatively large. It should be noted that a fan ventilator is a *forced*-draft rather than an induced-draft ventilator.

Components of a Roof Ventilator

The basic components of a typical roof ventilator are shown in Figure 6-14 and may be listed as follows:

1. Base
2. Barrel
3. Top
4. Windband
5. Airshaft
6. Dampers

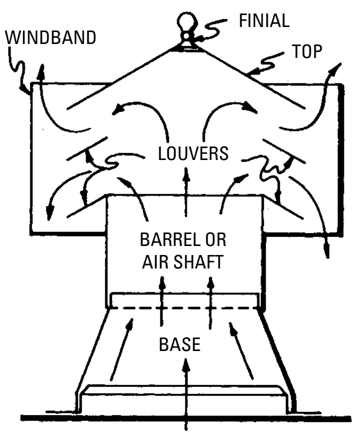


Figure 6-14 Component parts of a roof ventilator.

The *base* serves as the connection between the roof and the ventilator proper. A trough is usually provided around the inside bottom edge of the base to collect any condensation occurring in the ventilator and draw it out to the roof.

As bases are made to fit either a round or square opening and to conform to the shape and slope of the roof, they are essentially tailor-made for each installation.

After leaving the base, the air passes through the *barrel* (or *neck*) of the ventilator, which is merely the lower section of the head. It then enters the head proper and is exhausted to the outside air through the openings between louvers. The *top*, of course, covers the opening in the roof.

The *windband* is the vertical band encircling the ventilator head. The *airshaft* is the entire passageway through the ventilator from the roof to the top of the barrel.

The *dampers* are mechanical devices for closing the airshaft. They assume a number of forms and are referred to according to type as the *sliding sleeve*, *inverted cone*, *butterfly*, and *louver.*

Motive Force to Cause Air Circulation

Two agencies form the motive force to cause air circulation: (1) temperature differences inside and outside the building resulting in a chimney effect, and (2) inductive action caused by wind blowing against the ventilator.

Capacity of Ventilators

The following factors must be taken into consideration in making a selection of the proper ventilator for any specific problem:

1. Mean temperature difference.
2. Stack height (chimney effect).
3. Inductive action of the wind.
4. Area of opening in the ventilator.

The *mean temperature difference* refers to the average temperature difference between the air inside and outside the building (see Figure 6-15). If the ventilating problem is essentially a winter one, this difference may be as much as 40°F, while in summer, when doors and windows are open, this difference will probably drop to about 10°F.

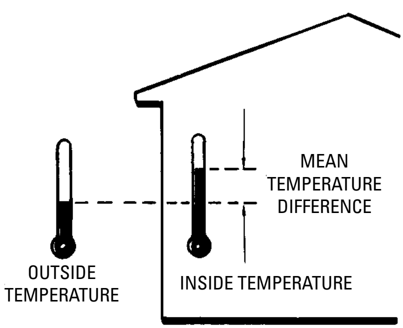


Figure 6-15 Mean temperature difference inside and outside.

Stack height (see Figure 6-16) is the height of the column of warm air that causes the chimney action of the ventilator. It is measured in feet from the floor of the building to the top of the ventilator barrel.

The *inductive action of the wind* (see Figure 6-17) is the effect of the wind as it passes over the ventilator in inducing a circulation out of the building.

The *area of the opening in the ventilator* (see Figure 6-18) is determined by the rated size of the ventilator, expressed as the inside diameter of the barrel in inches.

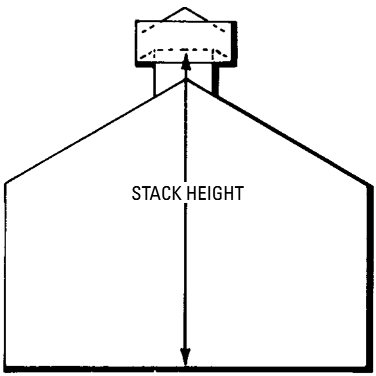


Figure 6-16 Stack height upon which the chimney effect depends.

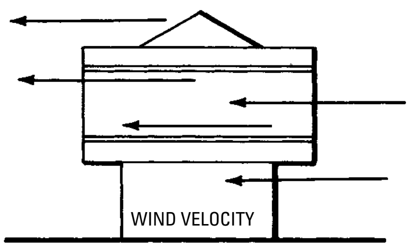


Figure 6-17 The suction action of the wind as it passes over the ventilator.

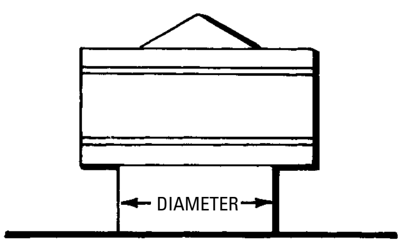


Figure 6-18 Diameter of the base, which governs the capacity of gravity ventilation.

Design and Placement of Inlet Air Openings

The purpose of a roof ventilator is to let air escape from the top of a building. This naturally means that a like amount of air must be admitted to the building to take the place of that exhausted. The nature, size, and location of these inlet openings are of importance in determining the effectiveness of the ventilating system.

Inlet air openings are frequently constructed in the form of louvered openings located near the floor line, but they also often consist of the building windows. In general, there are three factors that should be considered when planning for an effective ventilating system:

1. The relationship between the area of the air intakes and the airshaft areas.
2. The distribution of inlet air openings.
3. The height at which air inlets are placed.

The area of the air intakes should at all times be twice that of the combined airshaft area of all ventilators (see Figure 6-19). By keeping

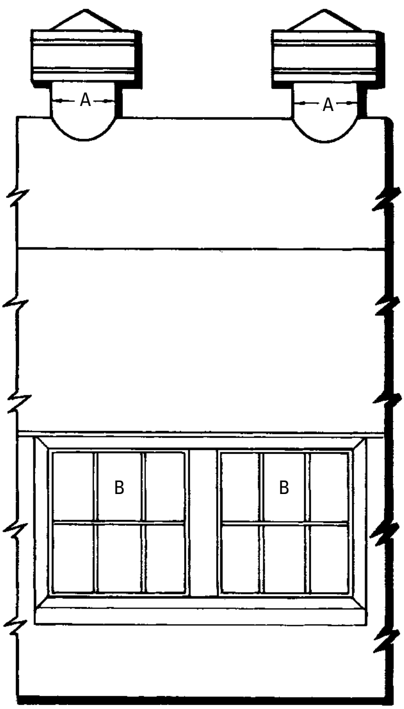


Figure 6-19 Open areas at B should be twice that of A.

this relationship, the full capacity of the ventilators will be realized, and the velocity of the incoming air will be low, thereby lessening the danger from drafts in the building. Any backdraft down the ventilator itself will also be eliminated.

These inlet air openings should also be distributed in such a way as to allow the admission of fresh air to all parts of the building. They should be located as close to the floor as possible in order to bring the incoming fresh air into the breathing zone.

Fresh Air Requirements

Table 6-1 lists necessary air changes for various rooms and buildings and thus offers a guide as to the amount of air required for efficient ventilation. This information should be used in connection with the ventilator capacity tables in the proper selection of the number and size of units required.

Where two figures are given for one type of building, use the smaller figure when conditions are normal and the larger figure when they are abnormal. Certain buildings are better figured on a cfm (cubic feet per minute) per occupant basis. Their requirements are given in this manner.

Ventilator Bases

The ventilator base is the connection between the other elements of the ventilator and the roof. It must be designed so as to fit the contour of the roof and the opening on which it is mounted. Its design and construction is important, particularly in ventilator sizes and types where weight and wind resistance are high. Ventilator manufacturers provide a wide variety of different ventilator base sizes. In their literature, illustrated base designs (see Figure 6-20) are cross-referenced with dimensional tables for the convenience of the buyer.

Gauges of metal are used that ensure rigidity and strength. Reinforcement is added where needed. Flashing flanges are amply wide to ensure rigid, weather-tight joints that will not leak when properly fastened and flashed to the roof. All seams are well riveted, soldered, or doped (the latter in asbestos-protected steel) to ensure storm-tight joints. All connections to the roof and to the next adjacent ventilator unit (the head in a gravity unit or the fan in a fan unit) are designed for 75-mph wind velocity as standard or 100 mph optional.

Since the outside sheet-metal surfaces of ventilators are exposed to atmospheric temperatures and the inside surfaces to room temperature, there is frequently a tendency for condensation to form on the

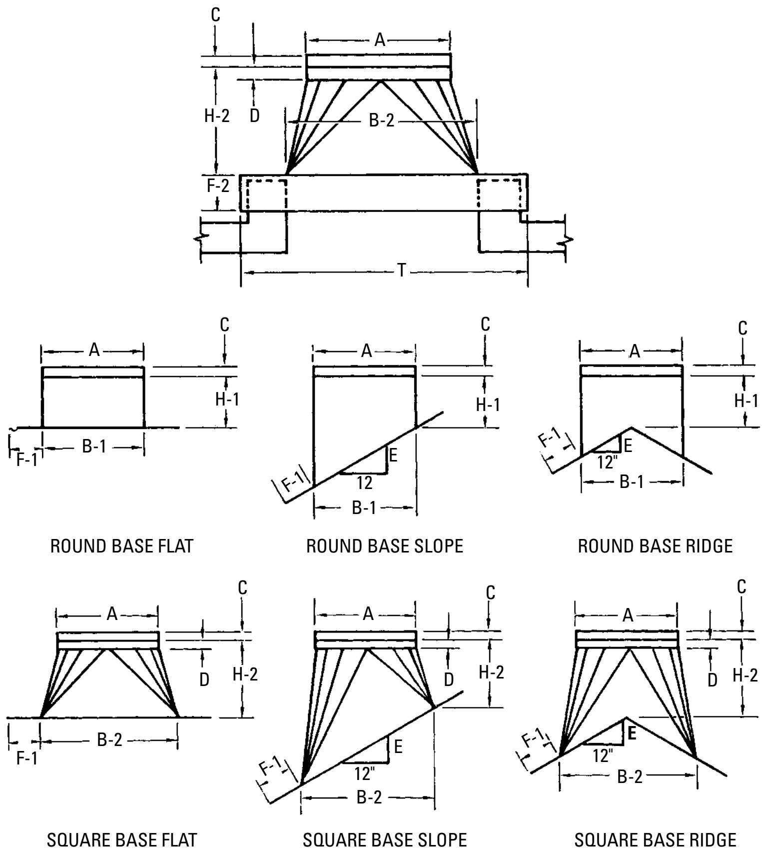


Figure 6-20 Standard ventilator bases. The letters refer to dimension on manufacturers' tables.

inside surfaces. In order to minimize the possibility of condensation drip into the ventilated space, condensation gutters may be provided to drain the water to the outside of the ventilator. These condensation gutters are usually located at the extreme lower edge of the base where as little water as possible can get past them.

The round ventilator bases in Figure 6-21 are standard but can be omitted if a duct is to be fitted into the lower end of the base with which the gutter would interfere. Examples of spare bases are shown in Figure 6-22, but these are special. In either type, drains

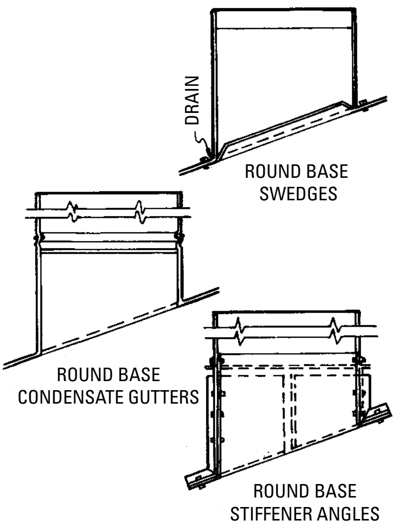


Figure 6-21 Round-base ventilators.

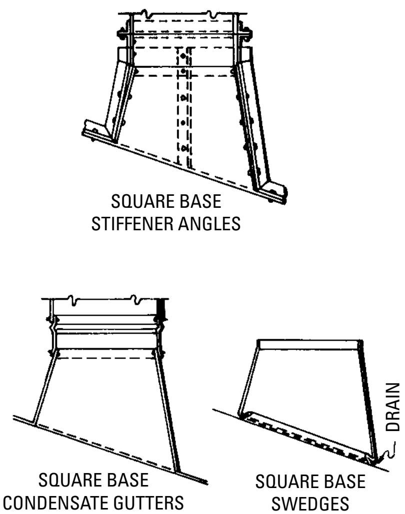


Figure 6-22 Square-base ventilators.

from the gutter to the roof are ample for drainage and to prevent clogging.

In ventilator sizes and types where weights are not great, bases are lapped into the next adjacent unit above. In order to properly position the units and to add stiffness, a wedge is provided in the base against which the next adjacent unit seats.

Angle Rings

In larger ventilator sizes where added strength, rigidity, and ease of erection are important, angle rings have been used to connect the base to the next adjacent unit (ventilator head, fan section, or stack).

In certain instances a one-ring connection (see Figure 6-23) is used with the upper edge of the base lapping into the next adjacent unit, which rests upon the angle ring. The bolted connection is made through the sheet-metal lap. The lap connection is ample to ensure proper bearing for connection screws or bolts. When angle rings are provided, wedges are not used.

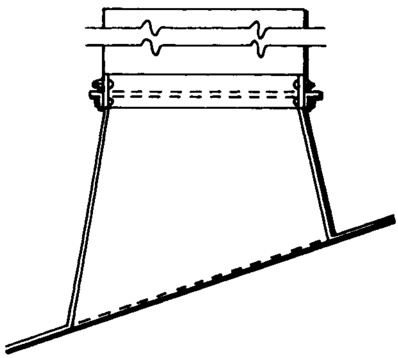


Figure 6-23 One-ring connection.

Sometimes a two-ring connection (see Figure 6-24) is used, one ring at the top of the base, another at the bottom of the adjacent unit. The two rings form a flanged connection and are bolted together. In every instance where angle rings are used, they are riveted to the bases to develop the full design strength of the assembly for velocities of 75 mph standard or 100 mph optional.

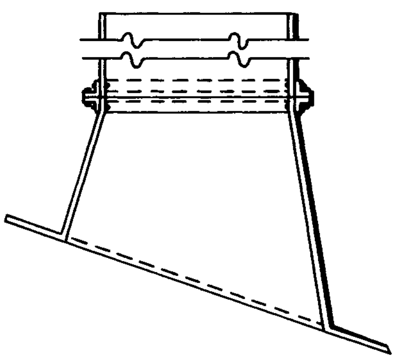


Figure 6-24 Two-ring connection.

Stiffener Angles

Stiffener angles are provided in conjunction with angle rings in certain applications where the sheet metal needs reinforcing. These lie vertically along the outside of the base surface at quarter points and extend from the angle ring at the top to the outer edge of the roof flange at the bottom. They are riveted to the base sheet metal and welded to the angle ring. Bolted connections through portions of the stiffener that lie along the roof flange to the curb or framing members below provide rigid structural members through which load is carried to the roof structure.

Where applicable and with certain types of dampers, a small clip can be supplied and riveted to the base (see Figure 6-25). The damper chain drops through this clip and can be locked at any point to properly position the damper. This clip is useful when the damper is to be operated from a point directly below the ventilator since it avoids the use of pulleys and complicated chain arrangements.

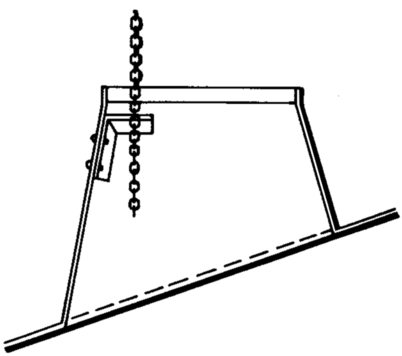


Figure 6-25 Base chain clip.

Prefabricated Roof Curbs

Prefabricated roof curbs (bases) for ventilators are available from a number of manufacturers. One of the advantages of the prefabricated type over those constructed at the site is the fact that they are generally cheaper. This, of course, is due to their being mass-produced. Although commonly designed for flat-roof installation, prefabricated roof curbs can also be built for installation on the ridge or single slope of a roof. Figures 6-26 and 6-27 illustrate some of the design features incorporated in a prefabricated roof curb.

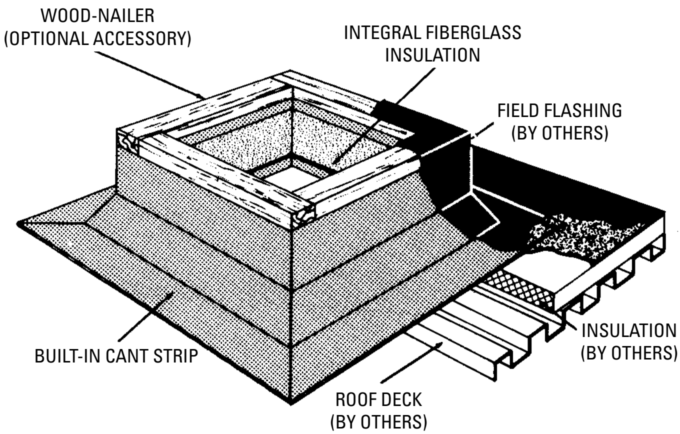


Figure 6-26 Prefabricated roof curb designed for flat-roof installation.
(Courtesy Penn Ventilator Co., Inc.)

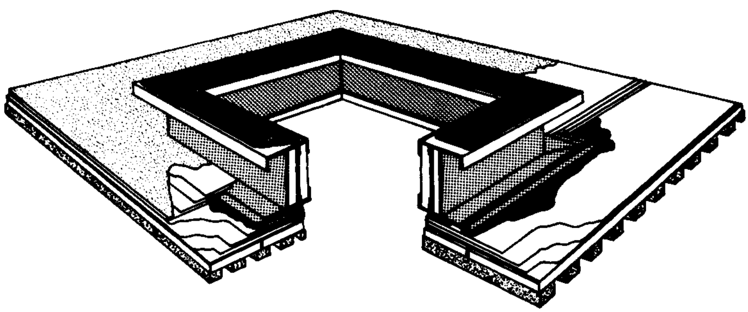


Figure 6-27 Prefabricated roof curb featuring self-flashing design.
(Courtesy Penn Ventilator Co., Inc.)

Ventilator Dampers

Ventilator dampers (see Figure 6-28) are made in a variety of types, from the single-disc butterfly to the multiblade louver, which has been designed to allow a flexible and reliable means of air movement control. A tight seal can be obtained through the use of a damper ring, which prevents the passage of air when the damper is closed.

Some dampers can be controlled only by hand chain; others may be remotely operated through the use of damper control motors of the electric or compressed-air type.

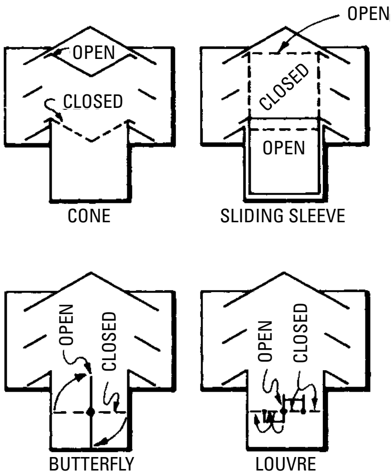


Figure 6-28 Various forms of dampers.

The principal types of ventilator dampers are as follows:

1. Sliding sleeve
2. Fire-retarding cone
3. Single butterfly
4. Divided butterfly
5. Louver

Louver Dampers

Figure 6-28 shows the general appearance of a louver damper. It is considered the best type for airflow. Louver dampers offer little resistance to the passage of air and in a partially open position create little turbulence in the airstream. In multiblade louvers, the blades on one half open up, and those on the other half open down.

The center blade is double the width, and its edges are connected to adjacent blades by clips and bars. The spacing of the blades along the connecting bars has been closely studied to ensure that the blade edges seat tightly on the damper ring when closed. This damper ring also allows all the blade pivot bearings to be placed inside the ventilator shaft, away from the weather. It also eliminates holes through the airshaft that might leak air and rain. Blades are regularly weighted so that the damper closes automatically. Any type of control may be used.

Sliding Sleeve Dampers

The sliding sleeve damper is frequently used for gravity ventilators. In construction it closely fits the under circumference of the ventilator airshaft and operates vertically. It occupies almost no space in the airshaft and offers no resistance or turbulence to the airstream in any position. Its normal position is open, and with a fusible link it can be used as an automatic-opening damper where there is need for such a control unit.

Sliding sleeve dampers have one principal advantage. Because of their vertical sides, there is no tendency for dust or dirt to accumulate.

The sliding sleeve damper is operated by chain only. Radial spiders keep the damper cylindrical to the operating chain attached to the hub of the spider, passing upward through a pulley fastened below the finial and then down past the spider hub, where a spring clip is located. The spring clip enables the damper to be positioned at any point between open and closed.

Sliding Cone Dampers

As shown in Figure 6-28, a sliding cone damper consists of a cone with apex down and with a flared outer rim that seats on the upper edge of the airshaft when closed. This directs the airstream to the outlet openings of the ventilator, lessens turbulence in the ventilator head, and consequently increases capacity.

From the apex of the damper, the operating chain passes upward to a pulley located below the finial, then downward through a slot in the cone to a pulley located on the inside of the airshaft, and then through the base to the building below.

When used in connection with the fusible link, this damper becomes an automatically closing, fire-retarding unit.

Butterfly Dampers

The two butterfly dampers used in roof ventilators are (1) the single-disc damper and (2) the divided-disc damper. They receive their name from the butterfly-wing appearance of the metal disc used to open or close the air passage.

The single-disc butterfly damper seats tightly against the ring channel, preventing air leakage when closed. When operated by hand chain, these dampers are normally counterweighted to close but can be supplied weighted to open when required.

The divided-disc butterfly damper is used for sizes that prevent the use of a single disc. The divided halves (or wings) of the disc swing upward, pivoted on two rods whose ends bear in the damper ring channel on which the damper edges seat tightly.

Butterfly dampers, single- and divided-disc, are the only dampers that can be successfully used in ventilators constructed of asbestos-protected steel. In this material, the damper ring is omitted and the damper pivot rods are mounted on brackets secured to the airshaft wall.

Method of Calculating Number and Size of Ventilators Required

The number and size of ventilators required by a particular building can be calculated by taking the following steps:

1. Determine the gross volume of the interior of the building in cubic feet by multiplying its length by its width and by its height.
2. Determine the number of air changes per hour required for the building in question. This can be found by referring to the tables given in the *Typical Installation* section.
3. Find the total number of cubic feet of air per hour necessary for the ventilators to exhaust by multiplying the number of changes per hour by the volume of each change, or 1×2.
4. Reduce this to cubic feet per minute by dividing by 60.
5. The effective range of a gravity ventilator is about 10 to 15 feet in the direction of the length of the building and 15 to 25 feet in the direction of the width of the building, where air is being admitted on the sides. The next step, therefore, is to space the units along the roof, using these restrictions, determining in this manner the number of ventilators that will be required.

   If the building is divided into bays, one unit is usually placed in each bay, provided the bays are not over 20 feet long. If there are no bays, one ventilator every 20 feet should be sufficient for buildings up to 50 feet in width. In wider buildings, the ventilators should be so arranged as to maintain approximately 20-foot spacing. If there are any spots where there is urgent need of ventilation, such as a machine or vat emitting fumes or dust, they should be cared for by ventilators placed above them. Such a layout will provide the number of ventilators required for the building.
6. Next, determine the exhaustive capacity required of each ventilator by dividing the total amount of air per minute to be exhausted by the number of ventilators to be used, or $4/5$. This is the capacity for which you should look in the capacity tables obtained from the manufacturer.

7. Determine the conditions under which the ventilators will operate, that is, stack height, mean temperature difference, and wind velocity. These factors, their use, and their probable values have already been explained.
8. Turn to the manufacturer's capacity tables and look under the proper columns of temperature difference, stack height, and wind velocity, as determined in step 7, to find a capacity in cfm that will fulfill the requirement as determined in step 6. This capacity is listed under the size that should be selected.

Ventilator Calculation Examples

Assume a building used as an automobile storage garage 50 feet wide by 150 feet long by 20 feet high to the eaves, 26 feet to the ridge of the roof.

1. Volume of space from the eaves down is 50 × 20 × 150 = 150,000 cubic feet. Volume of space from the eaves up is 50 × 3 × 150 = 22,500 cubic feet. Total volume = 172,500 cubic feet.
2. From the table of air change requirements, you will find that storage garages require four changes per hour for proper ventilation. Total air to be exhausted is then 172,500 × 4 = 690,000 cubic feet per hour, or 690,000 ÷ 60 = 11,500 cfm.
3. Spacing ventilators along the roof as indicated in Figure 6-29, with the aforementioned rules in mind, the resultant number of ventilators would be seven, spaced 15 feet from each end

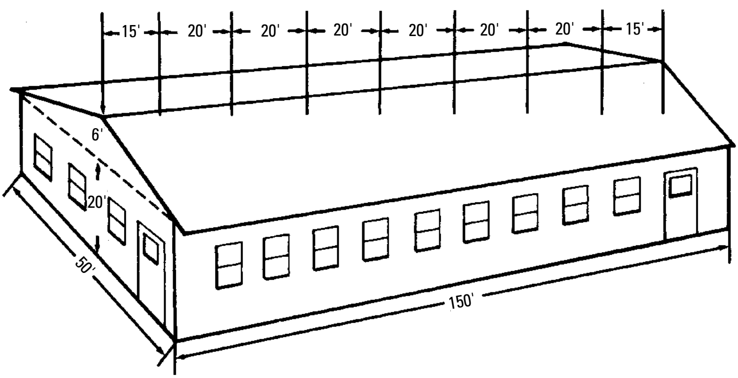


Figure 6-29 Typical building illustrating method of calculating number and size of ventilators required.

and 20 feet apart. Each ventilator would need to exhaust 11,500 ÷ 7 = 1643 cfm.

4. Suppose we have a mean temperature difference of 10°F, an average wind velocity of 5 mph, and a stack height of 26 feet (floor to roof ridge).
5. Turning to the capacity tables under that of the 30-inch cone damper unit in the proper columns for the factors given in step 4, we find that the capacity is 1750 cfm, which exceeds our requisite of 1643 cfm obtained in step 3. Even though this is a trifle higher than necessary, it should be used, inasmuch as the next size smaller would be too far under the required capacity. This can be seen by referring to the 24-inch unit, the capacity of which is 1165 cfm.

We have therefore determined that to properly ventilate this building, seven 30-inch cone damper ventilators will be necessary, located on the ridge of the roof and spaced 20 feet apart and 15 feet from each end.

Air Leakage

Air leakage is the passage of air in and out of various cracks or openings in buildings. It is also sometimes referred to as *infiltration.*

Air leaking *into* a building may be caused by wind pressure or by differences in temperature inside and outside of the building. In the former case, the wind builds up a pressure on one or two sides of a building, causing air to leak into the building. As shown in Figure 6-2 previously, the action of the wind on the opposite side or sides produces a vacuum that draws air out of the building. Thus, as shown in Figure 6-4 previously, a plan view of a single-room building is shown having a window and a door on one side and a window on the opposite side. The details are greatly exaggerated so that you can see the cracks.

Note that when the wind hits the *A* side of the building, its momentum (dynamic inertia) builds up a pressure higher than inside the building, which causes the air to leak through any cracks present, as indicated by the arrows.

As the wind traverses the length of the building, the air currents as they continue past the side *C* converge and produce a vacuum along side *C* by induction. Because the pressure on the outside of *C* is lower than inside the building, air leaks out as indicated by the arrows.

Air leakage due to temperature difference or thermal effect is usually referred to as *stack* or *chimney effect.* Air leakage due to cold air outside and warm air inside takes place when the building contains cracks or openings at different levels. This results in the cold and heavy air entering at low level and pushing the warm and light air out at high levels, the same as draft taking place in a chimney.

Thus, in Figure 6-4, assume a two-story building having a window open on each floor. Evidently when the temperature inside the building is higher than outside, the heavy cold air from outside will enter the building through window *A* and push the warm light air through window *B*, as indicated by arrow *a*; as it cools, it will increase in weight and circulate downward, as indicated by arrow *b*.

Although not appreciable in low buildings, this air leakage is considerable in high buildings unless sealing between various floors and rooms is adequate.

A reasonable amount of air leakage is actually beneficial to health. Any attempt to seal a building drum-tight will cause the inside air to become stale and putrid. Emphasis should be placed on the reduction of heat transmission rather than the absolute elimination of air leakage.

The application of storm sash to poorly filtered windows will generally result in a reduction of air leakage of up to 50 percent. An equal effect can be obtained by properly installed weather stripping.

Garage Ventilation

The importance of garage ventilation cannot be overestimated because of the ever-present danger of carbon monoxide poisoning. During warm weather, there is usually adequate ventilation because doors and windows are kept open. In cold weather, however, people close up openings tight as a drum, with considerable danger. Nobody can breathe the resulting carbon monoxide concentration long without being knocked out—hence the importance of proper ventilation in cold weather, regardless of physical comfort.

Where it is impractical to operate an adequate natural ventilation system, a mechanical system should be used that will provide for either the supply of 1 cubic foot of air per minute from out of doors for each square foot of floor area or the removal of the same amount, discharging it to the outside as a means of flushing the garage.

The following points should be carefully reviewed when considering a ventilating system capable of removing carbon monoxide from an enclosed area:

1. Upward ventilation results in a lower concentration of carbon monoxide at the breathing line and a lower temperature above the breathing line than does downward ventilation for the same rate of carbon monoxide production and air change and the same temperature at the 30-inch level.

2. A lower rate of air change and a smaller heating load are required with upward ventilation than with downward ventilation.
3. In the average case, upward ventilation results in a lower concentration of carbon monoxide in the occupied portion of a garage than is had with complete mixing of the exhaust gases and the air supplied. However, the variations in concentration from point to point, together with the possible failure of the advantages of upward ventilation to accrue, suggest the basing of garage ventilation on complete mixing and an air change sufficient to dilute the exhaust gases to the allowable concentration of carbon monoxide.
4. The rate of carbon monoxide production by an idling car is shown to vary from 25 to 50 cubic feet per hour, with an average rate of 35 cubic feet per hour.
5. An air change of 350,000 cubic feet per hour per idling car is required to keep the carbon monoxide concentration down to one part in 10,000 parts of air.

Ventilation of Kitchens

In estimating the requirements for the ventilation of kitchens, the following two methods should be considered:

1. It is customary to allow a complete change of air every 2 minutes.
2. In many cases it is desirable to have all the extracted air leave via hoods or canopies located over ranges, steam tables, urns, dishwashers, and so on.

The first method applies only to average conditions, and modification from this average should be made depending on the kitchen size and the heat- and vapor-producing equipment.

In the second method, the air volume should be calculated from the hood entrance velocity rather than the air-change method.

Light cooking requires an entrance velocity of only 50 feet per minute, while severe conditions may run to 150 feet per minute or higher.

The size of a hood will depend on its dimensions. For example, a hood 3 feet by 8 feet would have an area of 24 square feet using an average velocity of 100 feet per minute.

Where quiet operation is essential, the blower should be selected on the basis of a low outlet velocity. This will also result in lower operating costs.

If space is limited and noise is not a factor, smaller units with higher outlet velocities may be necessary. This may result in a lower initial cost.

General Ventilation Rules

The American Society of Heating and Ventilating Engineers offers the following recommendations for designing and installing an adequate natural ventilation system:

1. Inlet openings in the building should be well distributed and should be located on the windward side near the bottom, while outlet openings are located on the leeward side near the top. Outside air will then be supplied to the zone to be ventilated.
2. Inlet openings should not be obstructed by buildings, trees, signboards, and so on, outside or by partitions inside.
3. Greatest flow per square foot of total openings is obtained by using inlet and outlet openings of nearly equal areas.
4. In the design of window-ventilated buildings, where the direction of the wind is constant and dependable, the orientation of the building, together with amount and grouping of ventilation openings, can be readily arranged to take full advantage of the force of the wind. Where the wind's direction is variable, the openings should be arranged in sidewalls and monitors so that, as far as possible, there will be approximately equal areas on all sides. Thus, no matter what the wind's direction, there will always be some openings directly exposed to the pressure force and others to a suction force, and effective movement through the building will be ensured.
5. Direct shortcuts between openings on two sides at a high level may clear the air at that level without producing any appreciable ventilation at the level of occupancy.
6. In order for temperature difference to produce a motive force, there must be vertical distance between openings. That is, if there are a number of openings available in a building, but all are at the same level, there will be no motive head produced by temperature difference, no matter how great that difference might be.
7. In order for the forces of temperature difference to operate to maximum advantage, the vertical distance between inlet and outlet openings should be as great as possible.

Openings in the vicinity of the neutral zone are less effective for ventilation.

8. In the use of monitors, windows on the windward side should usually be kept closed, because if they are open, the inflow tendency of the wind counteracts the outflow tendency of temperature difference. Openings on the leeward side of the monitor result in cooperation of wind and temperature difference.
9. In an industrial building where furnaces that give off heat and fumes are to be installed, it is better to locate them in the end of the building exposed to the prevailing wind. The strong suction effect of the wind at the roof near the windward end will then cooperate with temperature difference to provide for the most active and satisfactory removal of the heat and gas-laden air.
10. In case it is impossible to locate furnaces in the windward end, that part of the building in which they are to be located should be built higher than the rest so that the wind, in splashing, will create a suction. The additional height also increases the effect of temperature difference to cooperate with the wind.
11. The intensity of suction or the vacuum produced by the jump of the wind is greatest just behind the building face. The area of suction does not vary with the wind velocity, but the flow due to suction is directly proportional to wind velocity.
12. Openings much larger than the calculated areas are sometimes desirable, especially when changes in occupancy are possible or to provide for extremely hot days. In the former case, free openings should be located at the level of occupancy for psychological reasons.
13. In single-story industrial buildings, particularly those covering large areas, natural ventilation must be accomplished by taking air in and out of the roof openings. Openings in the pressure zones can be used for inflow, and openings in the suction zone, or openings in zones of less pressure, can be used for outflow. The ventilation is accomplished by the manipulation of openings to get airflow through the zones to be ventilated.

Chapter 7

Ventilation and Exhaust Fans

Both ventilation and air circulation utilize fans to move the air. Ventilation is concerned with the moving of a *volume* of air from one space to another. It does not involve the weight of air but the volume of air in cubic feet moved per minute (cfm). The circulation of air, on the other hand, is concerned with the velocity at which air moves around a confined space and is expressed in feet per minute (fpm).

This chapter is concerned primarily with introducing the reader to the problems of fan selection and operation. Several sections of this chapter provide detailed instructions for fan sizing. Because the selection of a fan and the design of a duct system are mutually dependent, Chapter 7 of Volume 2 ("Ducts and Duct Systems") should also be consulted.

Codes and Standards

Always consult local codes and standards before designing or attempting to install a fan system. Other sources of information on codes and standards pertaining to fans and fan systems are as follows:

1. The Air Moving and Conditioning Association (AMCA).
2. The National Association of Fan Manufacturers (NAFM).
3. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).
4. Home Ventilation Institute (HVI).

Definitions

A number of terms and definitions largely related to fan selection and operation should be examined and learned for a clearer understanding of the materials in this chapter. Most of the terms and definitions contained in this section are provided by the Air Moving and Conditioning Association.

Air horsepower (AHP). The work done in moving a given volume (or weight) of air at a given speed. Air horsepower is also referred to as the Morse power output of a fan.

Area (A). The square feet of any plane surface or cross section.

Area of duct. The product of the height and width of the duct multiplied by the air velocity equals the cubic feet of air per minute flowing through the duct.

Brake horsepower (BHP). The work done by an electric motor in driving the fan, measured as horsepower delivered to the fan shaft. In belt-drive units, the total workload is equal to the workload of the electric motor plus the drive losses from belts and pulleys. The brake horsepower is always a higher number than air horsepower (AHP). Brake horsepower is also referred to as the *horsepower input* of the fan.

Cubic feet per minute (cfm). The physical volume of air moved by a fan per minute expressed as fan outlet conditions.

Density. The actual weight of air in pounds per cubic foot (0.075 at 70°F and 29.92 inches barometric pressure).

Fan inlet area. The inside area of the inlet collar.

Fan outlet area. The inside area of the fan outlet.

Mechanical efficiency (ME). A decimal number or a percentage representing the ratio of air horsepower (AHP) to brake horsepower (BHP) of a fan. It will always be less than 1.000 or 100 percent and may be expressed as follows:

$$\mathrm{ME} = \frac{\mathrm{AHP}}{\mathrm{BHP}}$$

Outlet velocity (OV). The outlet velocity of a fan measured in feet per minute.

Revolutions per minute (RPM). The speed at which a fan or motor turns.

Standard air. Air at 70°F and 29.92 inches barometric pressure weighing 0.075 lbs per cubic foot.

Static efficiency (SE). The static efficiency of a fan is the mechanical efficiency multiplied by the ratio of static pressure to the total pressure.

Static pressure (SP). The static pressure of a fan is the total pressure diminished by the fan velocity pressure. It is measured in inches of water (see *velocity pressure*).

Tip speed (TS). Also referred to as the peripheral velocity of wheel. It is determined by multiplying the circumference of the wheel by the rpm.

$$\mathrm{TP} = \frac{\times \text{ wheel diameter in feet} \times \text{RPM}}{12}$$

$\times$ wheel diameter in feet $\times$ RPM

The tip speed should not exceed 3300 rpm if a quiet operation is to be obtained.

Total pressure (TP). Any fan produces a total pressure (TP), which is the sum of the static pressure (SP) and the velocity pressure (VP). Total pressure represents the rise of pressure from fan inlet to fan outlet.

Velocity. The speed in feet per minute (fpm) at which air is moving at any location (for example, through a duct, inlet damper, outlet damper, or fan discharge point). When the performance data for air-handling equipment are given in feet per minute (fpm), conversion to cubic feet per minute can be made by multiplying the fpm by the duct area:

$$\text{Air velocity} = 1000 \text{ FPM}$$

$$\text{Duct size} = 8 \text{ in.} \times 20 \text{ in.} = 160 \text{ sq. in.}$$

$$\text{Duct area} = 160 \div 144 = 1.11 \text{ sq. ft.}$$

$$\text{Air flow} = 1000 \text{ FPM} \times 1.11 \text{ sq. ft.} = 1110 \text{ CFM}$$

Velocity pressure (VP). Velocity pressure results only when air is in motion, and it is measured in inches of water. One-inch water gauge corresponds to 4005 fpm (standard air) velocity. The following formula is used for determining velocity pressure:

$$\mathrm{VP} = \left[\frac{\text{Air Velocity}}{4005}\right]^2$$

Types of Fans

The various mechanical devices used to move the air in heating, ventilating, and air-conditioning installations are known as fans, blowers, exhausts, or propellers.

Every fan is equipped with an impeller, which forces (impels) the airflow. The manner in which air flows through the impeller provides the basis for the following two general classifications of fans:

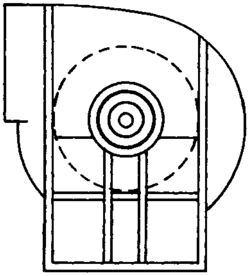


Figure 7-1 Centrifugal fan principles.

1. Centrifugal fans
2. Axial-flow fans

In a *centrifugal* (or *radial flow*) *fan* (see Figure 7-1), the air flows radially (that is, diverging from the center) through the impeller, which is mounted in a scroll-type housing. Centrifugal fans are further subdivided into a number of different types depending on several design variations, such as the forward or backward inclination of the blade.

An *axial-flow fan* is mounted within a cylinder or ring, and the air flows axially (that is, parallel to the main axis) through the impeller. Depending on the design of the enclosure and impeller, axial-flow fans can be subdivided into the following types:

1. Tubeaxial fans
2. Vaneaxial fans
3. Propeller fans

A *tubeaxial fan* consists of an axial-flow wheel within a cylinder (see Figure 7-2). These fans are available in a number of different types depending on the design and construction of the impeller blades.

A *vaneaxial fan* also consists of an axial-flow wheel but differs from a tubeaxial fan in that it uses a set of vanes to guide the airflow and increase efficiency (see Figure 7-3).

A *propeller fan* consists of a propeller or disc wheel within a ring casing or plate. These fans are by far the simplest in construction and operate best against low resistance (see Figure 7-4).

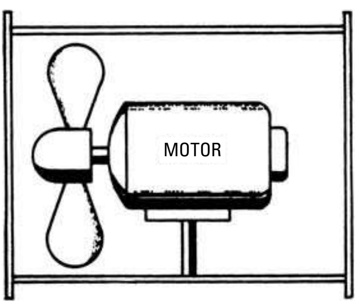


Figure 7-2 Tubeaxial fan principles.

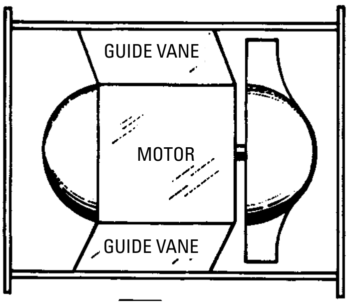


Figure 7-3 Vaneaxial fan principles.

Furnace Blowers

The blower used in a forced warm-air furnace is similar to the centrifugal fan used in ducts and other types of applications. Most blowers are designed with a belt drive, although some are equipped with a direct drive to the motor. Furnace blowers are described in considerable detail in the several chapters dealing with specific types of furnaces. See, for example, Chapter 11 of Volume 1 ("Gas-Fired Furnaces").

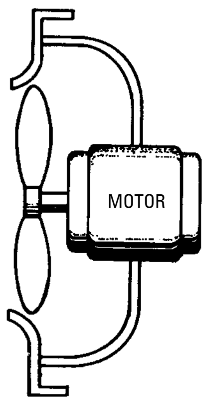


Figure 7-4 Propeller fan.

Basic Fan Laws

The performance of fans and their relationship to the ventilation system are governed by definite principles of fluid dynamics. An understanding of these principles is useful to anyone designing a ventilation system because they make possible the prediction of effects resulting from altered operating conditions. The principles (and formulas) associated with fan and ventilation system engineering are referred to collectively as *basic fan laws*.

The basic fan laws used in calculating fan performance depend on the fact that the mechanical efficiency (ME) of a fan remains constant throughout its useful range of operating speeds (that is, the fan rpm). They also apply only to fans that are geometrically similar.

A current edition of the *ASHRAE Guide* will contain detailed explanations of the principles and formulas associated with basic fan laws. A typical example is the production of fan speed (rpm), static pressure (SP), and horsepower when the volume of air moved by the fan is varied. The following three principles and formulas are involved:

1. Fan speed delivery will vary directly as the cfm ratio:

$$\text{New RPM} = \text{Old RPM} \times \left[\frac{\text{New CFM}}{\text{Old CFM}}\right]$$

2. Fan (and system) pressures will vary directly as the square of the rpm ratio:

$$\text{New SP (or TP or VP)} = \left[\frac{\text{New RPM}}{\text{Old RPM}}\right]^2 \times \text{Old SP (or TP or VP)}$$

3. Brake horsepower (bhp) on the fan motor (or air horsepower of the fan) will vary directly as the cube of the rpm ratio:

$$\text{New BHP (or AHP)} = \left[\frac{\text{New RPM}}{\text{Old RPM}}\right]^3 \times \text{Old BHP (or AHP)}$$

Example

A centrifugal fan delivers 10,000 cfm at a static pressure of 1.0 inch when operating at a speed of 600 rpm and requires an input of 3 hp. If 12,000 cfm is desired in the same installation, what will be the new fan speed (rpm), static pressure (SP), and horsepower (bhp) input? The three aforementioned formulas can be applied as follows:

$$1.\ \text{New RPM} = 600 \times \left[\frac{12{,}000}{10{,}000}\right]$$

$$= 600 \times 1.2 = 720$$

$$2.\ \text{New SP} = \left[\frac{720}{600}\right]^2 \times 1$$

$$= 1.44 \times 1 = 1.44$$

$$3.\ \text{New BHP} = \left[\frac{720}{600}\right]^3 \times 3$$

$$= 1.7 \times 3 = 5.1$$

The following three formulas also may prove useful in making fan calculations:

1. A (area) $\times$ V (velocity) $=$ CFM
2. CFM $\div V = A$
3. CFM $\div A = V$

Series and Parallel Fan Operation

Two separate and independent fans can be operated either in series or in parallel (see Figure 7-5). When two fans are operated in series, the cfm is *not* doubled. Instead, the total airflow is limited to the cfm capacity of one fan alone. Series operation is seldom desirable except when it is necessary to maintain the following conditions:

1. Constant pressure
2. Zero pressure
3. Constant vacuum

When fans are operated in parallel, they produce a total airflow equal to the sum of their individual cfm capacities. Parallel fan operation is necessary when a single fan is incapable of moving the total volume of air required or when airflow distribution is a factor.

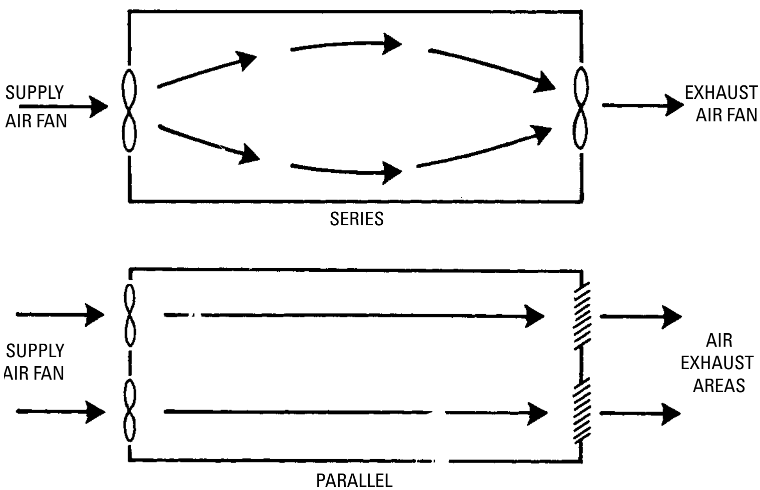


Figure 7-5 Series and parallel fan operations.

Fan Performance Curves

Fan performance curves are provided by fan manufacturers to graphically illustrate the relationship of total pressure, static pressure, power input, mechanical efficiency, and static efficiency to actual volume for the desired range of volumes at constant speed and air density. A typical performance curve for a forward-curved blade centrifugal fan is shown in Figure 7-6.

General Ventilation

General ventilation involves the moving of a volume of air from one space to an entirely separate space, where concern for a concentrated source of heat or contamination is not a factor. In this respect, it differs from *local ventilation*, which is used primarily to control atmospheric contamination or excessive heat at its source (see following section).

In general ventilation, the specific volume of air to be moved is measured in cubic feet per minute (cfm). The two principal methods of determining the required cfm are as follows:

1. Air-change method
2. Heat removal method

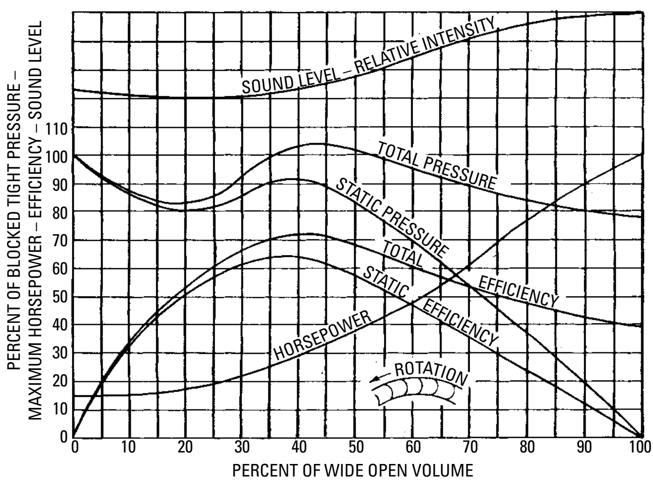


Figure 7-6 Typical performance curves for a forward-curved blade centrifugal fan.

Determining CFM by the Air-Change Method

In order to determine the required cfm for a structure of space by the air-change method, the following data are necessary:

1. The total cubic feet of air space in the structure or space.
2. The required number of air changes necessary to give satisfactory ventilation.

The total cubic feet of air space is easily determined by multiplying the dimensions of the structure of space. For example, a room 12 feet long and 10 feet wide with an 8-foot ceiling would have 960 cubic feet of air space (12 ft × 10 ft × 8 ft = 960 ft^3).

The required number of air changes necessary to give satisfactory ventilation will depend on a variety of factors, including (1) use, (2) number of people, (3) geographic location, and (4) height of ceiling.

Usually local health department codes will specify the required number of air changes for various installations. When there are no code requirements, the data given in Table 7-1 are recommended.

Once the necessary data have been obtained, the following formula can be used to determine the cfm:

$$\text{CFM} = \frac{\text{Building Volume in Cubic Feet}}{\text{Minutes Air Change}}$$

Let's use the space shown in Figure 7-7 to illustrate how the air-change method is used to determine cfm. First, let's assume that the space is being used as a bakery. In Table 7-1 you will note that a 2- to 3-minute air-change range is recommended for a bakery. The fact that a range is given is important because the number selected for the air-change method will depend on several variables. For example, a

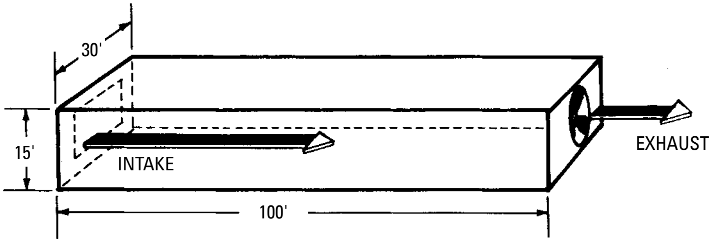


Figure 7-7 Bakery building dimensions.

Table 7-1 Average Air Changes Required per Minute for Good Ventilation

	Minutes per Change
Assembly halls	2–10
Auditoriums	2–10
Bakeries	2–3
Banks	3–10
Barns	10–20
Bars	2–5
Beauty parlors	2–5
Boiler rooms	1–5
Bowling alleys	2–10
Churches	5–10
Clubs	2–10
Dairies	2–5
Dance halls	2–10
Dining rooms	3–10
Dry cleaners	1–5
Engine rooms	1–3
Factories	2–5
Forge shops	2–5
Foundries	1–5
Garages	2–10
Generator rooms	2–5
Gymnasiums	2–10
Kitchens, hospitals	2–5
Kitchens, resident	2–5
Kitchens, restaurant	1–3
Laboratories	1–5
Laundries	1–3
Markets	2–10
Offices	2–10
Packing houses	2–5
Plating rooms	1–5
Pool rooms	2–5
Projection rooms	1–3
Recreation rooms	2–10
Residences	2–5

(continued)

Table 7-1 (continued)

	Minutes per Change
Sales rooms	2–10
Theaters	2–8
Toilets	2–5
Transformer rooms	1–5
Warehouses	2–10

higher number is used when the structure or space is located in a warm climate, when the ceiling is a particularly low one, or when there are a large number of people using a relatively small space. Comfort cooling, on the other hand, may be obtained by using the lowest figure in each stated range.

For the sake of our example, let's assume that the bakery has *not* been designed for comfort cooling. Furthermore, the ceilings are higher than average (15 feet), and the structure is located in a warm climate. With this information, the cfm can be determined in the following manner:

1. 100 ft. × 30 ft. × = 45,000 cu. ft. of air space (Fig. 7-7).
2. 3-minute required air change (Table 7-1).
3. $\text{CFM} = \dfrac{45{,}000}{3} = 15{,}000$

Thus, 15,000 cfm are required to change the air in the bakery every 3 minutes. Assuming a 300 fpm intake velocity, 50 square feet of free air intake are needed.

Determining CFM by the Heat Removal Method

The heat removal method is useful for determining cfm in installations where the ventilation of sensible heat is required.

In order to determine cfm by this method, you need to know the total Btu per minute, the average outdoor temperature, and the desired inside temperature. This information is then used in the following formula:

$$\text{CFM} = \frac{\text{Total Btu per minute}}{0.0175 \times \text{Temp. Rise °F}}$$

Note that the cfm determined by the heat removal method deals primarily with sensible heat, not with radiant heat. The cfm obtained from the previous formula indicates the amount of air that needs to be passed through a structure or space in order to maintain the desired inside temperature.

Determining Air Intake

Adequate air intake area should be provided where fans are used to exhaust the air. The same holds true for fans used to *supply* air to a room (that is, adequate air exhaust area should be provided). The size of the air intake (or air exhaust) area depends on the velocity (fpm) of the entering or existing air and the total cfm required by the structure or space. This may be expressed by the following formula:

$$A = \frac{\text{CFM}}{\text{FPM}}$$

where A = square feet of free intake (or exhaust) area
cfm = cubic feet per minute
fpm = feet per minute

The bakery previously described requires 15,000 cfm. Assuming a 300-fpm intake velocity, 50 square feet of free air intake area are required.

$$\text{Area} = \frac{15{,}000 \text{ CFM}}{300 \text{ FPM}} = 50$$

Doors and windows are suitable air intake areas if they are located close enough to the floor and provide a full sweep through the area to be ventilated. When you have determined the total free air intake area by the aforementioned formula, *deduct* the area for doors and windows that function as passageways for air. Fixed or adjustable louvers can be installed over the other intake areas.

Screen Efficiency

It is frequently necessary to cover an air intake (or exhaust) area with a bird or insect screen. These screens reduce the free intake area, but the amount of the reduction will depend on the type of screen used. In Figure 7-8, the net (effective) free area for each of three screens is shown as a percentage. The small holes required by an insect screen reduce the net free area to approximately 50 percent. The ½-inch mesh screen, on the other hand, provides a net free area of 90 percent.

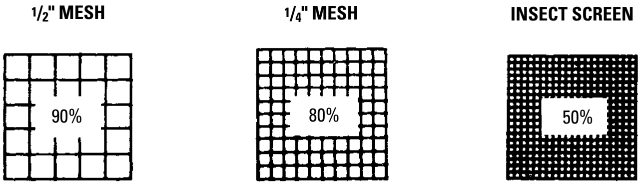


Figure 7-8 Net free air of various screens.

The reduction of the free intake area by screens can be compensated for by using a larger overall area.

Static Pressure

The *static pressure* of a fan may be defined as the total pressure diminished by the fan velocity pressure.

Calculating the total external static pressure of a system is important to the selection of a fan or blower because it must be capable of handling the required volume of air (in terms of cfm) against this pressure.

The total external static pressure is determined by adding the static pressures of any of the air-handling components in a system capable of offering resistance to the flow of air. A 10 percent allowance of the sum of these static pressures is added to obtain the total external static pressure.

The static pressures (that is, friction losses in inches of water) used in determining the *total* external static pressure of an air-handling system will include the following:

1. Entrance loss
2. Friction loss through filters
3. Friction loss through tempering coils
4. Friction loss through air washer
5. Duct system resistance
6. Supply grille resistance

Most friction losses can be obtained from data tables provided by manufacturers; however, duct loss is based on the longest run of duct, and this will vary from one installation to another.

In determining the length of duct, start at the point where the air enters the system and include all ducts in the main supply duct to the end of the system. An example of this type of calculation is shown in Table 7-2. The sum (406 ft) is then multiplied by the

Table 7-2 Total Length of Duct for an Installation

	Equivalent Length of Straight Duct (ft)
1 gooseneck at roof (double elbow 18″ × 63″)	39
28 feet straight duct to basement	28
1 elbow (18″ × 63″) to transition piece	20
40 feet straight duct	40
1 elbow (63″ × 18″)	68
60 feet straight duct	60
1 elbow (63″ × 18″)	68
15 feet straight duct	15
1 elbow (63″ × 18″)	68
	406

resistance for the ducts. For example, if the resistance is found to be 0.1 inch per 100 feet, the static pressure for the *total* run of duct will be 0.406 inch (that is, 406 ft ÷ 100 ft = 4.06 ft × 0.1 in = 0.406 in).

Local Ventilation

Local ventilation is used to control atmospheric contamination or excessive heat at its source with a minimum of airflow and power consumption. It is *not* used to move a volume of air from one space to another for human comfort.

Air velocity is an important factor in local ventilation. Air must move fast enough past the contaminant source to capture fumes, grease, dust, paint spray, and other materials and carry them into an exhaust hood.

Both the capture velocity of the air at the contaminant source and the velocity at the discharge duct must be considered when designing a localized ventilation system. It is important to remember that capture velocities will differ depending on the contaminant. Table 7-3 lists the capture velocities for contaminants found in a variety of booths (that is, enclosures designed to isolate areas used for special purposes).

The selection of a suitable fan for a local ventilation system requires knowledge of the required fan cfm capacity and the static pressure (SP) at which the fan must work. Once these facts are known, you have all the necessary information required for sizing the fan from the manufacturer's rating tables.

Table 7-3 Capture Velocities for Various Types of Booths

Process	***Type of Hood***	***Capture Velocity (fpm)***
Aluminum furnace	Enclosed hood, open one side	150–200
	Canopy or island hood	200–250
Brass furnace	Enclosed hood, open one side	200–250
	Canopy hood	250–300
Chemical lab	Enclosed hood, front opening	100–150
Degreasing	Canopy hood	150
	Slotted sides, 2″–4″ slots	1500–2000
Electric welding	Open front booth	100–150
	Portable hood, open face	200–250
Foundry shakeout	Open front booth	150–200
Kitchen ranges	Canopy hoods	125–150
Paint spraying	Open front booth	100–175
Paper-drying machine	Canopy hood	250–300
Pickling tanks	Canopy hood	200–250
Plating tanks	Canopy hood	225–250
	Slotted sides	250 cfm per foot of tank surface
Steam tanks	Canopy hood	125–175
Soldering booth	Enclosed booth, open one side	150–200

Courtesy Hayes-Albion Corporation

The required fan cfm capacity is determined by multiplying the open face area of any booth by the capture (face) velocity (fpm) of the air at the source of contamination.

$$\text{CFM} = \text{Face Area (sq. ft.)} \times \text{Face Velocity (FPM)}$$

The total open face area of any booth is determined by its physical size and the required access to the work area. If a booth is designed with several open face areas, all of them must be calculated and added together.

Capture (face) velocities (fpm) can be determined for various types of booths from data available from manufacturers and other sources. An example of such data is illustrated in Table 7-3.

The precise calculation of static pressure (SP) is not necessary for the sizing of a fan (or fans) in a local ventilation installation. An approximate calculation of static pressure will usually suffice, and the following steps are suggested for making such a calculation:

1. Assume the losses in the exhaust hood itself to be 0.05 inch to 0.10 inch SP.
2. Size the cross-sectional area of the main duct to ensure 1400-2000 fpm velocity.

$$\text{Duct Area (sq. ft.)} = \frac{\text{CFM}}{\text{FPM}}$$

3. Keep all ductwork as short and straight as possible and avoid elbows and sharp turns (see Figure 7-9).
4. Determine the total straight duct length.
5. Add the equivalent straight duct length for each turn (see Table 7-4), and add it to step 4.
6. Multiply the sum of steps 4 and 5 by 0.0025 inch to determine an approximate static pressure for the ductwork.
7. The static pressure for filters usually can be obtained from the filter manufacturer. If this is not possible, assume 0.25 inch SP for clean filters and 0.50 inch for dirty filters.

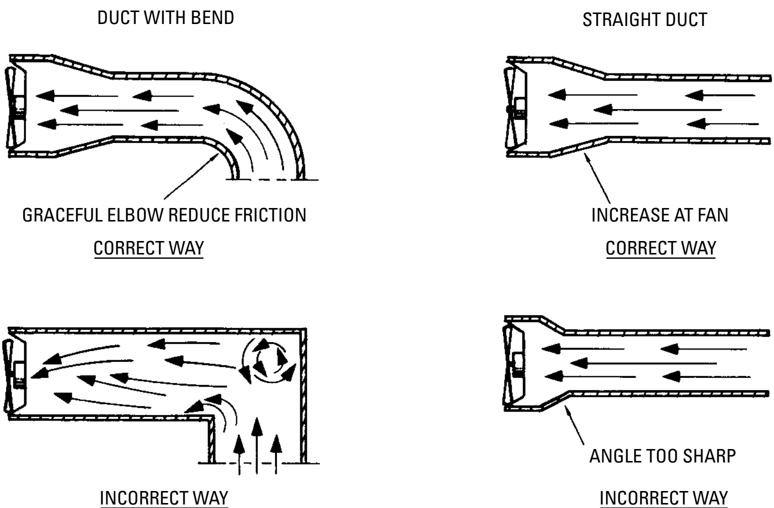
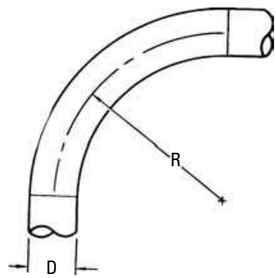


Figure 7-9 Various designs to avoid when designing a duct system.

Table 7-4 Equivalent Lengths of Straight Pipe

	90° Elbow* Centerline Radius		
Dia. of Pipe	***1.5 D***	***2.0 D***	***2.5 D***
3″	5	3	3
4″	6	4	4
5″	9	6	5
6″	12	7	6
7″	13	9	7
8″	15	10	8
10″	20	14	11
12″	25	17	14
14″	30	21	17
16″	30	24	20
18″	41	28	23
20″	46	32	26
24″	57	40	32
30″	74	51	41
36″	93	64	52
40″	105	72	59
48″	130	89	73



**For 60° elbows-x.67; for 45° elbows-x.5.*
(Courtesy Hayes-Albion Corporation)

8. Add the static pressures from steps 1, 6, and 7 to obtain the approximate total static pressure for the installation.
9. Use the total static pressure for the installation and the required cfm capacity for sizing the fan.

Caution

Always check local building and safety codes for regulations pertaining to hazardous conditions. For extremely critical installations, such as those dealing with acids, poisons, or toxic fumes, consult the fan manufacturer for engineering analysis. It is *strongly* recommended that you do not attempt to make these calculations yourself. Finally, *never* undersize a fan. If you have any doubts about the correct size or horsepower, then select the next size larger.

Exhaust-Hood Design Recommendations

A properly designed exhaust hood (see Figure 7-10) is an important part of a local ventilation system. The following recommendations are offered as design guidelines:

1. Use the shortest duct run possible.
2. Avoid the use of elbows and transitions.
3. Size the exhaust hood to provide a minimum 100 fpm face velocity (150 fpm for island-type work).
4. Provide sufficient hood overhang on all sides to overlap work area.
5. Use more than one exhaust fan on very large hoods.
6. Use as many individual hood and duct systems as possible (that is, try to avoid grouping hoods together on the same duct system).
7. Use filters where required. Velocities over filters should be sized in accordance with filter manufacturer's recommendations.
8. Provide makeup air units.

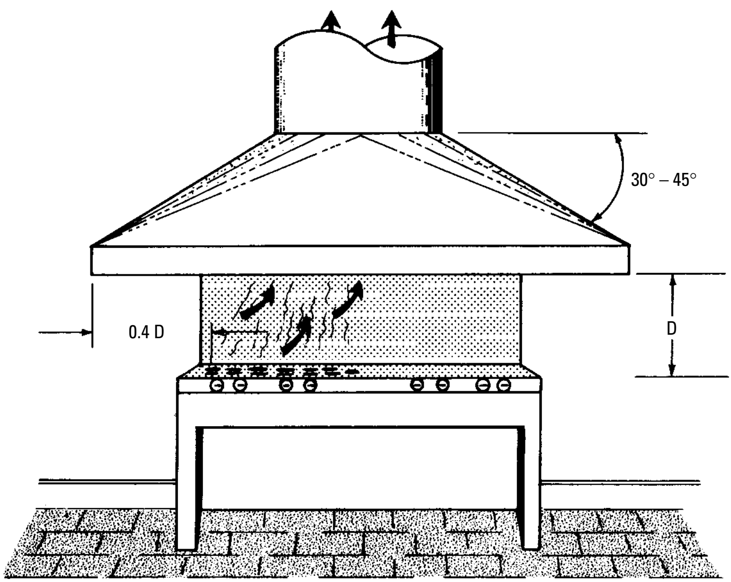


Figure 7-10 Recommended hood design. *(Courtesy Penn Ventilator Co., Inc.)*

Fan Motors

Most fans used in heating, ventilating, and air-conditioning installations are powered by electric motors. Because of the small size of many of these fans, the majority are equipped with direct-connected motors. A V-belt drive arrangement is used with larger fans, particularly centrifugal fans used in forced warm-air furnaces or the larger ventilating units found in commercial and industrial installations.

It is the general rule to select a fan one size larger than the fan requirements for the installation. This is particularly so in installations that may require the movement of large volumes of air for short intervals.

The advantage of fans equipped with a belt-drive arrangement is that adjustments can be made for different speeds. It is simply a matter of changing the pulley size. A belt drive is especially desirable when the required horsepower requirement is in doubt.

A fan wheel directly connected to the motor shaft is the best arrangement, but this is only feasible with the smaller centrifugal fans and propeller fans under 60 inches in diameter.

A direct-connected fan is generally driven by a single-phase AC motor of the split-phase, capacitor, or shaded-pole type. The capacitor motor is recommended when there are current limitations. Its major advantage is its greater efficiency electrically. The major disadvantage of such motors is that they are usually designed to operate at only one speed. A damper arrangement can be used to throttle the air when it becomes necessary to vary the air volume or pressure of the fan.

The variation of pressure and air volume in larger fan installations (for example, mechanical draft fans) can be accomplished by means of a constant-speed, direct-connected motor equipped with movable guide vanes in the fan inlet.

The National Electrical Manufacturer's Association (NEMA) has recently revised motor voltage designations to conform to system voltages now present throughout the country. Single-phase motor voltages should now be specified as 115 volts or 230 volts instead of the 110-volt or 220-volt designations formerly in effect. Polyphase voltages should be expressed as 208 volts or 230/460 volts instead of the 220/440 voltages formerly in effect. Motors for special voltages such as 177, 480, or 575 volts are available from many fan manufacturers on special order. Fan motors have been designed to operate satisfactorily over the range of plus or minus 10 percent of the nameplate voltage ratings. *Always* check the fan motor nameplate voltage ratings before installing the motor.

Tables 7-5 and 7-6 list nominal full-load ampere ratings for single-phase and three-phase motor voltages. The amperes given are approximate values only and represent averages compiled from tables of leading motor manufacturers. Compare these with the specific amperages listed for Airmaster fans in Table 7-7.

Table 7-5 Nominal Full-Load Ampere Ratings for Single-Phase Motors

		Full-Load Current	
HP	***RPM***	***115 V***	***230 V***
1⁄25	1550	1.0	0.5
1⁄25	1050	1.0	0.5
1⁄12	1725	2.0	1.0
	1140	2.4	1.2
	860	3.2	1.6
1⁄10	1550	2.4	1.2
1⁄8	1725	2.8	1.4
	1140	3.4	1.7
	860	4.0	2.0
1⁄6	1725	3.2	1.6
	1140	3.84	1.92
	860	4.5	2.25
1⁄4	1725	4.6	2.3
	1140	6.15	3.07
	860	7.5	3.75
1⁄3	1725	5.2	2.6
	1140	6.25	3.13
	860	7.35	3.67
1⁄2	1725	7.4	3.7
	1140	9.15	4.57
	860	12.8	6.4
3⁄4	1725	10.2	5.1
	1140	12.5	6.25
	860	15.1	7.55
1	1725	13.0	6.5
	1140	15.1	7.55
	860	15.9	7.95

(Courtesy Penn Ventilator Company, Inc.)

Table 7-6 Nominal Full-Load Ampere Ratings for Three-Phase Motors

		Full-Load Current	
HP	***RPM***	***115 V***	***230 V***
	1725	0.95	0.48
1/4	1140	1.4	0.7
	860	1.6	0.8
	1725	1.19	0.6
1/3	1140	1.59	0.8
	860	1.8	0.9
	1725	1.72	0.86
1/2	1140	2.15	1.08
	860	2.38	1.19
	1725	2.46	1.23
3/4	1140	2.92	1.46
	860	3.26	1.63
	1725	3.19	1.6
1	1140	3.7	1.85
	860	4.12	2.06
	1725	4.61	2.31
1 1/2	1140	5.18	2.59
	860	5.75	2.88
	1725	5.98	2.99
2	1140	6.50	3.25
	860	7.28	3.64
	1725	8.70	4.35
3	1140	9.25	4.62
	860	10.3	5.15
	1725	14.0	7.0
5	1140	14.6	7.3
	860	16.2	8.1
	1725	20.3	10.2
7 1/2	1140	20.9	10.5
	860	23.0	11.5

(Courtesy Penn Ventilator Company, Inc.)

Table 7-7 Ampere Rating Table for Airmaster Fans

	RPM	*3-Phase, 60 Cycle AC*			*Single-Phase AC*	
HP	***Syn. Speed***	***220 Volts***	***440 Volts***	***550 Volts***	***110 Volts***	***220 Volts***
1/30	1050	—	—	—	1.90	—
1/25	1050	—	—	—	2.00	—
1/20	1550	—	—	—	2.30	—
	1140	—	—	—	2.40	—
	1050	—	—	—	3.10	—
1/15	1550	—	—	—	3.20	—
1/12	1550	—	—	—	3.80	—
	860	—	—	—	2.80	—
1/8	1800	—	—	—	2.80	1.40
	1200	—	—	—	3.40	1.70
	860	—	—	—	5.40	2.70
1/6	1800	—	—	—	3.00	1.50
	1200	—	—	—	3.60	1.80
	860	—	—	—	5.60	2.80
1/4	1800	0.96	0.48	0.38	4.12	2.06
	1200	1.16	0.58	0.46	5.50	2.75
	900	1.45	0.73	0.58	6.50	3.25
1/3	1800	1.16	0.58	0.47	5.00	2.50
	1200	1.43	0.72	0.58	6.00	3.00
	900	1.75	0.88	0.71	8.40	4.20
1/2	1800	1.68	0.84	0.67	7.16	3.58
	1200	2.07	1.04	0.83	10.00	5.02
	900	2.90	1.45	1.16	—	—
3/4	1800	2.33	1.17	0.93	9.86	4.94
	1200	2.85	1.43	1.14	11.90	5.96
	900	3.45	1.73	1.38	—	—
1	1800	3.05	1.53	1.22	10.60	5.28
	1200	3.54	1.77	1.42	12.30	6.12
	900	3.74	1.87	1.50	12.90	6.48
1 1/2	1800	4.28	2.14	1.71	14.80	7.40
	1200	4.85	2.43	1.94	16.80	8.40
	900	5.81	2.91	2.32	20.00	10.10
2	1800	5.76	2.88	2.30	20.00	10.00
	1200	6.35	3.18	2.54	22.00	11.00
	900	7.21	3.61	2.88	25.00	12.50

(continued)

Table 7-7 (continued)

	RPM	3-Phase, 60 Cycle AC			Single-Phase AC	
HP	**Syn. Speed**	**220 Volts**	**440 Volts**	**550 Volts**	**110 Volts**	**220 Volts**
	900	7.21	3.61	2.88	25.00	12.50
3	1800	8.29	4.14	3.32	28.80	14.30
	1200	8.92	4.46	3.56	30.80	15.40
	900	10.20	5.09	4.08	35.40	17.60
5	1800	13.20	6.60	5.28	45.60	22.80
	1200	13.10	7.05	5.64	48.80	24.40
	900	15.60	7.80	6.24	54.00	27.00
7½	1800	19.30	9.70	7.72	67.00	33.40
	1200	20.30	10.20	8.12	70.20	35.20
	900	23.80	11.90	9.51	82.40	41.20

(Courtesy Hayes-Albion Corporation)

Overload relay heaters should not be selected solely on the basis of the data listed in Tables 7-5 and 7-6. Heaters must be selected in accordance with the actual motor current as shown on the nameplate. It is also important that ambient temperatures of the area in which the motor control is located be taken into consideration when making heater selections. Ambient compensated overload relays are available for abnormal temperature conditions.

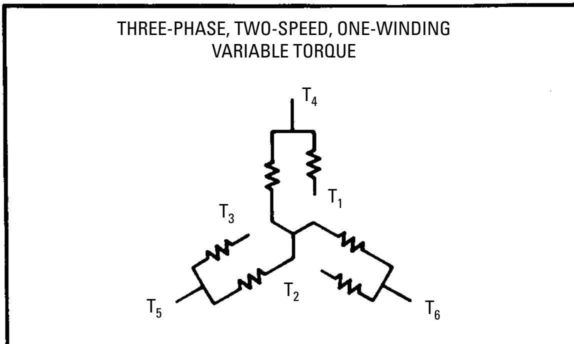
Typical connection diagrams for two-speed, three-phase motors are illustrated in Figures 7-11 and 7-12. Two-speed motors are available for most fan lines. Because *all* two-speed motors are always single-voltage, it is necessary to specify the available line voltage phase and frequency when ordering.

Examples of fans equipped with the belt-drive arrangement and direct-connected motors are shown in Figures 7-13 and 7-14.

Troubleshooting Fans

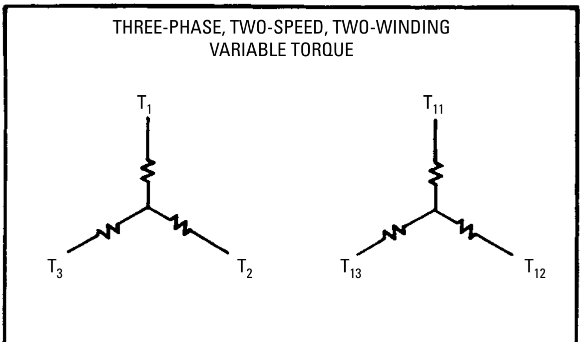
Fan motors are electrically powered (see Table 7-8). Always turn off the electricity before attempting to service or repair a fan. Failure to do so could result in serious injury or even death because high voltages are involved. Electrical tests on fan motors should be done by a qualified electrician.

Fan motors mounted in the airstream are cooled by a portion of the air drawn around them. This acts to hold motor temperatures



SPEED	L_1	L_2	L_3	OPEN	TOGETHER
LOW	T_1	T_2	T_3	ALL OTHERS	
HIGH	T_6	T_4	T_5		T_1, T_2, T_3

Figure 7-11 Connection diagram for three-phase, two-speed, one-winding variable-torque motors. *(Courtesy Penn Ventilator Co., Inc.)*



SPEED	L_1	L_2	L_3	OPEN
LOW	T_1	T_2	T_3	T_{11}, T_{12}, T_{13}
HIGH	T_{11}	T_{12}	T_{13}	T_1, T_2, T_3

Figure 7-12 Connection diagram for three-phase, two-speed, two-winding variable-torque motors. *(Courtesy Penn Ventilator Co., Inc.)*

down and makes it possible for the motor to run continuously at substantial brake horsepower (bhp) overloads without exceeding its rated temperature rise.

The actual brake horsepower load has little relation to its nameplate horsepower as long as it remains at or below its rated maximum

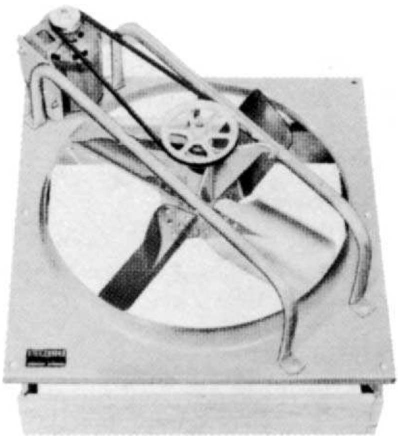


Figure 7-13 Belt-driven propeller fan assembly.
(Courtesy Hayes-Albion Corp.)

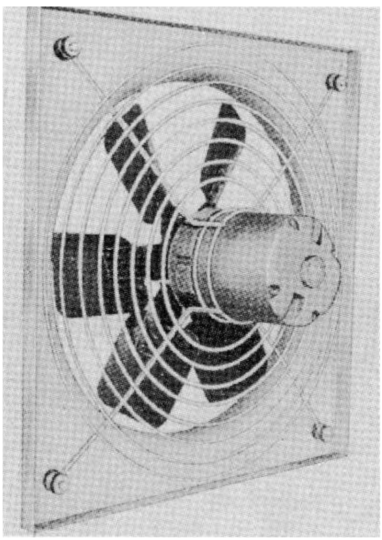


Figure 7-14 Fan with direct-connected motor.
(Courtesy Penn Ventilator Co., Inc.)

temperatures. It is *temperature rise* that is crucial to the breakdown or burning out of a fan motor (even though it may be physically underloaded).

A fan motor will normally run at a temperature too hot to hold a hand against it, but this will still be at or below the manufacturer's temperature rise limit as stated on the nameplate. When a fan motor

Table 7-8 Fan Maintenance and Troubleshooting

Symptom and Possible Cause	***Possible Remedy***
Fan motor hums but blades do not rotate.	
(a) Motor overheated from thermal overload.	(a) Turn off fan and wait 20 minutes. If motor is not defective, it will restart after cooling off.
(b) Defective motor.	(b) Turn off electricity and check motor starting capacitor.
Fan motor will not start.	
(a) Fan unplugged at attic outlet.	(a) Plug fan into outlet.
(b) Blown fuse or tripped circuit breaker.	(b) Replace fuse or reset circuit breaker. Call electrician if problem continues.
(c) Thermostat set too low.	(c) Turn thermostat to higher setting.
(d) Defective fan motor starting capacitor.	(d) Test and replace if necessary.
(e) Defective fan motor.	(e) Replace fan motor.
Noisy fan.	
(a) Loose fan blade.	(a) Tighten connection or replace.
(b) Loose fan motor mounting.	(b) Tighten.
(c) Unbalanced fan blade.	(c) Tighten if loose connection, replace if defective, or clean if dirt accumulation on one blade is causing imbalance.
(d) Defective motor bearing.	(d) Repair or replace motor.
(e) Not insulated against vibration.	(e) Insert foam or rubber pad between fan motor and structure surface.
(f) Motor bearing needs lubrication.	(f) Lubricate motor bearings.

does overheat or burn out, it is usually for one of the following reasons:

1. Defective motor.
2. Line voltage too high or too low for the rated motor voltage (more than plus or minus 10 percent voltage deviation is considered excessive).

3. The belts on belt-driven fans may be too tight or too loose, causing slippage and consequent loss of the cooling effect of air passing around the motor.
4. Improper pulleys on belt-driven fans will result in too high a fan rpm, which causes overloading.
5. Backward- and forward-curved wheel centrifugal fans or roof ventilators running backward will guarantee an overload condition. Remember that all centrifugal fans blow in one direction only, regardless of rotation; propeller fans that run backward blow backward.
6. Propeller fans may be starved for air as a result of insufficient intake (or outlet) area. The fans are literally starved for air, which causes the static pressure to rise and the brake horsepower load on the motor to increase. The air that flows around the motor is also reduced, causing the motor to overheat. Attic fans are frequently damaged as a result of inadequate outlet area.

Fan Selection

The following information is generally required for the selection of a suitable fan:

1. Volume of air required (cfm)
2. Static pressure (SP)
3. Type of application or service
4. Maximum tolerable noise level
5. Nature of load and available drive
6. Ambient and airstream temperature
7. Mounting arrangement of the system
8. Available line voltage

The *volume of air required* refers to the volume of air that must be moved by the fan to meet the needs of the building or space. It is expressed in cubic feet per minute and is determined by dividing the total cubic feet of air space by the required number of air changes necessary to give proper ventilation.

The *static pressure* of a fan may be defined as the total pressure diminished by the fan velocity. In other words, it is the resistance offered by the system (ducts, air intakes, and so on) to the flow of air. After the duct sizes have been determined, it is necessary to calculate the static pressure of the system so that the proper fan can be selected which will handle the desired volume of air (that is, the required cfm) against the static pressure of the system. The various fan manufacturers provide tables indicating the operating characteristics of various-size fans against a wide range of static pressures. These tables list static pressures for different sizes of various fans.

The *type of application* (or service) is often an important consideration in what kind of fan is used in an installation. For example, a duct system will offer sufficient resistance to require a centrifugal, tubeaxial, or vaneaxial fan. A propeller fan is usually recommended for an installation without a duct system. Other factors, such as the volume of air that must be moved, the allowable noise level, the air temperature, use for general or local ventilation, and cost, are also important considerations in fan selection.

The *maximum tolerable noise level* is the highest acceptable noise level associated with air exchange equipment. The fan should be of suitable size and capacity to obtain a reasonable operating speed without overworking.

The *nature of load and available drive* is an important factor in controlling the noise level. High-speed motors are usually quieter than low-speed ones. Either belt- or direct-drive units are used in fan installations, and a high-speed motor connected to the fan with a V-belt offers the quietest operation.

The dry-bulb temperature of either ambient air or exhaust-stream air (*ambient or airstream temperature*) is a determining factor in selecting a suitable fan. Most fans operate satisfactorily at temperatures up to about 104°F (40°C). Special fans that can operate at higher temperatures are also available. For example, standard belt-driven tubeaxial fans are usable for temperatures up to 200°F (where the motor is out of the airstream).

The *mounting arrangement of the system* is directly determined by the application or service of the fan. Certain types of fans will prove to be more suitable than others, depending on the kind of installation. Fan manufacturers often offer useful recommendations for mounting arrangements.

The *available line voltage* will determine the size and type of fan motor most suitable for the installation. Motor voltage designations conform to the following system of voltages now used throughout the country: 115 volts, 230 volts, and 460 volts. Motors for special voltages (that is, 117, 480, or 575 volts) are available on special order.

Fan manufacturers provide information and assistance in selecting the most suitable fan or fans for your installation. Remember that ventilation requirements vary under different climatic conditions, and it is impossible to provide exact rules for determining the

Table 7.9 Minimum Fan Capacity (CFM) for Various Sections of the Country

Approx. Volume of House (ft^3)		*Minimum Fan Capacity Needed For Satisfactory Results (CFM)*							
		North			***Central***			***South***	
3000		1000			2000		24″	3000	
4000		1320			2640			4000	
5000		1650			3300			5000	30″
6000		2000		24″	4000			6000	
7000		2310			4620	30″		7000	
8000		2540			5280		36′	8000	
9000		3000			6000			9000	
10,000		3330			6660			10,000	42″
11,000		3630			7260			11,000	
12,000	24″	4000		36″	8000			12,000	
13,000		4290			8580		48″	13,000	
14,000		4620	30″		9240			14,000	
15,000		5000			10,000	42″		15,000	
16,000		5280			10,560			16,000	
17,000		5610			11,220			17,000	
18,000		6000			12,000			18,000	
19,000		6270			12,540			19,000	
20,000		6660			13,320			20,000	
21,000		7000			14,000			21,000	
22,000		7260			14,520			22,000	

(Courtesy Hayes-Albion Corporation)

variables of local climate and topography (see Table 7-9). Allowances must be made for these climatic variables.

The following suggestions are offered only as a general guide to the selection of a fan and should not be construed as applying in every situation.

1. Use a ½ hp, ⅓ hp, or ¼ hp 860-rpm direct-drive fan on three-phase motor voltages whenever possible to eliminate the possibility of single-phase magnetic hum.
2. A belt-driven fan is less expensive, less noisy, more flexible, and more adaptable to capacity change than the direct-drive type.

3. Prolonged motor life can be expected of direct-driven fans using other than shaded-pole motors. For that reason, 1550-rpm and 1050-rpm motors should be avoided when very heavy duty and/or extremely long motor life is required.
4. Use a propeller fan when operation offers little or no resistance, or when there is no duct system.
5. Use a centrifugal or axial-flow fan when a duct system is involved.
6. Never try to force air through ducts smaller than the area of the fan.

Fan Installation

The following recommendations are offered as guidelines for proper fan installation.

1. Install the fan and air intake openings at opposite ends of the enclosure so that the intake air passes lengthwise through the area being ventilated (see Figure 7-15).
2. When possible, install exhaust fans or air outlets on the leeward side so that the air leaves with the prevailing winds (see Figure 7-16).
3. When possible, install ventilation (supply) fans or air intakes on the windward side so that the entering air utilizes pressure produced by prevailing winds (see Figure 7-17).
4. Provide a net intake area *at least* 30 percent greater than the exhaust fan opening.
5. When filters are used, increase the net intake area to allow minimum pressure loss from resistance of the filter.
6. Steam, heat, or odors should be exhausted by fans using totally enclosed motors mounted near the ceiling. The air intakes should be located near the floor (see Figure 7-18).
7. An explosion-proof motor with a spark-proof fan should be used when the exhaust air is hazardous.
8. Spring-mount fans and connect them to the wall opening by a canvas boot when extremely quiet operation is required.

Fan Installation Checklist

A properly installed fan motor (unless defective) will operate efficiently and will never overheat or burn out. To ensure proper installation, the following guidelines are suggested:

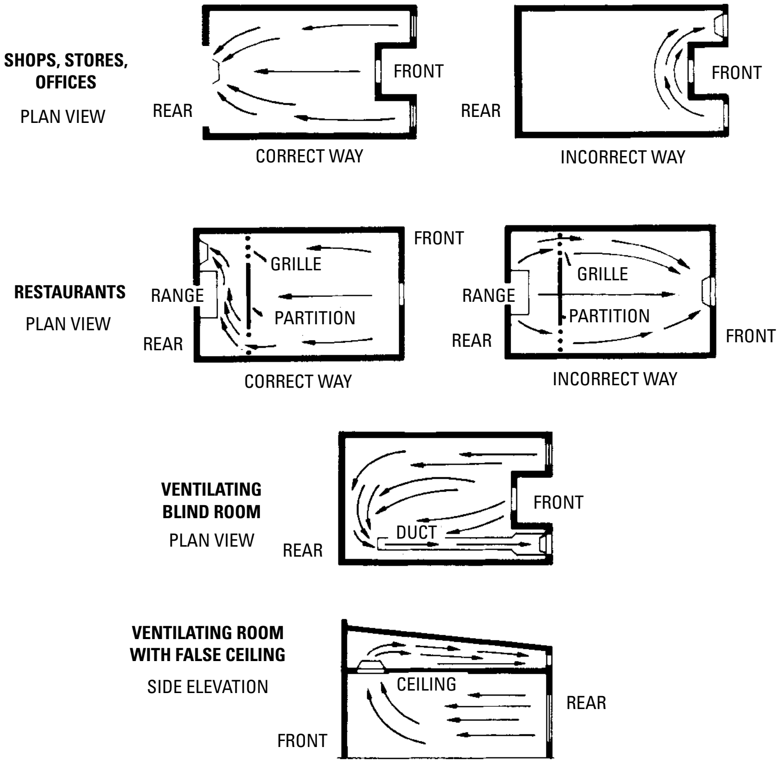


Figure 7-15 Locations of fans and air intake openings.
(Courtesy Hayes-Albion Corp.)

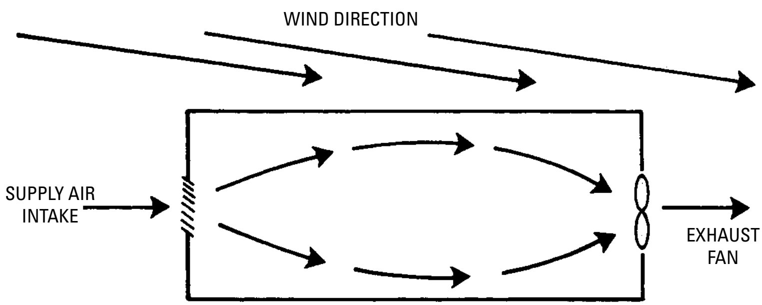


Figure 7-16 Exhaust fan installed on the leeward side, away from prevailing winds.

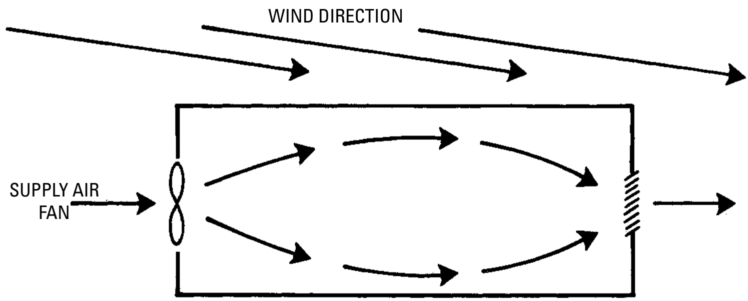


Figure 7-17 Supply air fan installed on the windward side, with the prevailing winds.

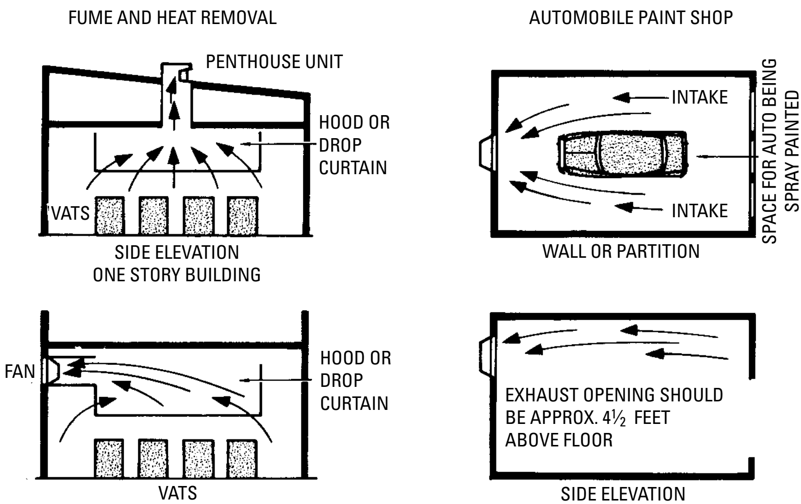


Figure 7-18 Recommended locations for exhaust openings.
(Courtesy Hayes-Albion Corp.)

1. Check the line current to be sure it is not more than plus or minus 10 percent voltage deviation.
2. Check belt tension for looseness after the first or second day of operation.
3. Check to be sure the fan is running in the right direction.
4. Inspect and lubricate fans subject to heavy usage. Do this after the first 15,000 hours or 5 years of service (whichever comes first).

5. Use open, drip-proof motors where fan motors are installed outside the airstream.
6. Use enclosed, nonventilated, air-over motors where fan motors are mounted in the airstream to reduce obstruction by dirt, grease, or other contaminants.

Air Volume Control

Sometimes it becomes necessary to vary the air volume handled by a fan. The following methods can be used for this purpose:

1. Dampers placed in the duct system.
2. Changing the pulley on the fan motor.
3. Changing the pulley on the fan.
4. Using variable-speed pulleys.
5. Using variable-speed motors.
6. Using variable inlet vanes on fans.
7. Reduction or increase of speed through power control.

Noise Control

In order to decrease the noise associated with the air exchange equipment, the following recommendations should be observed:

1. The equipment should be located a reasonable distance from important rooms.
2. The fans should be of proper size and capacity to obtain reasonable operating speed.
3. The equipment should be mounted on resilient bases made from a sound-dampening material.
4. When possible, the quieter high-speed AC motors with belt-driven fans should be used.

Fan Applications

Many different fans are used in ventilation and air-circulation systems, and these fans are classified on the basis of certain design and operating characteristics. Fan applications, on the other hand, are classified by the specific function they serve in the ventilation or air-circulation system. Among the numerous fan applications used for ventilation and air circulation are the following:

1. Attic fans
2. Exhaust fans

3. Circulating fans
4. Kitchen fans
5. Cooling tower fans
6. Unitary system fans

Attic fans are generally propeller types used during the summer to draw the cool night air through the structure and discharge it from the attic. The air can be discharged through windows or grilles or directly through an attic exhaust fan. The air is circulated, not conditioned.

Exhaust fans are used in local ventilation to remove contaminants at their source, or as a general means of discharging air from a space (for example, attic exhaust fans, wall fans, bathroom fans). Hood exhaust fans used with a duct system are generally centrifugal types. Because wall fans operate against very low resistance or no resistance at all, they are most commonly propeller types.

Circulating fans and *kitchen fans* are propeller types used for air circulation purposes. *Cooling tower fans* are also generally propeller types, although centrifugal fans have also been used in installations requiring a forced draft.

Unitary system fans are centrifugal or propeller fans used in unit ventilators, unit heaters, unit humidifiers, and similar types of equipment. A propeller fan is used in these units when no ductwork exists.

Attic Ventilating Fans

A noninsulated attic on a hot summer day will experience temperatures as high as 130°F to 150°F. This accumulated heat seeps down through the ceiling and raises the temperatures in the rooms below, making living and sleeping areas very uncomfortable. This hot air from an uninsulated attic also increases the load on the air conditioner, which will raise the energy costs during the summer months. After sunset, the outside temperature sinks to pleasant cool levels, but the indoor air (especially in the upstairs bedrooms of a two-story house) remains uncomfortably hot with temperature readings that can reach as high as 85°F. This condition results from the fact that a house loses accumulated heat at a very slow rate.

This condition can be alleviated considerably by installing an attic ventilating fan. Such a fan placed in the attic will cool the air by replacement; that is, it will ventilate rather than condition. An attic ventilating fan can reduce temperatures in the attic by as much as 20 to 30 percent, and by approximately 10 to 15 percent in the bedrooms immediately below the attic.

Attic ventilating fans are controlled by a thermostat located in the attic or in the fan housing. The thermostat turns the fan on at a preset temperature and shuts it off when the temperature is lowered to the minimum setting in the thermostat preset temperature range. Many attic fans are equipped with a firestat, which will shut off the fan if there is a fire in the house.

In areas where high humidity is a problem, the fan should be equipped with a humidistat to remove excess moisture from the attic during the winter months. Moisture accumulating in the attic will contribute to the formation of ice dams on the roof. Ice will also form on the rafter surfaces inside the attic, which may lead to rot and damage to the roof framing.

Because of the low static pressures involved (usually less than 0.125 inch), disc or propeller fans with the blade mounted directly on the motor shaft are generally recommended for attic installation. It is recommended that these fans have quiet operating characteristics and sufficient capacity to give at least 30 air changes per hour.

The two general types of attic fans in common use in houses and other buildings are the following:

1. Boxed-in fans
2. Centrifugal fans

The *boxed-in* attic fan is installed within the attic in a box or suitable housing, located directly over a ceiling grille or in a bulkhead enclosing an attic stair. This type of fan can be connected to individual room grilles by means of a duct system.

In operation, outside cool air entering through the windows in the downstairs rooms is discharged into the attic space and escapes to the outside through louvers, dormer windows, or screened openings under the eaves. A general arrangement showing a typical installation of this type of fan is illustrated in Figure 7-19.

The installation of a multiblade centrifugal attic fan is shown in Figure 7-20. At the inlet side, the fan is connected to exhaust ducts leading to grilles, which are placed in the ceiling of the two bedrooms. The air exchange is accomplished by admitting fresh air through open windows, moving it up through the suction side of the fan, and finally discharging it through louvers.

The fan shown in Figure 7-21 is of the centrifugal curved-blade type, mounted on a light angle-iron frame, which supports the fan wheel, shaft, and bearings, with the motor that supplies the motive power to the fan through a belt drive.

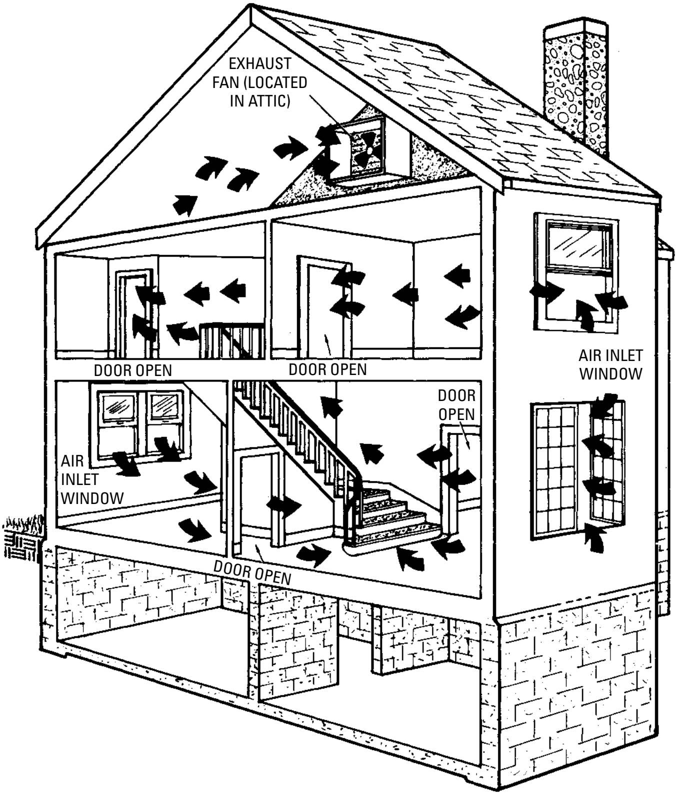


Figure 7-19 Attic ventilation system.

The air inlet in this installation is placed close to a circular opening that is cut in an airtight board partition, which serves to divide the attic space into a suction and discharge chamber. The air is admitted through open windows and doors and then drawn up the attic stairway through the fan into the discharge chamber, from which it flows through the attic open window.

For best results, the outlet area for an attic fan should be 1½ times the area of the fan. Satisfactory results will be obtained as long as the area is *at least* equal to the blade area of the fan. Recommended dimensions for attic fan exhaust outlets are given in Table 7-9.

Tables 7-10, 7-11, and 7-12 provide data for square- and triangular-type louvers used with various fan diameters. These tables

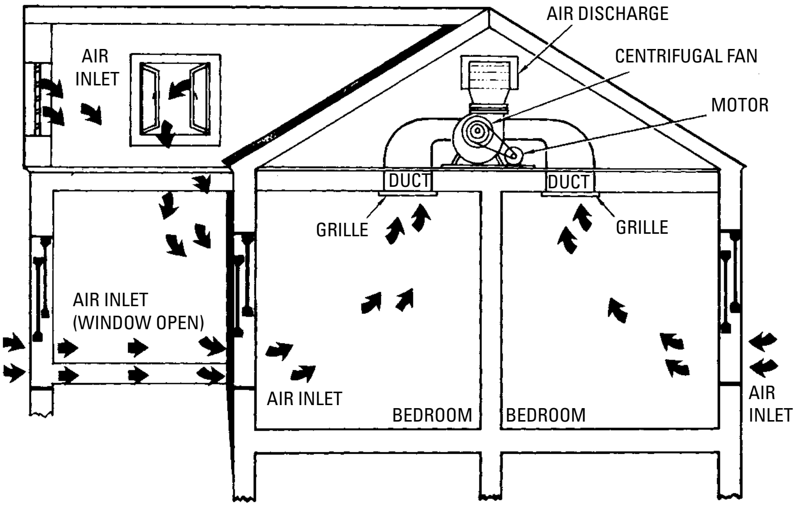


Figure 7-20 Multiblade centrifugal attic fan connected to exhaust ducts.

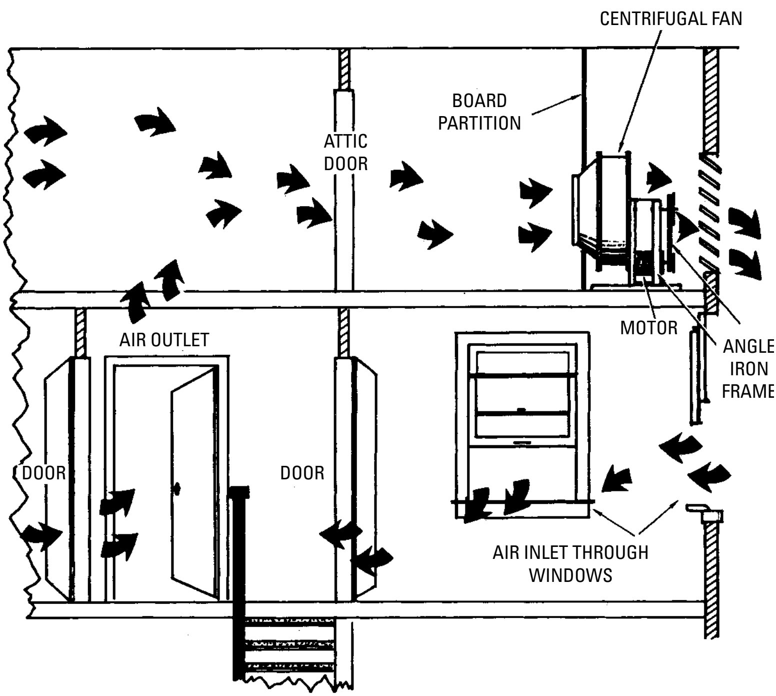


Figure 7-21 Centrifugal curved-blade fan.

Table 7-10 Recommended Dimensions for Attic Fan Exhaust Outlets

Recommended Dimensions of Attic Fan Exhaust Outlet		
Fan Diameter	***Air Delivery Range (cfm)***	****Free Outlet Area Needed (ft²)***
24″	3500/5000	4.70
30″	4500/8500	7.35
36″	8000/12000	10.06
42″	10000/15500	14.40
48″	12000/20000	18.85

**1.5 times fan area*
(Courtesy Hayes-Albion Corporation)

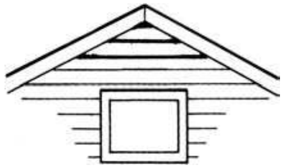
Table 7-11 Data for Square-Type Louvers

	Minimum Size of Square Outlet (inches)		
	Metal Shutters		***Wood Slats***
Fan Diameter	***Automatic (90% Open Area)***	***Fixed (70% Open Area)***	***Fixed (60% Open Area)***
24″	26 × 26	32 × 32	34 × 34
30″	32 × 32	39 × 39	42 × 42
36″	38 × 38	45 × 45	49 × 49
42″	44 × 44	54 × 54	60 × 60
48″	50 × 50	62 × 62	68 × 68

(Courtesy Hayes-Albion Corporation)

include the net free areas for 1-inch mesh wire screening. Remember that in order to keep insects and other foreign objects out of the attic, the exhaust air outlets should be covered with ½-inch or 1-inch wire mesh screen. The fan should be boxed-in on the intake side with conventional fly screening. This screening has

Table 7-12 Data for Triangular-Type Louvers



Fan Diameter	*Height of Triangular Louvers (for different roof pitches) 5/12 Pitch One Louver	6/12 Pitch One Louver	7/12 Pitch One Louver	8/12 Pitch One Louver
24″	2′0″	2′2″	2′4″	2′6″
30″	2′6″	2′9″	3′0″	3′3″
36″	3′0″	3′3″	3′6″	3′9″
42″	3′3″	3′9″	4′1″	4′4″
48″	3′10″	4′3″	4′7″	4′9″

**Heights given are for one triangular louvered opening only; when two openings are used, reduce heights by approximately 80%.*
(Courtesy Hayes-Albion Corp.)

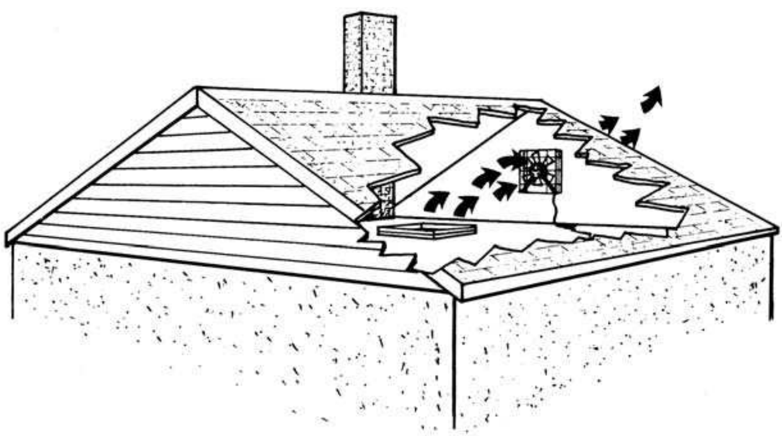


Figure 7-22 Fan mounted at the attic window with the ceiling opening in central hallway. *(Courtesy Hayes-Albion Corp.)*

only 50 percent free area; therefore, the boxing must have a total area twice that of the inlet opening.

The location of the attic fan always depends on the design of the structure. In a house having a suitably sized window in an attic end wall or dormer, the best results (and fewest construction problems) can usually be obtained by mounting the fan directly against the window (see Figure 7-22). An automatic shutter should be installed outside the window for window-mounted fans. If the window is opened and the fan is mounted inside the opening, louvers should be installed a few inches in front of the fan to keep rain out of the attic.

In one-floor houses, the ceiling openings can be installed in any convenient *central* location (see Figure 7-23). In houses of two or more stories, the opening is generally located in the ceiling of the top-floor hallway. Again, a central location is usually best. The ceiling opening and its accompanying grille or shutter must be of sufficient size to avoid excessive resistance to airflow, permitting the airstream to pass through at a moderate, quiet velocity.

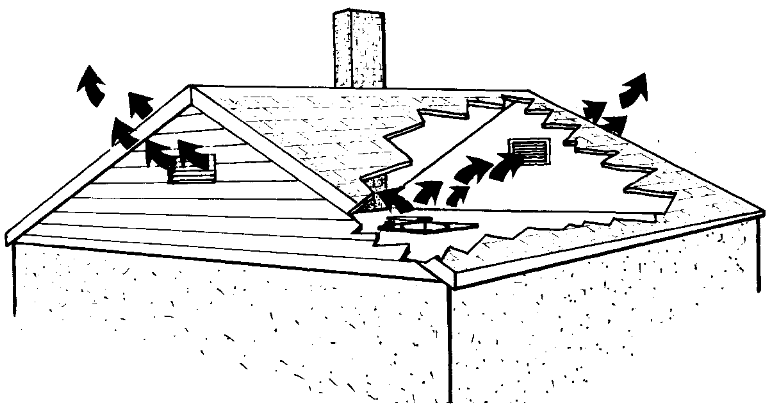


Figure 7-23 Fan mounted in ceiling hallway. *(Courtesy Hayes-Albion Corp.)*

Some attic fans require periodic lubrication of their motor bearings. Check the fan manufacturer's installation and operating instructions for the recommended lubrication schedule. Lubricate the bearings by pouring oil into the oil cups. Fan motors with sealed bearings do not require lubrication.

Clean the fan housing and blades in the spring before the beginning of the cooling season. The screens on the fan vent, soffits, and attic vents should also be cleaned at this time. Blocked vents will prevent air from being drawn into or exhausted from the attic.

Exhaust Fans

Exhaust fans are small, electrically operated fans used to remove odors, heat, and moisture from kitchens and bathrooms. They are commonly mounted in the wall or ceiling. Kitchens also will have an exhaust fan in the range hood over the stove.

Exhaust fans require very little maintenance. Wash the fan housing and fan blades every 6 months. Check the fan in the range hood for a grease filter. This should be cleaned every 3 months or more often depending on how much cooking is being done.

Kitchen Exhaust Fans

In estimating the requirements for ventilating kitchens, it is customary to allow a complete change of air every 2 minutes. In many cases, it is also desirable to have all the extracted air leave via hoods or canopies located over ranges, steam tables, dishwashers, and similar sources of localized heat and contaminants.

Allowing for a complete change of air every 2 minutes only applies to average conditions, and modifications from this average should be made on the basis of the kitchen size and the type of heat- and vapor-producing equipment.

An entrance velocity at the hood opening of 100 fpm is considered satisfactory as an allowance for average conditions. For very light cooking, an entrance velocity of only 50 fpm is usually sufficient. Heavy cooking may require an entrance velocity of 150 fpm or higher.

Exhaust hoods are usually located overhead in the majority of kitchen exhaust systems. They should be placed directly over the heat- and vapor-producing equipment and approximately 80 inches from the floor line to allow sufficient head clearance.

An overhead exhaust hood should be larger in horizontal area than the source of the heat or fumes. When located not over 2 feet above the range, the hood should be 6 inches larger in all directions than the overall dimensions of the range when the distance exceeds 2 feet. Thus, a range 2 feet by 7 feet with a clearance of 2 feet would require a hood 3 feet by 8 feet. Such a hood would have an area of 24 square feet. Using an average entrance velocity at the hood of 100 fpm, the volume of air to be handled would be 2400 cfm.

The area of the branch duct leading from the hood should be made $1/16$ of the hood area (that is, 24 square feet ÷ 16) or 1.5 square feet. With the hood located 4 feet above the range, the dimensions would be 4 feet by 9 feet with a branch duct area of 2.25 square feet.

If a supply system is required, the amount of exhaust air should be greater than the volume of supply air to prevent undesirable cooking odors spreading to adjoining rooms. The supply air is usually figured on the basis of 75 percent of the exhaust air.

Bathroom Exhaust Fans

An air change every 3 minutes, or 20 complete changes per hour, is desirable for bathroom ventilation. Systems of this type should be entirely different and separated from other ventilating systems. Bathrooms located on the inside of a structure require ducts to exhaust air to the outside.

Compact fans are especially recommended for use in bathroom exhaust systems. Their compact design requires a minimum of space, and they are capable of operating against the resistance of the system.

Note

> In tightly constructed and insulated houses, vent fans, clothes dryers, and kitchen exhaust fans can create a negative pressure that draws air into the house through holes in the framing, chimneys, and even exhaust flues. This can cause backdrafting in combustion appliances, which can be a serious health hazard. While the bathroom can be maintained at a negative pressure to control odor problems, the remainder of the house should be maintained at a slightly positive pressure. In hot, humid climates, it is best to operate the exhaust fan only when the bathroom is in use, so that the negative pressure does not draw humid outside air into the building cavities.

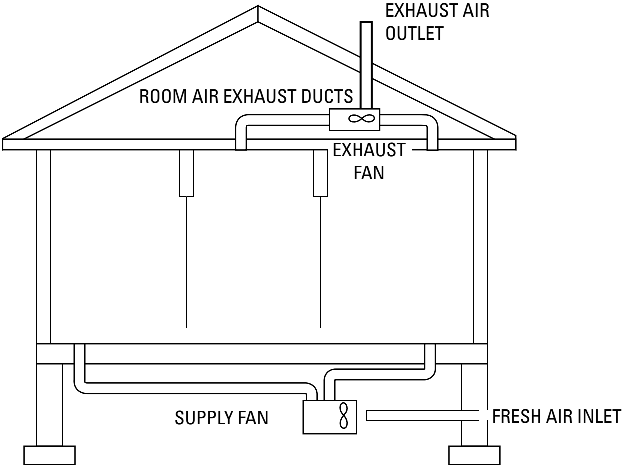
Whole-House Ventilation

Whole-house ventilation is a ventilating system in which a large centrally located fan provides natural air-conditioning. In very dry climates where hot days and very cool nights are the norm, whole-house ventilating fans often provide a suitable replacement for air-conditioning. Cooler outside air is drawn in through the windows on the lower floors during the night and forced out through the attic vents (see Figure 7-24). This system produces a steady supply of filtered, fresh air to all the living spaces of the house. It works most efficiently when the outdoor temperature is below 82°F. A whole-house ventilation system can also reduce air-conditioning costs by using it instead of the air conditioner to cool the house between the heating and cooling seasons, or by using it to ventilate the house before turning on the air conditioner.

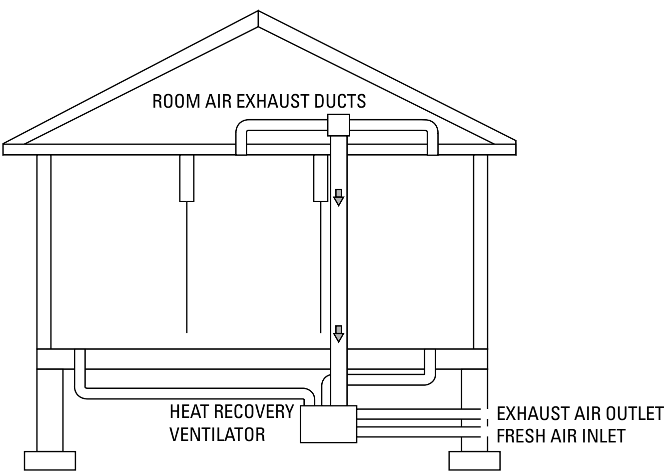
Note

> Whole-house ventilation is not very suitable for humid climates because it draws excess moisture into the house.

In cold climates, the type of whole-house ventilator used in the system is commonly designed to capture some of the heat from the



BALANCED VENTILATION



BALANCED HEAT-RECOVERY VENTILATION

Figure 7-24 Typical whole-house ventilation systems.

(Courtesy U.S. Department of Energy)

air before it is exhausted from the attic. These are sometimes called *air-to-air heat exchangers* or *heat recovery ventilators* (HRVs). These air-to-air heat exchangers are designed to recover as much as 80 percent of the heat energy from the indoor air before it leaves the attic.

Some whole-house ventilators are designed to add or remove moisture from the air. These units are sometimes called *energy recovery ventilators* (ERVs). An energy recovery ventilator operates by balancing the humidity levels between the air drawn into the structure and the air exhausted from the attic. During the winter when the outdoor air is drier, moisture is added to the air by the unit as it is drawn into the house. In the summer when the air is more humid, the energy recovery ventilator removes moisture from the air before it is blown out of the attic.

The fans used in whole-house ventilation are much larger than the standard attic ventilating fans because they are required to move much more air. These are high-velocity cooling fans commonly installed in a hallway ceiling directly beneath the attic. Because some of these fans are too large to be installed between ceiling joists, a box frame is constructed on top of the joists to house them. The box frame must be built by the homeowner or building contractor because it is not provided by the fan manufacturer.

These fans are either belt-driven or direct drive. Belt-driven fans are the quieter of the two, but they require belt replacement every 2 or 3 years. Direct-drive fans are almost maintenance-free.

Note

Low-velocity whole-house ventilating fans should not be confused with the high-velocity types used in whole-house ventilation systems. The former are used only to provide a continuous stream of fresh air and remove indoor pollutants.

A whole-house ventilation fan is switched on when the outside temperature falls below the indoor temperature and continues to operate throughout the night. The fan can be operated both manually and automatically through centrally located controls. Many installations have only a wall-mounted manual on-off switch.

Warning

Windows must be open when operating a whole-house ventilator in order to prevent backdrafting. Depressurization can be prevented if the total open area of the windows is approximately equal to the total net free area of the attic.

Select a whole-house ventilator large enough to deliver 20 air changes per hour (ACH). A typical sizing method for these fans is to divide the volume of the house (width $\times$ height $\times$ length) by 3 to obtain the air changes per hour for the fan.

Whole-house ventilators require very little maintenance. If the unit is equipped with a filter, it will have to be periodically cleaned or replaced. Inspect the fan blades from time to time and clean them when there is a noticeable buildup of dirt or grease.

Chapter 8

Air-Conditioning

Although it is a commonly held belief, it is incorrect to regard air-conditioning as simply the *cooling* of air. Conditioning the air of a space means to change it in whatever way necessary to improve the comfort of those living or working there. This may mean warming air to a livable temperature and holding it there; cooling the air; adding or subtracting moisture; filtering out contaminants such as dust, bacteria, and toxic gases; and maintaining a proper distribution and movement of the air. In general, air-conditioning includes the following processes:

1. Heating
2. Cooling
3. Humidification
4. Dehumidification
5. Cleaning and filtering
6. Air movement (circulation)

Each of these processes contributes in some way to the improvement of those conditions that affect the comfort and health of an individual. For example, air nearly always contains certain impurities, such as ammonia, sulphurous acid, and carbon dioxide. The last named is a product of exhalation from the lungs and the combustion process in internal combustion engines. It is so universally present (about in the same proportions everywhere, except where concentrated by some local conditions) that it may be regarded as a normal part the air. Air-conditioning is an efficient means of eliminating carbon dioxide from the air. The same is true of other impurities. Some dry strainer filters used in air-conditioning systems are capable of removing 99.98 percent of radioactive dust from the air.

To understand how an air-conditioning system works and how to calculate cooling loads, you should have a basic understanding of the physical properties of air and how its moisture content, temperature, and pressure will influence your calculations. These topics and the associated terminology are described in the following sections.

Properties of Air

Air is composed of water vapor and dry air. These two components are combined in such a way that neither loses its distinct characteristics. A number of different terms are used to describe the qualities or properties of air, but the two terms essential in heating and cooling calculations are humidity and temperature.

Humidity

Humidity is a general term used to refer to the water vapor (moisture) content of air. When this term is used, it is usually in reference to the sensation (or lack of sensation) of moisture in the air. For purposes of heating and cooling calculations, the more narrowly defined terms of *absolute humidity*, *relative humidity*, and *specific humidity* are used.

Water vapor is actually steam at low temperatures and, consequently, low pressures; hence its properties are those of steam. According to Dalton's law, in any mechanical mixture of gases, each gas has a partial pressure of its own, which is entirely independent of the partial pressures of the other gases of the mixture.

Note

> In *all* air-conditioning calculations it should be understood that the dry air and water vapor composing the atmosphere are separate entities, each with its own characteristics. Water vapor is not dissolved in the air in the sense that it loses its own individuality and merely serves to moisten the air.

Air is capable of holding, as a mechanical mixture within itself, varying quantities of water vapor, depending on its temperature. When air absorbs moisture; that is, when it is humidified, the latent heat of evaporation must be supplied either from the air or from another source. And conversely, when the moisture from the air is condensed, the latent heat of condensation (equivalent to the latent heat of evaporation) is recovered.

Air is said to be saturated when it contains all the water vapor it can hold. If partly saturated air is reduced in temperature until the amount of moisture present corresponds to the amount that the air is capable of holding at the given temperature, it will become saturated air.

If the temperature of the air is still further reduced, its ability to hold moisture will be reduced accordingly. As a result, the excess moisture will be condensed, which means that it will be converted from a vapor to a liquid. This is the reverse of the process that occurred as the air absorbed the moisture.

Converting liquid water into water vapor requires a great quantity of heat. The heat necessary for this process is used only in performing the conversion, the temperature of the liquid and the vapor being the same at the end of the process. If the conversion is from liquid to vapor, this involves the latent heat of *evaporation*. The latent heat of *condensation* is involved if the conversion is from vapor to liquid.

Cold air is saturated when it contains very small quantities of water vapor, whereas warm air is not saturated until it contains larger quantities of vapor. For example, air at zero degrees Fahrenheit is saturated when it contains but one-half of one grain (1/7000 lb) of water vapor per cubic foot. Air at 70°F is saturated when it contains 8 grains of vapor per cubic foot, while at 83°F, 12 grains per cubic foot are required to saturate.

Absolute Humidity

Absolute humidity is the actual mass of water vapor in one cubic foot of air (that is, the weight of water vapor per unit volume of air) and is expressed in grains or pounds per cubic foot (1 lb = 7000 grains), or grams per cubic centimeter. Absolute humidity is equivalent to the density of the air.

Specific Humidity

Specific humidity is the *weight* of water vapor per pound of dry air. Do not confuse specific humidity with relative humidity. The latter term indicates the percentage of water vapor, the former the weight.

Relative Humidity

Relative humidity is the ratio of absolute humidity to the maximum possible density of water vapor in the air at the same temperature. In other words, it is a *percentage* or *ratio* of water vapor in the mixture of dry air and water vapor at a certain temperature relative to the maximum quantity that the volume of air could possibly carry at that temperature. The relative humidity at any given temperature can be obtained by first using a sling psychrometer to determine the amount of moisture (that is, water vapor) actually present in the air and then dividing this figure by the amount of moisture that the air can hold at that temperature, and multiplying the result by 100 in order to obtain the percentage factor.

Drying Effect of Air

The drying effect of air varies approximately inversely with its relative humidity. In other words, the drying effect decreases as the relative humidity increases. It should be noted that it is relative humidity that determines the drying effect of air, and this effect depends on both the temperature and the water content of the air since relative humidity depends on both these factors.

The quantity of heat that dry air contains is very small because its specific heat is low (0.2415 for ordinary purposes), which means that 1 lb of air falling 1°F will yield only 0.2415 of the heat that would be available from 1 lb of water reduced one degree in temperature. The presence of water vapor in the air materially increases the total heating capacity of the air because of the latent heat of the vapor itself.

Most hygroscopic materials in the presence of dry air, even at high, dry-bulb temperatures, may actually be cooled rather than heated. This occurs because the dry air immediately begins to evaporate moisture form the material.

The Dew Point

The *dew point* is the temperature of saturation for a given atmospheric pressure. In other words, for a given atmospheric pressure (barometer), it is the temperature at which moisture begins to condense in the form of tiny droplets, or dew.

The saturation temperature for any given quantity of water vapor in the atmosphere is known as the dew point. Any reduction in temperature below the dew point will result in condensation of some of the water vapor present, with a consequent liberation of the latent heat of the vapor, which must be absorbed before any further condensation can take place.

If the vapor pressure of the water vapor in a given space is the same as the vapor pressure of saturated steam at the prevailing dry-bulb temperature, the space contains all the water vapor it can hold at that temperature. The term *saturated water vapor* is applied to water in this state.

Humidification

Humidification may be defined as the *addition* of moisture to the air. The conditioning machine that functions to add moisture to the air is called a humidifier. A humidifier is commonly a low-pressure, low-temperature boiler in which the water is evaporated and the vapor (low-pressure steam) thus formed is caused to mix with air.

In a sense, water functions as a natural humidifier by acting as the medium that conveys heat to the air and as the source of the water vapor required to saturate the heated air. Contrast this with what takes place in a humidifier unit. A machine functions as a humidifier when the temperature of the spray water is above that at which the moisture in the air will condense.

Dehumidification

Dehumidification may be defined as the *removal* of moisture from the air. A machine that functions to remove moisture from the air is called a dehumidifier.

The removal of moisture from the air is accomplished by condensation, which takes place when the temperature of the air is lowered below its dew point. The condensation thus formed falls into the tank of the conditioning machine. In this case the water acts solely as a conveyor of heat from the air (in addition to its cleansing action) and, as such, the finely divided mist is extraordinarily effective (practically 100 percent).

Some conditioning machines can function both as humidifiers or dehumidifiers. This can often be done without alteration to the unit except that the valves in the control line from the dew point thermostat on some designs are adjusted to connect the steam control of the water heater for winter operation, and to connect the three-way mixing valve to the water supply line for summer operation.

Whether the requirement is humidification or dehumidification, the unit always operates under accurate automatic control, maintaining the required indoor conditions winter and summer, regardless of the outdoor weather.

Temperature

Temperature is a general term used to describe the sensation (or lack of sensation) of heat in the air. Among the more specific terms used in the heating and cooling calculations to describe the air temperature are dry-bulb temperature and wet-bulb temperature.

Note

> Sometimes both temperature and humidity are used in conjunction with one another as a calculation factor, and the temperature-humidity index is an example of this. By definition, the *temperature-humidity index* (formerly called the *discomfort index*) is a numerical indicator of human *discomfort* resulting from temperature and moisture. It is calculated by adding the indoor dry-bulb and the indoor wet-bulb thermometer readings, multiplying the sum by 0.4 and adding 15. The results you obtain are the same as those used for the effective temperature index (see *Standards of Comfort*). This can be worked out from the data provided in Table 8-1.

Dry-Bulb and Wet-Bulb Temperatures

Dry-bulb temperature is the actual temperature of air as measured by an ordinary thermometer. *Wet-bulb temperature* is the temperature at

Table 8-1 Recommended Scale of Interior Effective Temperatures for Various Outside Dry-Bulb Conditions

Degrees Outside	*Degrees Inside*			
Dry-Bulb	*Dry-Bulb*	*Wet-Bulb*	*Dew Point*	*Effective Temperature*
100	82.5	69.0	62.3	76.0
95	81.0	67.7	60.8	74.8
90	79.5	66.5	59.5	73.6
85	78.1	65.3	58.0	72.5
80	76.7	64.0	56.6	71.3
75	75.3	63.0	55.6	70.2
70	74.0	62.0	54.5	69.0

which the air would become saturated if moisture were added to it without the addition or subtraction of heat. It is the temperature of evaporation. In actual practice, the wet-bulb temperature reflects humidity conditions in the area. A high wet-bulb reading, for example, means that the humidity is also high.

The wet-bulb temperature in conjunction with the dry-bulb temperature is an exact measure of both the humidity of the air and its heat content. In air-conditioning the dry-bulb temperature and the wet-bulb temperature must *both* be controlled if the effects of air are to be regulated.

If the bulb of an ordinary thermometer is surrounded with a moistened wick and placed in a current of air and superheated water vapor, it will be found that a reading at some point below the dry-bulb temperature is obtained. The minimum reading thus obtained is the *wet-bulb temperature* of the air. The reduction in temperature is caused by the sensible heat being withdrawn from the air to vaporize the water surrounding the wet bulb, thus raising the dew point of the air.

Note

> The point of equilibrium at which the withdrawn sensible heat balances with the heat of vaporization necessary to bring the dew point up to the same point is the wet-bulb temperature.

In this transformation of energy from sensible heat of vaporization, there is no change in the total amount of energy in the mixture. For this reason, the wet-bulb temperature, once fixed, is an indication of the total heat in any mixture of air and water vapor.

The *daily temperature range* is the difference between the maximum and minimum dry-bulb temperatures during a 24-hour period on a typical day for a heating or cooling system. It is used in determining the factors used in making Btu tabulations. The Btu tabulation cooling form illustrated in Figure 8-9 shows their use. In Figure 8-9 you will note that the tables labeled "wall factors" and "ceiling factors" each have a column reserved for four different degrees of daily temperature range (that is, 15°F, 20°F, 25°F, and 30°F). Reading across from left to right, the different daily temperature ranges intersect with a number of other columns representing differences in the dry-bulb temperatures. The selection used will depend on the type (or absence) of insulation.

Wet-Bulb Depression

Because outdoor summer air is rarely fully saturated, there is usually a considerable difference between its dry-bulb and its wet-bulb temperatures. This difference is referred to as *wet bulb depression* and is greatest during the summer.

As previously mentioned, the wet-bulb temperature is that temperature to which air would be cooled by evaporation if the air was brought into contact with water and allowed to absorb sufficient water vapor to become saturated. For example, if the outdoor summer air is drawn through a humidifier and completely saturated, its dry-bulb temperature will be reduced to its wet-bulb temperature, and the air will leave the humidifier at the outdoor wet-bulb temperature. This cooling is accomplished entirely by evaporation and is due to the latent heat required to convert the liquid water vapor. This conversion occurs the instant the air is brought into contact with the mist in the spray chamber of the humidifier, the heat being taken from the air.

The spray water in a humidifier is used over and over again, only that quantity being added which is actually absorbed by the air. Thus, without any additional expense, a humidifier will perform the function of cooling the air through the wet-bulb depression in the summer.

The extent of the wet-bulb depression in some localities is as much as 25° or 30°. Even in localities adjacent to large bodies of water where the humidity is high and the wet-bulb depression correspondingly low, the latter will quite commonly range from 10° to 15°.

In the vicinity of New York, for instance, the maximum outdoor wet-bulb temperature is about 78°. On such a day the dry-bulb temperature would probably be about 90°, making the wet-bulb depression 12° (90° − 78° = 12°).

In Denver, on the other hand, the maximum outdoor wet-bulb temperature is usually less than 78°. Because the coincident dry-bulb temperature is usually much higher then 90°, it results in a greater wet-bulb depression, which means that more cooling can be accomplished by evaporation.

Sensible and Latent Heat

The distinction between dry air and the moisture content of air and between dry-bulb and wet-bulb temperatures is extended to the two types of heat carried by the entering air and the air already contained in the space: sensible and latent heat.

Sensible Heat

Sensible heat is the amount of heat in air that can be measured by an ordinary thermometer (that is, a dry-bulb thermometer). The daily weather report gives us sensible heat temperatures, but it does not represent the total heat we experience. It constitutes a *portion* of the heat resulting from air infiltration and ventilation, and internal heat sources such as people, electric lights, and electric motors. Sensible heat also results from heat leakage (or heat loss in the case of heating calculations) and solar radiation.

Latent Heat

Latent heat is the amount of heat contained in the water vapor (moisture) of the air. It constitutes a portion of the heat resulting from infiltration and ventilation and any internal sources capable of adding water vapor to the air (for example, cooking vapors, steam, people). The amount of latent heat in the air can be determined by using a psychrometric chart (see Appendix E, "Psychrometric Charts"). The amount of *excess* latent heat so determined will indicate the amount of moisture that must be removed from the air in order to obtain comfortable conditions.

Both sensible heat gain and latent heat gain are expressed in Btu. When the total of the two are added together, their sum represents the *total* heat gain in Btu that must be removed from the air each hour by the air conditioner.

Sensible heat gain (or load) is represented by a change in the *dry-bulb* temperature readings, whereas latent heat gain is represented by a change in the *web-bulb* temperature.

Pressure

Atmospheric air is air at the pressure of the standard atmosphere. *Standard atmosphere* is considered to be air at a pressure of 29.921 inches of mercury, which is equal to 14.696 pounds per square inch (usually written 14.7 psi). In any air-conditioning system, atmospheric air is regarded as being air at the atmospheric pressure at the point of installation.

Standard atmospheric pressure at sea level is 29.921 inches of mercury. Since most pressure gauges indicate gauge pressure or pounds per square inch, a barometer reading can be converted into gauge pressure by multiplying inches of mercury by 0.49116 psi. Thus, a barometer reading of 29.921 inches is equivalent to a gauge pressure of 14.696 psi ($29.921 \times 0.49116 = 14.696$, or 14.7 psi).

So 0.49116 psi is a constant value for 1 inch of mercury and is determined by dividing the pressure in pounds per square inch by the barometer readings in inches of mercury (that is, $14.696 \div 29.921 = 0.49116$). Table 8-2 gives the atmospheric pressure for various readings of the barometer.

The pressure of the atmosphere does not remain constant in any one place. It continually varies depending on the conditions of the weather and the elevation. With respect to elevation, atmospheric pressure will decrease approximately ½ lb for each 1000 feet of ascent. Table 8-2 illustrates the effect of altitude and weather (the barometer reading) on atmospheric pressure.

Table 8-2 Atmospheric Pressure and Barometer Readings for Various Altitudes

Altitude above Sea Level (Feet)	*Atmospheric Pressure (Pounds per Square Inch)*	*Barometer Reading (Inches of Mercury)*
0	14.69	29.92
500	14.42	29.38
1000	14.16	28.86
1500	13.91	28.33
2000	13.66	27.82
2500	13.41	27.31
3000	13.16	26.81
3500	12.92	26.32
4000	12.68	25.84
4500	12.45	25.36
5000	12.22	24.89
5500	11.99	24.43
6000	11.77	23.98
6500	11.55	23.53
7000	11.33	23.09
7500	11.12	22.65
8000	10.91	22.22
8500	10.70	21.80
9000	10.50	21.38
9500	10.30	20.98

(continued)

Table 8-2 (*continued*)

Altitude above Sea Level (Feet)	*Atmospheric Pressure (Pounds per Square Inch)*	*Barometer Reading (Inches of Mercury)*
10,000	10.10	20.58
10,500	9.90	20.18
11,000	9.71	19.75
11,500	9.52	19.40
12,000	9.34	19.03
12,500	9.15	18.65
13,000	8.97	18.29
13,500	8.80	17.93
14,000	8.62	17.57
14,500	8.45	17.22
15,000	8.28	16.88

Absolute pressure is pressure measured from true zero or the point of no pressure. It is important to distinguish absolute pressure from *gauge pressure*, whose scale starts at atmospheric pressure. For example, when the hand of a steam gauge is at zero, the absolute pressure existing in the boiler is approximately 14.7 psi. Thus, 5 lbs pressure measured by a steam gauge (that is, gauge pressure) is equal to 5 lbs plus 14.7 lbs, or 19.7 psi of absolute pressure.

Compression and Cooling

The objective of the use of compression in air-conditioning is to cool the air being conditioned. It is important to note, however, that it is not the air that is compressed, but the refrigerant gas used in the coils of the air-conditioning unit. The low temperature is produced by the expansion and contraction of the refrigerant gas. When a gas is compressed, both its pressure and temperature are changed in accordance with Boyle's and Charles's laws.

The English scientist Robert Boyle (1627–1691) determined that the absolute pressure of a gas at constant temperature varies inversely as its volume. Somewhat later, the French scientist Jacques Charles (1745–1823) established that the volume of a gas is proportional to its absolute temperature when the volume is kept at constant pressure. These findings came to be known as Boyle's and Charles's laws respectively. In Tables 8-3 and 8-4 a series of relations based on these two laws are tabulated for convenient reference.

A more simplified explanation of the interrelationship of these two laws may be gained with the aid of the cylinder illustrated in

Table 8-3 Summary of Boyle's Law

1. Pressure volume formula

$$PV = P'V' \quad \ldots\ldots\ldots(1)$$

$$P = \frac{P'V'}{V} \quad \ldots\ldots\ldots(2)$$

$$V = \frac{P'V'}{P} \quad \ldots\ldots\ldots(3)$$

2. Compression constant

$$PV = \text{constant} \quad \ldots\ldots(4)$$

3. Pressure at any point

$$P = \frac{\text{constant}}{V} \quad \ldots\ldots(5)$$

4. Volume at any point

$$V = \frac{\text{constant}}{P} \quad \ldots\ldots(6)$$

5. Ratio of compression

$$R = V_i \div V_f \quad \ldots\ldots(7)$$

where,

R = ratio or number of compressions
V_i = initial volume
V_f = final volume

$$R = P_i \div P_f = V_i \div V_f \quad \ldots(8)$$

6. Initial pressure of compression

$$P_i = R \div P_f \quad \ldots\ldots\ldots\ldots(9)$$

where,

P_i = initial pressure absolute
P_f = final pressure absolute

7. Final pressure of compression

$$P_f = P_i \div R$$

Table 8-4 Summary of Charles's Law

1. At constant volume

$$\frac{P}{T} = \frac{V'}{T'} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where, P = initial pressure absolute
P' = final pressure absolute
T = initial temperature absolute
T' = final temperature absolute

2. At constant pressure

$$\frac{V}{T} = \frac{V'}{T'} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where V = initial volume (usually in cubic feet)
V' = final volume (usually in cubic feet)

Figure 8-1. If the cylinder is filled with air at atmospheric pressure (14.7 psi) represented by volume *A*, and piston *B* is moved to reduce the volume by, say, ⅓ of *A*, as represented by *B*, then according to Boyle's law, the pressure will be tripled ($14.7 \times 3 = 44.1$ lbs absolute or $44.1 - 14.7 = 29.4$ gauge pressure). According to Charles's law, a pressure gauge on a cylinder would at this point indicate a *higher* pressure than 29.4 gauge pressure because of the increase in temperature produced by compressing the air. This is called *adiabatic compression* if no heat is lost or received externally.

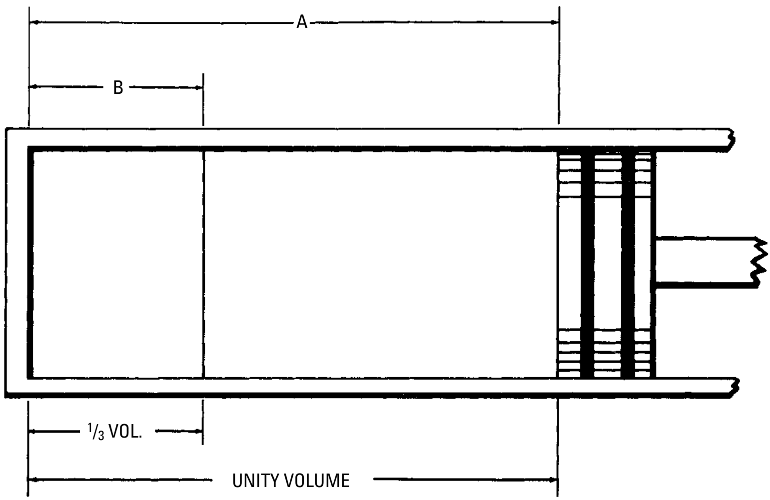


Figure 8-1 The interrelationship of Boyle's and Charles's laws.

Measuring the Physical Properties of Air

A number of instruments are used for measuring the physical properties of air. These include the following:

1. The thermometer
2. The barometer
3. The psychrometer
4. The pressure gauge

A *thermometer* (see Figures 8-2 and 8-3) is a device used to measure temperature, and consists of a glass tube terminating in a bulb charged with mercury or colored alcohol. It measures the temperature by the contraction or expansion of the liquid with temperature changes, causing the liquid to rise or recede in the tube. The scale of an ordinary thermometer, either Fahrenheit or Celsius, is simply an arbitrary standard by means of which comparisons can be established.

An ordinary thermometer is used to measure dry-bulb temperature. Dry-bulb temperature is the degree or intensity of heat. In other words, dry-bulb temperature measures the degree of effort that the heat will exert to move from one position to another.

A specially designed thermometer is used to measure wet-bulb temperature. The latter represents the temperature at which the air becomes saturated if moisture is added to it *without* a change of heat. The bulb of an ordinary thermometer is surrounded with a moistened wick, placed in a current of air, and superheated with water vapor. Essentially this represents a wet-bulb thermometer.

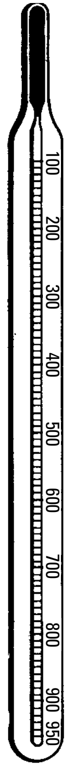


Figure 8-2 A pencil-style stack thermometer.

A *barometer* (see Figure 8-4) is an instrument designed to measure atmospheric pressure. Early barometers consisted of a 30-inch-long glass tube open at one end and filled with mercury. The open end was submerged in a bowl of mercury, and the mercury in the glass tube would assume a level in accordance with the existing atmospheric pressure. Thus, the height of the mercury column in the tube is a measure of the atmospheric pressure. *Standard* atmospheric pressure at sea level is 29.921 inches of mercury.

A *psychrometer* (or *sling psychrometer*) is an instrument used to measure relative humidity. It consists of a dry-bulb (for air temperature) and a wet-bulb thermometer mounted side by side. The reading on the wet-bulb thermometer is determined by the rate at which the moisture evaporates from its bulb. If the psychrometer is working correctly, the reading on the wet-bulb thermometer will be lower than the one on the dry-bulb thermometer. The *difference* between the two readings serves as a basis for determining the relative humidity.

Pressure gauges (see Figures 8-5, 8-6, and 8-7) are used to measure pressure. A *high-pressure gauge* (see Figure 8-5) is used to measure pressures ranging from zero to 300 or 400 psig. A *compound gauge* (see Figure 8-6) is used to measure low pressures

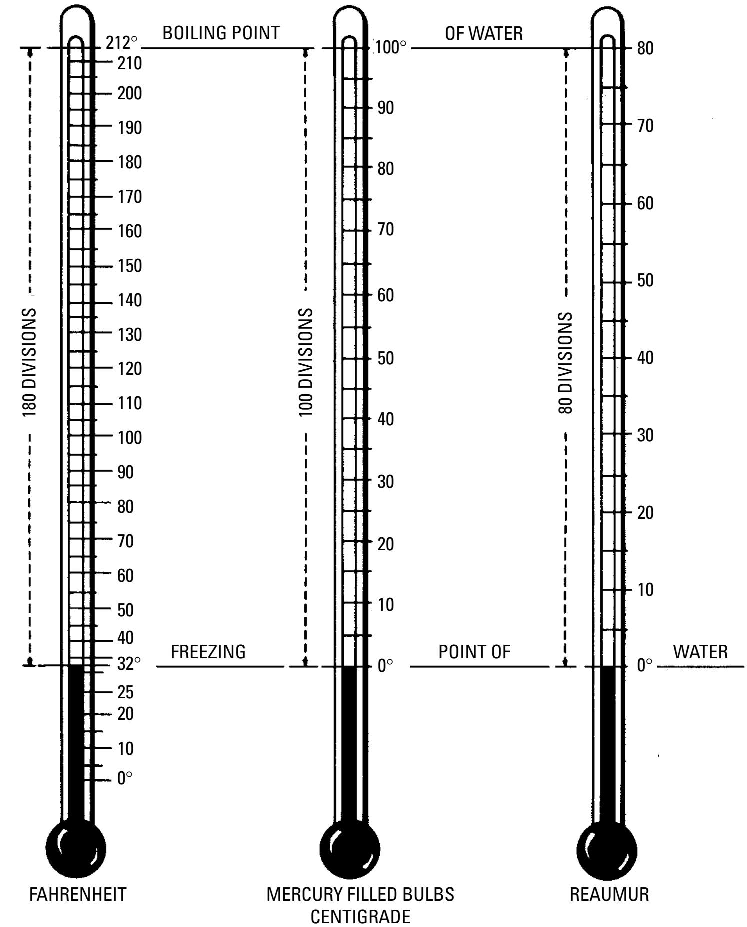


Figure 8-3 Various thermometer scales.

above atmospheric pressure in psig and below atmospheric pressure in vacuum in inches of mercury.

Cleaning and Filtering the Air

The purpose of cleaning and filtering the air is to remove dust and other contaminants that could be harmful to the health or discomforting. Many bacteria that cause diseases are carried on dust particles.

Cleaning and filtering may be accomplished with equipment using one of the following four methods:

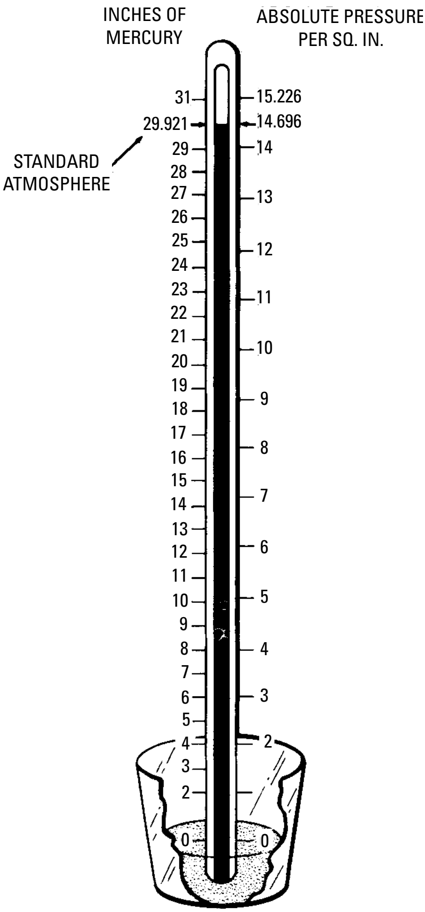


Figure 8-4 Mercurial barometer illustrating the relationship between inches of mercury and absolute pressure in pounds per square inch.

1. Filtering
2. Washing
3. Combined filtering and washing
4. Electrostatic field

Filters trap particles by bringing them in contact with specially coated surfaces or by straining them through dry materials of particularly close texture. The filters used in air-conditioning equipment may be either dry or wet (viscous) types. Depending on the type used, air-cleaning filters may be replaceable or periodically

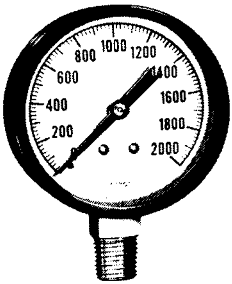


Figure 8-5 A high-pressure gauge.
(Courtesy Ernst Gage Co.)

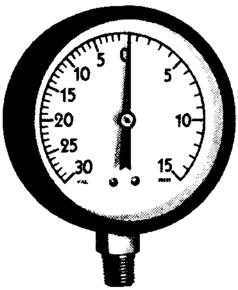


Figure 8-6 A compound gauge that measures both pressure and vacuum.
(Courtesy Ernst Gage Co.)

cleaned. In the latter case, either manual or automatic cleaning is possible.

Air washers form a part of the cooling and humidifying apparatus of the air-conditioning system. They operate by passing the air first through fine sprays of water and then past baffle plates upon the wetted surface of which is deposited whatever dust and dirt not caught by the sprays.

Electronic air cleaners employ an electrostatic ionizing field to remove dust particles from the air. The particles are given an electrical charge when passing through the field and are subsequently attracted to metal plates having an opposite polarity.

Cleaning and filtering processes are described in greater detail in Chapter 12 ("Air Cleaners and Filters").

Standards of Comfort

The influence of air temperature, moisture, and movement on physical comfort has been very thoroughly investigated. Once again, the most authoritative sources of information on this subject are the results of research conducted by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers. The most current edition of the *ASHRAE Guide* should be consulted for details because some revisions have been made.

The sensations of warmth or cold experienced by the human body depend not only on the dry-bulb temperature but also on the moisture content of the air. Cooling applications that remove only the sensible heat fall short of establishing comfortable conditions if the latent heat gain is particularly high. The air will be cooler under these conditions, but it will feel damp and uncomfortable. In order to meet minimal standards of comfort, both sensible and latent heat must be reduced to an acceptable level.

The average comfort conditions in summer and winter are considerably different, although the two zones overlap to some degree. This difference is caused largely by differences in clothing, and the natural inclination of the body to acclimate itself to somewhat higher temperatures in the summer.

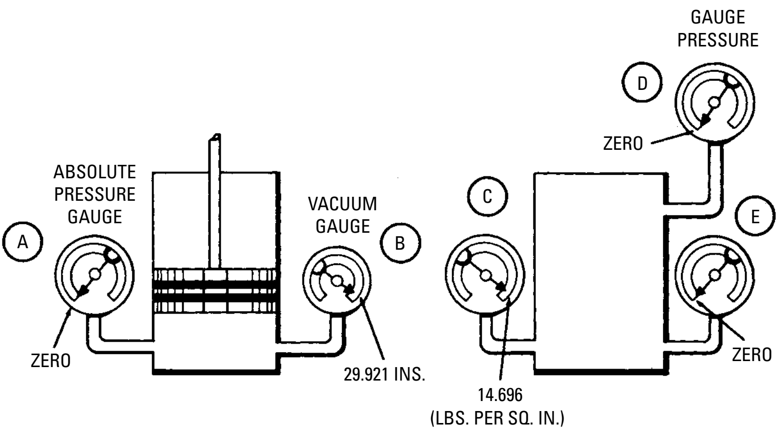


Figure 8-7 Gauge illustrating absolute and zero pressure.
(Courtesy Ernst Gage Co.)

The *effective temperature* is an arbitration index of the degree of warmth or cold as apparent to the human body, and takes into account the temperature, moisture content, and motion of the surrounding air.

Effective temperatures are not strictly a degree of heat; at least not in the same sense that dry-bulb temperatures are. For instance, the effective temperature could be lowered by increasing the rate of airflow even though wet- and dry-bulb temperatures remain the same. Consequently, effective temperature is more correctly defined as the *body sensation* of warmth or cold resulting from the combined effect of temperature, humidity, and air movement. For space cooling and heating, however, the air movement factor is considered a constant at approximately 20 feet per minute, and under this condition effective temperature is determined by the wet-bulb and dry-bulb thermometer readings only.

The Comfort Chart

The *comfort chart* (see Figure 8-8) is an empirically determined effective temperature index that has been published by the *ASHRAE* since 1950.

The purpose of the comfort chart is to indicate the percentage of people feeling comfortable at various effective temperatures in the winter and summer. This serves only as an approximate standard of comfort, because individual reactions to warmth and cold are much too variable, but it *is* the most precise and scientific form of measurement available.

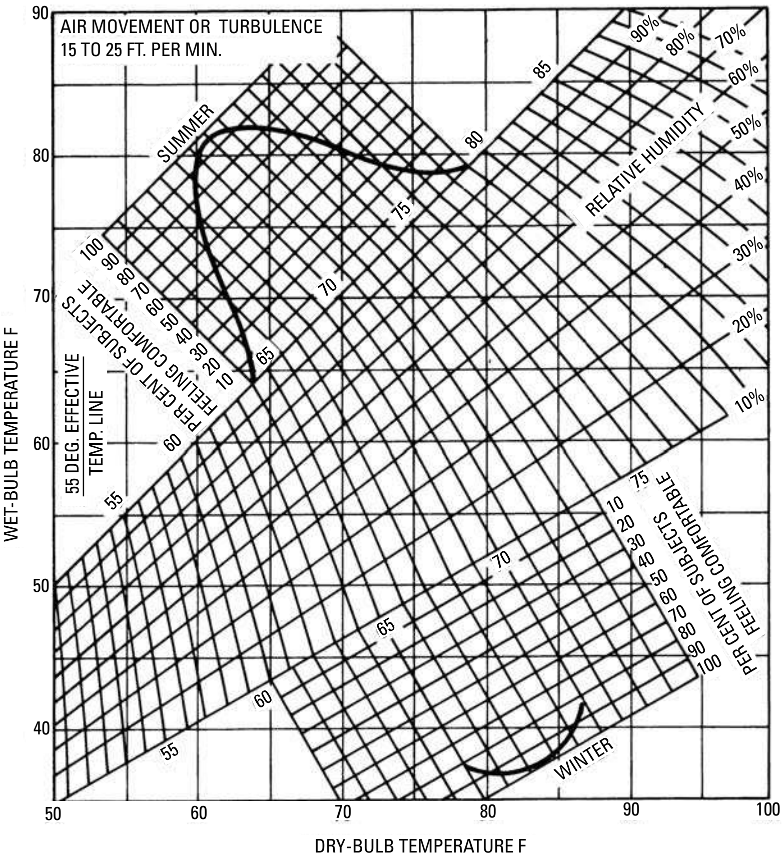


Figure 8-8 Comfort chart for still air. *(Courtesy ASHRAE 1960 Guide)*

From the chart, one can obtain an approximate idea of the various effective temperatures at which a majority of people will feel comfortable (that is, the summer and winter comfort zones).

Most air-conditioning systems are designed with a recommended indoor design relative humidity of about 50 percent or slightly lower. Budget jobs will range as high as 60 percent relative humidity. The indoor dry-bulb temperature will range from 75°F or slightly below to about 80°F, depending on the degree of occupancy and whether it is a budget job or not. In any event, the indoor design conditions *should* fall within the comfort zone.

More information about the use of the comfort chart is included in Appendix E ("Psychrometric Charts").

Cooling Load Estimate Form

Air-conditioning equipment manufacturers often provide their local representatives with forms for making cooling load estimates. Along with these forms they also provide tables, slide charts, tabulation sheets, and other aids for computing the cooling load.

Typical tabulation sheets and cooling load estimate forms are shown in Figures 8-9 and 8-10. These forms contain lists of factors that represent *approximate* values for a variety of different items (for example, walls, ceilings, people). For example, the form illustrated in Figure 8-9 requires that you select the appropriate design dry-bulb temperature and its column of factors. After calculating the area (in square feet) of the structural section, you must multiply this figure by its factor to determine the Btu per hour of heat gain and enter the result in the column on the extreme right.

Because a manufacturer's cooling estimate form will probably not be available, it may be necessary to create your own. If this should be the case, then provisions should be made on the cooling estimate form for distinguishing between sensible and latent heat sources.

Your cooling load estimate form should contain the following basic categories of heat gain:

A. Sensible heat gain
- **1.** Heat leakage
- **2.** Solar radiation
- **3.** Internal heat sources
- **4.** Infiltration
- **5.** Ventilation
- **6.** Electric lights
- **7.** Electric motors
- **8.** People
- **9.** Appliances

B. Latent heat gain
- **1.** Infiltration
- **2.** Ventilation
- **3.** People

AMANA REFRIGERATION INC., AMANA, IOWA

BTU TABULATION
(BASED ON 24 HOUR PER)

Job Name ______________________ Date ______________________

Location ______________________ Computed By ______________________

ROOM			LIVING ROOM		DINING ROOM		KITCHEN		BED ROOM 1	
Room Size (LxWxH)										
Linear Ft. Exposed Wall										
Floor Ceiling Area										
		FACTOR	AREA OR QUAN	BTUH	AREA OR QUAN	BTUH	AREA OR QUAN	BTUH	AREA OR QUAN	BTUH
Windows	DIRECTION									
Walls	Shade									
	Sunlit									
Ceiling										
Cooking								1200		
People		380	3						1	
Room Sensible Heat										
Room CFM										

WINDOW & DOOR FACTORS

Temp. Diff. F	15	20	25	30
North	12	18	25	31
NE & NW	23	29	36	42
East & West	32	38	44	51
SE & SW	35	41	48	55
South	26	32	39	45

Above factors assume shades or venetian blinds. If no shades double factors.

For outside shading or awnings multiply factor x .60.

For double glazed or storm windows multiply factor x .80.

NOTES:
PEOPLE LOAD — One Person in each bedroom and three persons in living room.

ROOF OVERHANG — South walls only. 36" overhang provides complete shade to wall and windows. Use shade values for windows and walls.

DOORS — Treat all outside doors as windows.

WALL FACTORS — Light Color

Temp. Diff. F		15	20	25	30
15 Daily Temp. Range	No Insul.	3.6	5.4	7.2	9.0
	1½" Insul.	2.1	3.0	4.0	5.1
	3" Insul.	1.5	2.1	2.9	3.6
20 Daily Temp. Range	No Insul.	2.7	4.5	6.5	8.2
	1½" Insul.	1.5	2.6	3.6	4.7
	3" Insul.	1.1	1.8	2.6	3.3
25 Daily Temp. Range	No Insul.	1.4	3.6	5.4	7.4
	1½" Insul.	0.9	2.1	3.0	4.1
	3" Insul.	0.6	1.5	2.1	2.9

For masonry walls multiply factors x 1.2. For ½ Value in Table.

CEILING FACTORS

	Temp. Diff. F	15
15 Daily Temp. Range	2" Insul.	5.7
	4" Insul.	3.6
	6" Insul.	3.2
20 Daily Temp. Range	2" Insul.	5.0
	4" Insul.	3.2
	6" Insul.	2.9
25 Daily Temp. Range	2" Insul.	4.4
	4" Insul.	2.9
	6" Insul.	2.6

Factors assume dark color roof with attic having vents.
If light color roof — take 75" of values in tables.
If no vents in attic space double values.

Figure 8-9 Btu tabulation cooling form. *(Courtesy Amana Refrigeration, Inc.)*

C. Ventilation heat gain (from outside sources)

1. Sensible heat

2. Latent heat

The sum of these categories will represent the total heat gain expressed in Btu per hour. A balance must be established between

COOLING (Residential)
(DAY OPERATION OF EQUIPMENT)

Outside Design Temp ______

Inside Design Temp ______

Temp Diff. ______

______ Outside Humidity Factor ______ Daily Temp Range ______

	BED ROOM 2						BATH		BTUH TOTALS
	AREA OR QUAN	BTUH	AREA OR QUAN	BTUH	AREA OR QUAN	BTUH	AREA OR QUAN	BTUH	

Dark Color

	15	20	25	30
	5.1	6.9	8.9	10.7
	2.7	3.0	4.7	5.1
	2.0	2.6	3.3	4.1
	4.2	6.0	7.8	9.8
	2.1	3.2	4.2	5.1
	1.5	2.3	3.0	3.6
	3.3	5.1	6.9	8.9
	1.7	2.7	3.6	4.7
	1.2	2.0	2.6	3.3

North or Shaded Wall Figure

	20	25	30
	6.9	8.7	9.6
	4.4	5.1	5.7
	4.0	4.6	5.1
	6.2	7.5	8.6
	3.7	4.7	5.4
	3.5	4.2	4.9
	5.5	6.9	7.6
	3.6	4.4	5.0
	3.2	4.0	4.5

HOUSE TOTAL SENS. BTUH ______

DUCT. GAIN ______ % ______

VENTILATION LOAD BTUH ______

TOTAL SENSIBLE BTUH ______

GRAND TOT. = TOT. SENS. x HUM. FACTOR ______

% DUCT GAIN

	1 Story	$1\frac{1}{2}$ Story	2 Story
Ducts Insulated	8	6	4
Ducts not Insulated	18	15	12

NOTE: All ducts in attic spaces must be insulated with 3" minimum thickness insulation with vapor barrier. Ducts in crawl spaces and damp basements must be covered with 2" minimum thickness insulation with vapor barrier.

Do not figure duct gain for concrete slab under floor ducts

HUMIDITY FACTORS

% Outside Hum.	Below 40	40 to 45	Above 45
Factor	1.25	1.30	1.35

VENTILATION LOAD

House Volume Cu. Ft. (LxWxH) x .40 BTUH/ CU. Ft.

Figure 8-9 ***(continued)***

this hourly heat gain within the conditioned space and the hourly capacity of the air-conditioning unit to remove this heat gain in order to maintain the inside design temperature.

Figure 8-11 is a floor plan (not drawn to scale) of a house that will serve as a basis for most of the cooling calculations used in this chapter.

Customer .... Address ....
Buyer .... Installation by ....
Estimate Number .... Estimate by .... Date ....
Equipment Selected ....; Model ....; Size ....
Direction House Faces ....; Gross Floor Area ....sq ft; Gross Inside Volume .... cu ft

Design Conditions:	Degrees North Latitude	Dry-Bulb Temperature (F)	Wet-Bulb Temperature (F)
	....	....	....

ITEM	AREA (sq ft)	FACTOR (Circle the factors applicable.)				BTU/HR (Area x Factor)
1. (a) WINDOWS, Gain from Sun (Figure all windows for each exposure, but use only the exposure with the largest load.)		For glass block, reduce factors by 50%; for storm windows or double-glass, reduce factors by 15%. No Shading	Inside Shades	Outside Awnings	Load for Each Exposure (Area x Factor)	
Northeast	....	60	25	20	....	
East	....	100	40	25	....	
Southeast	....	75	30	20	....	
South	....	75	35	20	.... Use only the largest load.	....
Southwest	....	110	45	30	....	
West	....	150	65	45	....	
Northwest	....	120	50	35	....	

For calculating gain from sun through windows under overhanging roofs, see example given in Instructions.

ITEM	AREA	DESIGN DRY-BULB TEMPERATURE (F) 90	92	95	97	100	102	105	110	115	BTU/HR
(b) WINDOWS, Heat Gain (Total of all windows)											
Single-glass	....	13	15	19	22	25	27	30	36	42	....
Double-glass or glass block	....	7	8	9	10	11	12	13	16	19	....
2. WALLS											
No insulation (brick veneer, frame, stucco, etc.)	....	4	4	5	6	6	7	8	9	10	....
1 in. insulation or $^{25}/_{32}$ in. insulation sheathing	....	3	3	4	4	5	5	6	7	9	....
2 in. or more insulation	....	2	2	2	2	3	3	3	4	4	....
3. PARTITIONS (Between conditioned and unconditioned space)	....	2	2	3	3	4	4	5	6	7	....
4. ROOFS											
(a) Pitched or flat with vented air space, and:											
No insulation	....	18	18	19	20	21	21	22	24	25	....
No insulation, with attic fan	....	9	11	12	14	16	17	19	22	25	....
2 in. insulation	....	5	5	5	5	6	6	6	7	7	....
4 in. insulation	....	3	3	4	4	4	4	4	5	5	....
(b) Flat with no air space, and:											
No insulation	....	28	29	30	31	33	34	35	38	40	....
1 in. or $^{25}/_{32}$ in. insulation	....	14	14	15	16	16	17	18	19	20	....
$1\frac{1}{2}$ in. insulation	....	8	9	9	9	10	10	11	11	12	....
3 in. insulation	....	6	6	6	6	7	7	7	8	8	....
5. CEILING (Under unconditioned rooms only)	....	3	3	4	4	5	5	6	7	8	....
6. FLOORS (Omit if over basement, enclosed crawl space, or slab.)											
Over unconditioned room	....	2	2	2	3	3	4	4	5	6	....
Over open crawl space	....	3	3	4	5	5	6	7	8	9	....
7. OUTSIDE AIR Total sq ft of floor area	....	2	2	2	2	3	3	4	4	5	....
8. PEOPLE (Use minimum of 5 people)		............(number of people) x 200									....
9. SUB-TOTAL											
10. LATENT HEAT ALLOWANCE		30 per cent of Item 9									
11. TOTAL		Sum of Items 9 and 10									

Figure 8-10 Residential cooling load estimate form.

(Courtesy Amana Refrigeration, Inc.)

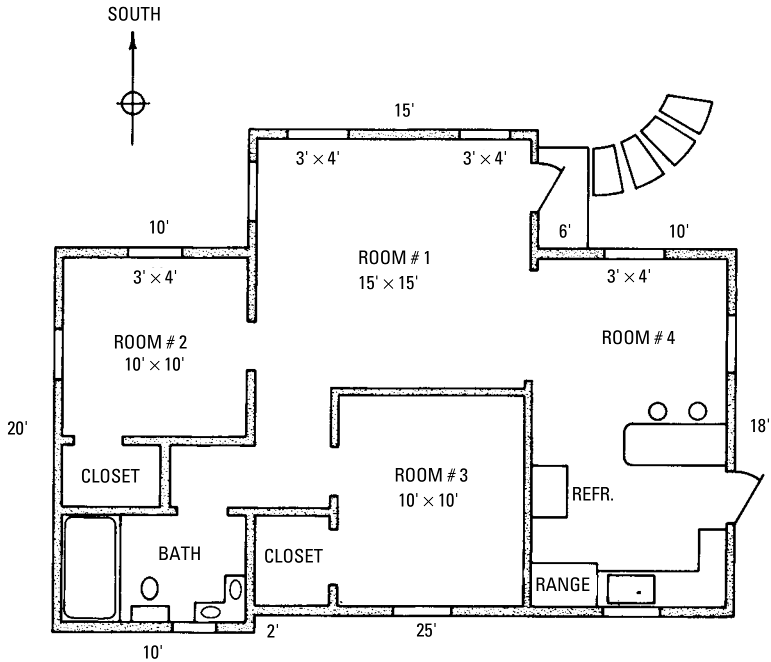


Figure 8-11 Floor plan of a one-story residence constructed on concrete slab.

The house is located 30° north, and complete exposure to the sun occurs at 1:00 P.M. The structure contains 740 square feet of floor space divided into four rooms and a bath. There are ten 3′ × 4′ windows, with four of them facing south. The indoor design temperature is 80°F.

Indoor-Outdoor Design Conditions

The indoor and outdoor design conditions must be established *before* any cooling load calculations can be made. This will be the first step in your procedure. As you will see, the *difference* between the indoor and outdoor design temperatures will eventually serve as a basis for selecting the correct size air conditioner.

Designing a system to meet the *maximum* outdoor summer temperature is generally not necessary because these temperatures either rarely occur or occur for a comparatively short duration of time. It is the general practice to design the system for slightly less severe conditions and thereby save on equipment and installation costs.

Ventilation Requirements

Each conditioned space requires a specific amount of outside fresh air to be circulated through it in order to remove objectionable odors (for example, cooking odors, tobacco smoke, body odors) and to maintain comfort standards.

Ventilation standards indicating recommended air changes for a variety of space usages and occupancy have been established by the ASHRAE. Local codes are often based on ASHRAE research and data. These ventilation standards are easy and convenient to use, but are objected to by some authorities because the sources of contamination seldom bear any relationship to cubic area.

The air-conditioning system must be capable of supplying enough outside fresh air to maintain air purity and comfort standards. The ventilation requirements for a given structure or space are based either on the desired number of air changes or the number of occupants. The volume rate of ventilation air is expressed in cubic feet per minute (cfm).

According to the ASHRAE, the outside fresh air requirement for both residences and apartments ranges from 10 cfm (minimum) to 20 cfm (recommended). Fresh air requirements for other types of structures are listed in Table 8-5.

Table 8-5 Fresh Air Requirements

Type of Building or Room	*Minimum Air Changes per Hour*	*Cubic Feet of Air per Minute per Occupant*
Attic spaces (for cooling)	12–15	
Boiler room	15–20	
Churches, auditoriums	8	20–30
College classrooms		25–30
Dining rooms (hotel)	5	
Engine rooms	4–6	
Factory buildings (ordinary manufacturing)	2–4	
Factory buildings (extreme fumes or moisture)	10–15	
Foundries	15–20	
Galvanizing plants	20–30	
Garages (repair)	20–30	
Garages (storage)	4–6	

Table 8-5 ***(continued)***

Type of Building or Room	*Minimum Air Changes per Hour*	*Cubic Feet of Air per Minute per Occupant*
Homes (night cooling)	9–17	
Hospitals (general)		40–50
Hospitals (children's)		35–40
Hospitals (contagious diseases)		80–90
Kitchens (hotel)	10–20	
Kitchens (restaurant)	10–20	
Libraries (public)	4	
Laundries	10–15	
Mills (paper)	15–20	
Mills (textile—general buildings)	4	
Mills (textile dyehouses)	15–20	
Offices (public)	3	
Offices (private)	4	
Pickling plants	10–15	
Pump rooms	5	
Restaurants	8–12	
Schools (grade)		15–25
Schools (high)		30–35
Shops (machine)	5	
Shops (paint)	15–20	
Shops (railroad)	5	
Shops (woodworking)	5	
Substations (electric)	5–10	
Theaters		10–15
Turbine rooms (electric)	5–10	
Warehouses	2	
Waiting rooms (public)	4	

The *amount* of outside fresh air required for each air change per hour equals the amount of inside air that must be removed from the structure or space during the same time span. The following formula can be used to determine the amount of air supplied per minute:

$$\text{CFM} = \frac{\text{area in cubic feet}}{\text{minutes of air change}}$$

The floor plan of the residence shown in Figure 8-11 contains 740 square feet. The height of each room is 7 feet, which gives an area of 5180 cubic feet.

Table 7-1 in Chapter 7 ("Ventilation and Exhaust Fans") lists the number of average air changes per minute required for good ventilation for a number of different applications. You will note that each listed air change ranges from a minimum to a maximum number of changes. The rate of air change you select will depend on the following:

1. Geographical location
2. Occupancy
3. Ceiling height

Warmer climates and larger numbers of occupants require a greater rate of air change. Conversely, an 8-foot ceiling will require more ventilation than a 15-foot ceiling.

Using a 3-minute rate of air change for the residence illustrated in Figure 8-11, the required number of air changes necessary to give proper ventilation can be determined as follows:

$$\text{CFM} = \frac{5180 \text{ cu. ft.}}{3} = 1726.7$$

Thus, 1726.7 cfm is needed to change the air every 3 minutes (or 20 air changes every hour).

Always check the local health department codes or local building codes for required ventilation standards first. If none exist, use the recommended air changes listed in this table, or data available from ASHRAE research.

Cooling a Structure

The aspect of air-conditioning most familiar to us is the reduction of indoor temperatures to a comfortable level. There are a number of different sources of indoor heat, some are external and some are internal.

External Sources of Heat

The principal sources of heat from outside the structure are solar radiation, heat leakage, infiltration, and ventilation.

Heat Leakage

Heat leakage refers to the amount of heat flow through structural sections and is stated in Btu per hour, per degree Fahrenheit, per square foot of exposed surface. A significant portion of the total heat gain of a space is due to heat from the outside of a structure or from a nonconditioned space passing (that is, leaking) through walls, ceilings, floors, and roofs to the interior of the structure.

The coefficient of heat transmission (U-factor) is the specific value used in determining the amount of heat leakage. It has already been described in Chapter 4 ("Heating Calculations") in Volume 1 in the section *Heat Loss*. Actually the only difference between heat leakage and heat loss is the direction of heat flow. Both are concerned with the same thermal properties of construction materials and the rate at which heat flows through them. Insofar as heat leakage is concerned, the direction of heat flow is from the outside to the inside of the structure. In the case of heat loss, the reverse is true.

The formula used for calculating heat leakage is identical to the one used for heat loss, and may be stated as follows:

$$Q = UA(t_o - t_i)$$

where,

Q = Amount of heat transmission in Btu/h

U = Overall coefficient of heat transfer (U-factor) between the adjacent space and the conditioned space (stated in Btu per hour, per square foot, per degree Fahrenheit)

t_o = Air dry-rule temperature in degrees Fahrenheit of adjacent space or outdoors

t_i = Air dry-bulb temperature in degrees Fahrenheit of conditioned space of the structure

Heat Gain from Solar Radiation

A portion of the heat gain in the interior of a structure can be attributed to solar radiation coming in through the windows. To disregard this factor when calculating the total loads of the structure can result in serious error. It is particularly important to consider the *type* of shading because this will determine the amount of heat gained from solar radiation.

One method of determining heat gain from solar radiation *through window glass* is illustrated by the following equation:

$$\begin{array}{l} \text{Total} \\ \text{Instan-} \\ \text{taneous} \\ \text{Heat} \\ \text{Gain} \\ \text{Through} \\ \text{Window} \\ \text{Glass} \end{array} = \begin{array}{l} \text{Area of} \\ \text{Window} \\ \text{Glass} \end{array} \times \begin{array}{l} \text{Factor} \\ \text{for} \\ \text{Shading} \end{array} \times \begin{array}{l} \text{Heat} \\ \text{Gain by} \\ \text{Solar} \\ \text{Radiation} \end{array} + \begin{array}{l} \text{Heat} \\ \text{Gain by} \\ \text{Convection} \\ \text{and} \\ \text{Radiation} \end{array}$$

The ASHRAE has conducted extensive research into all aspects of solar radiation, and makes the results of this research available through its publications. As you saw earlier, Tables 8-3 and 8-4 were adapted by permission from the *ASHRAE 1960 Guide* to illustrate the aforementioned equation for determining total instantaneous heat gain through window glass.

Calculating the amount of heat gain due to solar radiation through a glass window can be even more clearly illustrated by using the above equation to solve a problem. Let us assume that you have a residence containing four 3′ × 4′ windows *facing south*. The structure is located 30° north, and complete exposure to the sun occurs at 1:00 P.M. The indoor temperature is 80°F. The windows are shaded by dark brown canvas awnings that are open at the sides. As you will note by looking carefully at Tables 8-6 and 8-7, each of these points in the description of the structure is important in the solution. The total instantaneous heat gain through these windows can be determined as follows:

1. Window glass area = 3′ × 4′ = 12 square feet
2. Factor for shading = 0.25
3. Heat gain by solar radiation = 45 Btu/h per square foot
4. Heat gain by convection and radiation = 17 Btu/h per square foot

Total instantaneous heat gain through the four windows can be found as follows:

$$12 \times (0.25 \times 45 + 17)$$
$$12 \times 28.25$$
$$339 \text{ Btu/h (for one window)} \times 4 \text{ windows}$$
$$1356 \text{ Btu/h}$$

In Table 8-7, note that the shading factors are given not only for such items as shading screens and awnings located on the outside of the structure but also for window shades, venetian blinds, and draperies located on the inside. It is *always* recommended that windows of air-conditioned spaces be shaded in some manner.

Heat Gain from Infiltration and Ventilation

A certain amount of warm outdoor air will enter the interior of a structure by means of infiltration and ventilation. Both phenomena are described in considerable detail in Chapter 6 (“Ventilation

Table 8-6 Heat Gain Due to Solar Radiation (Single Sheet of Unshaded Common Window Glass)

	Sun Time		*Instantaneous Heat Gain in Btu per Hour (ft²)*								
Latitude	*A.M.* →	*P.M.* ↓	*N*	*NE*	*E*	*SE*	*S*	*SW*	*W*	*NW*	*Horiz.*
30° north	6 A.M.	6 P.M.	25	98	108	52	5	5	5	5	17
	7	5	23	155	190	110	10	10	10	10	71
	8	4	16	148	205	136	14	13	13	13	137
	9	3	16	106	180	136	21	15	15	15	195
	10	2	17	54	128	116	34	17	16	16	241
	11	1	18	20	59	78	45	19	18	18	267
	12		18	19	19	35	49	35	19	19	276
40° north	5 A.M.	7 P.M.	3	7	6	2	0	0	0	0	1
	6	6	26	116	131	67	7	6	6	6	25
	7	5	16	149	195	124	11	10	10	10	77
	8	4	14	129	205	156	18	12	12	12	137
	9	3	15	79	180	162	42	14	14	14	188
	10	2	16	31	127	148	69	16	16	16	229
	11	1	17	18	58	113	90	23	17	17	252
	12		17	17	19	64	98	64	19	17	259

(continued)

Table 8-6 *(continued)*

Latitude	Sun Time A.M. →	P.M. ↓	N	NE	E	SE	S	SW	W	NW	Horiz.
			Instantaneous Heat Gain in Btu per Hour (ft^2)								
50° north	5 A.M.	7 P.M.	20	54	54	20	3	3	3	3	6
	6	6	25	128	148	81	8	7	7	7	34
	7	5	12	139	197	136	12	10	10	10	80
	8	4	13	107	202	171	32	12	12	12	129
	9	3	14	54	176	183	72	14	14	14	173
	10	2	15	18	124	174	110	16	15	15	206
	11	1	16	16	57	143	136	42	16	16	227
	12		16	16	18	96	144	96	18	16	234
		↑	N	NE	E	SE	S	SW	W	NW	Horiz.
		P.M. →									

(Courtesy ASHRAE 1960 Guide)

Table 8-7 Shade Factors for Various Types of Shading

Type of Shading	*Finish on Side Exposed to Sun*	*Shade Factor*	
Canvas awning sides open	Dark or medium	0.25	
Canvas awning top and sides tight against building	Dark or medium	0.35	
Inside roller shade, fully drawn	White, cream	0.41	
Inside roller shade, fully drawn	Medium	0.62	
Inside roller shade, fully drawn	Dark	0.81	
Inside roller shade, half drawn	White, cream	0.71	
Inside roller shade, half drawn	Medium	0.81	
Inside roller shade, half drawn	Dark	0.91	
Inside venetian blind, slats set at 45°	White, cream	0.56	
Inside venetian blind, slats set at 45°	Diffuse reflecting aluminum metal	0.45	
Inside venetian blind, slats at 45°	Medium	0.65	
Inside venetian blind, slats set at 45°	Dark	0.75	
Outside venetian blind, slats set at 45°	White, cream	0.15	
Outside venetian blind, slats set at 45° extended as awning fully covering window	White, cream	0.15	
Outside venetian blind, slats set at 45° extended as awning covering 2/3 of window	White, cream	0.43	
		Dark	***Green tint***
Outside shading screen, solar altitude 10°		0.52	0.46
Outside shading screen, solar altitude 20°		0.40	0.35
Outside shading screen, solar altitude 30°		0.25	0.24
Outside shading screen, solar altitude, above 40°		0.15	0.22

(Courtesy ASHRAE 1960 Guide)

Principles") and in the section *Ventilation Standards* in this chapter. These materials should be read before proceeding any further.

Insofar as cooling load calculations are concerned, infiltration (that is, natural ventilation) is the leakage of warmer outdoor air into the interior of a structure usually as the result of wind pressure. This occurs primarily through cracks around windows and doors. As a result, the *crack method* is considered the most accurate means of calculating heat leakage by air infiltration (see the appropriate section of Chapter 4 in Volume 1 ("Heating Calculations"). A rule-of-thumb method for calculating heat leakage around doors located in exterior walls is to allow *twice* the window heat leakage.

Some authorities feel that infiltration will fulfill the ventilation requirements of small structures (for example, houses, offices, and small shops) and that no special provisions need be made for a mechanical ventilating system. Unfortunately, there is little or no infiltration on days during which the outdoor air is perfectly still.

The amount of ventilation is generally determined by the number of air changes (inside air replaced by air from the outdoors) required by a structure. This is most commonly based on the number of occupants and building use. In structures having air-conditioning, *most* of the outdoor air used for ventilation will pass through the air-conditioning unit. A small portion of the air will bypass the air-conditioning coils and add to the sensible and latent heat levels of the interior spaces of the structure. The temperature and humidity of the air that does pass over the cooling coils of the unit are reduced to room conditions or below.

Internal Sources of Heat

A number of heat sources within a structure contribute to heat gain independently from outside sources. The most important internal heat gain sources are the following:

1. People
2. Electric lighting
3. Appliances
4. Electric motors
5. Steam

The occupants of conditioned spaces give off both sensible and latent heat. The *amount* of heat gain will depend on a number of variables, including (1) the duration of occupancy, (2) the number of people, and (3) their principal activity. Table 8-8 lists estimated heat gains from a variety of activities performed by individuals.

Table 8-8 Rate of Heat Gain from Occupants of Conditioned Spaces

Degree of Activity	***Typical Application***	***Total Heat Adults, Male (Btu/h)***	***Total Heat Adjusted (Btu/h)***	***Sensible Heat (Btu/h)***	***Latent Heat (Btu/h)***
Seated at rest	Theater—matinee	390	330	180	150
	Theater—devening	390	350	195	155
Seated, very light work	Offices, hotels, apartments	450	400	195	205
Moderately active office work	Offices, hotels, apartments	475	450	200	250
Standing, light work, walking slowly	Department store, retail store, dime store	550	450	200	250
Walking, seated	Drugstore, bank	550	500	200	300
Standing, walking slowly					
Sedentary work	Restaurant	490	550	220	330
Light bench work	Factory	800	750	220	530
Moderate dancing	Dance hall	900	850	245	605
Walking 3 mph, moderately heavy work	Factory	1000	1000	300	700
Bowling	Bowling alley	1500	1450	465	985
Heavy work	Factory				

(Courtesy ASHRAE 1960 Guide)

Calculating Infiltration and Ventilation Heat Gain

It has been shown that outdoor air enters a structure by means of both infiltration and ventilation. Because air is composed of a mixture of dry air and moisture particles, the heat gain produced by the entering air will be expressed in terms of both its sensible heat gain and its latent heat gain in Btu per hour.

The sensible and latent heat gain resulting from entering air represents only a small portion of the total heat gain involved in determining the design cooling load of a structure. For many applications, however, the calculation of this portion of the heat gain is crucial to a well-designed system. The following formulas, adapted from ASHRAE materials, are used for making these calculations:

(1) $Q_S = \text{cfm} \times 1.08\ (t_o - t_i)$
(2) $Q_L = \text{cfm} \times 0.68\ (w_o - w_i)$
(3) $Q_T = Q_S + Q_L$

where,
Q_S = Sensible load
Q_L = Latent load
Q_T = Total load
cfm = Rate of entry of outdoor air (cubic feet per minute)
t_o = Dry-bulb temperature of outside (entering) air
t_i = Dry-bulb temperature of inside air
w_o = Outdoor wet-bulb temperature
w_i = Indoor wet-bulb temperature

In order to use these formulas, it is first essential to determine the outdoor and indoor design conditions (that is, the dry-bulb and wet-bulb temperatures) and the maximum rate of entering air (in cubic feet per minute).

Rule-of-Thumb Methods for Sizing Air Conditioners

Manufacturers of air-conditioning equipment and mail order houses (for example, Sears, Montgomery Ward) that sell air-conditioning equipment through their catalogs provide rule-of-thumb methods for calculating the size of the air conditioner required by a structure. The Btu calculation formulas are based on recommended coefficient factors for different types of construction and conditions. The responsibility for calculating the cooling load (and ultimately selecting a suitable air conditioner) lies with the purchaser of the equipment.

The problem of using *any* rule-of-thumb method is that the results are not precise. In other words, the results represent an approximate estimate; not the results one would expect from an engineer's calculations. There is always the danger of oversizing or undersizing the air conditioner. Under normal conditions, however, this method of calculating the size of a central air conditioner is reasonably accurate.

The Btu tabulation and cooling estimate forms illustrated in Figures 8-9 and 8-10 are typical examples of the forms provided by manufacturers of air-conditioning equipment. Note that these forms not only provide coefficient factors for various types of construction but also recommend standard loads for different activities. For example, the cooling load estimate form shown in Figure 8-10 provides for a latent heat allowance of 30 percent of the total heat gain from all other sources. Another example of this practice is the commonly used standard load of 1500 Btu for kitchen activities. People are usually given a 200 Btu allowance per person, and residences are calculated on the basis of two people per bedroom. Thus, a three-bedroom house would have a 1200 Btu allowance for six people ($3 \times 2 = 6 \times 200 = 1200$ Btu).

The Btu calculation formulas used with the various rule-of-thumb methods also provide for temperature and humidity adjustments where conditions differ from the recommended levels. This is sometimes accomplished by providing humidity factors and a range of dry-bulb temperature differences (see Figure 8-9) or by providing humidity and temperature adjustment allowances. In the latter case, the coefficient factors are usually based on a specific wet-bulb temperature and dry-bulb temperature difference. If, for example, the former were 75°F and *your* wet-bulb reading were 80°F, the instructions might require that you add 10 percent of the total heat gain of the structure for the humidity adjustment. Similar allowances are provided for temperature adjustments.

One of the easier and more popular rule-of-thumb methods employed for calculating the size of *large* central air conditioners is to use one ton of refrigeration for each 500–700 square feet of floor area, or each 5000–7000 cubic feet of space. A *ton of refrigeration* is equivalent to 12,000 Btu per hour. This figure is based on the fact that 1 lb of melting ice will absorb 144 Btu of heat over a 24-hour period. Therefore, a ton of ice will absorb 288,000 Btu during the same period of time (that is, 144 Btu $\times$ 2000 lbs) ($288{,}000 \div 24$ hours = 1 ton of refrigeration).

HVAC Contractor's Cooling Load Estimate

If you are not satisfied with your own cooling load estimate, you should invite several air-conditioning contractors to give their bids. This is particularly true if you are considering a central air-conditioning system. For a central air-conditioning system, each contractor should include the estimated Btu per hour required to cool the structure. Each of the bids should be fairly close in estimated Btu and cost. Your choice will be based largely on availability of replacement parts, the reputation of the local dealer for quick and reliable service, and the estimated Btu output. You will naturally want an air-conditioning system that will efficiently remove the required amount of heat. If this proves to be more expensive than another type, you would be wise to choose the more expensive one because your operating costs will be cheaper over the long run. Any contractor's bid that shows a wide variation from the others either in cost or estimated Btu required to cool the structure should be regarded with some suspicion. It may simply be an attempt to win the contract. Most reliable bids will be fairly close.

Using the ACCA Design Manuals for Sizing Air-Conditioning Systems

The Air-Conditioning Contractors of America (ACCA) publishes a series of manuals used by contractors to size heating and cooling loads. These manuals are updated regularly to match changes in HVAC technology and construction materials. These manuals are available for purchase from the ACCA web site (or their mailing address) by both members and nonmembers. Check the ACCA listing in Appendix A ("Professional and Trade Associations").

- ***Manual J Residential Load Calculation (8th Edition).*** *Manual J* provides the contractor with the industry-standard residential load calculation method, required by most building codes around the country. The revised and expanded eighth edition procedures produce improved equipment sizing loads for single-family detached homes, small multiunit structures, condominiums, town houses, and manufactured homes.
- ***Manual S Residential Equipment Selection.*** *Manual S* is an essential companion to *Manual J*. It describes how to select and size heating and cooling equipment to meet *Manual J* loads based on local climate and ambient conditions at the building site. *Manual S* covers sizing strategies for all types of cooling and heating equipment, as well as how to use comprehensive manufacturer's performance data on sensible, latent, or heating capacity for various operating conditions.
- ***Manual C What Makes a Good Air-Conditioning System?*** *Manual C* provides an overview of appropriate air-handling characteristics for an efficient and comfortable HVAC system.

- *Manual D Residential Duct Systems. Manual D* describes the different types of residential duct systems, their selection, and their application. Design criteria for duct systems are included in this manual.

Note

Use the *ACCA Manual N* for sizing the heating or cooling equipment in commercial or industrial buildings. Typically, these structures are larger than homes, are constructed differently, and have correspondingly greater internal HVAC loads. Using an HVAC load calculation method designed for homes can result in oversizing or undersizing the HVAC equipment.

Central Air-Conditioning

The term central air-conditioning refers not so much to the method of cooling used in a structure as it does to the type of installation and its location. A central air-conditioning system is one that is generally *centrally* located in a structure in order to simultaneously serve a number of rooms and spaces.

The following sections describe first the different cooling methods used in central air-conditioning systems and then the various central air-conditioning applications used in homes and light commercial buildings.

Cooling Methods

Central air-conditioning can be accomplished by means of a variety of different cooling methods. The following are described in this chapter:

1. Evaporative cooling
2. Cold-water coil cooling
3. Gas compression refrigeration
4. Gas absorption refrigeration
5. Thermoelectric refrigeration
6. Cooling with steam

In a majority of air-conditioning installations, and almost exclusively in the smaller horsepower range found in residences and small commercial buildings, the vapor or gas compression method of cooling is used (see *Gas Compression Refrigeration*).

A comparatively recent entry into the field of residential air-conditioning is thermoelectric refrigeration. This method of cooling is based on the thermocouple principle; the cool air is produced by the cold junctions of a number of thermocouples wired in series (see *Thermoelectric Refrigeration*).

Absorption refrigeration and cooling with steam are cooling methods generally found in large commercial and industrial applications (see *Gas Absorption Refrigeration* and *Cooling with Steam*).

Evaporative Cooling

An evaporative cooling system cools the indoor air by lowering its dry-bulb temperature. In effect, it cools by evaporation, and it accomplishes this function by means of an evaporative cooler. Figures 8-12, 8-13, and 8-14 show the basic components of three evaporative coolers.

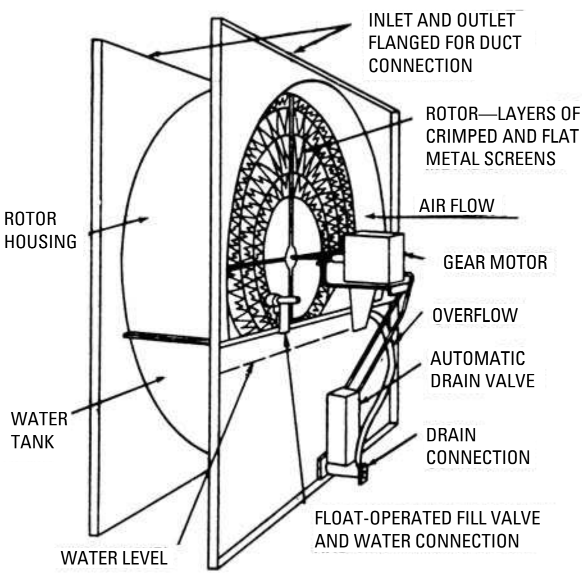


Figure 8-12 Typical rotary evaporative cooler.
(Courtesy 1965 ASHRAE Guide)

As shown in Figure 8-15, an evaporative cooler consists of a blower and blower motor, water pump, water distribution tubes, water pads, and a cabinet with louvered sides. In operation, the blower draws air through the louvers of the cabinet where it comes into contact with the moisture in the pads. The air passes through these moist water pads and into the interior of the structure.

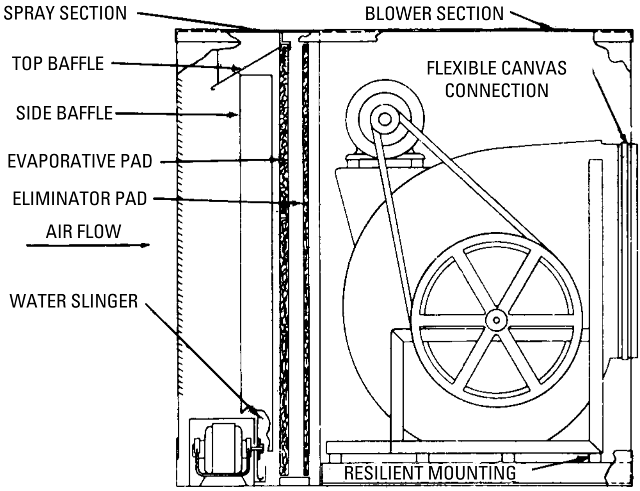


Figure 8-13 Typical spray evaporative cooler.
(Courtesy 1965 ASHRAE Guide)

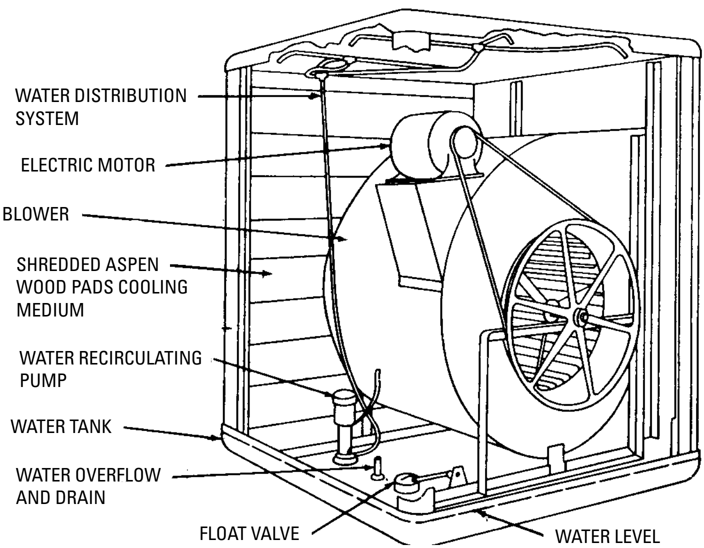


Figure 8-14 Typical drip evaporative cooler.
(Courtesy 1965 ASHRAE Guide)

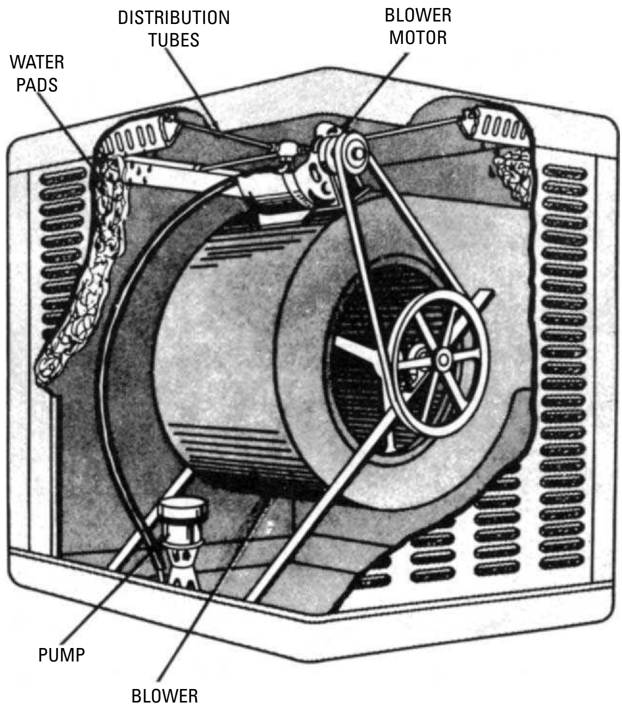


Figure 8-15 Evaporative cooler. *(Courtesy Honeywell Tradeline Controls)*

The water in the pads absorbs heat from the air as it passes through them. This causes a portion of the water to evaporate and lowers the dry-bulb temperature of the air as it enters the room or space. It is this lower dry-bulb temperature that produces the cooling effect.

In an evaporative cooling system, the water is recirculated and used over and over again. Only enough water is added to replace the amount lost by evaporation. The pump supplies water to the pads through the distribution tubes.

The air is never recirculated because it contains too much moisture once it has passed through the evaporative cooler. New air must always be drawn from the outdoors.

An evaporative cooling system is generally not very effective in a humid climate because the outdoor air is not dry enough. Evaporative coolers have been used for years with excellent results in New Mexico, Arizona, Nevada, and similar areas with dry climates.

Cold-Water Coil Cooling

Indoor air temperatures can also be reduced by passing warm room air over a cold surface, such as a water-cooled coil, and then recirculating it back into the room. When a water-cooled coil is used for this purpose, the system is referred to as *cold-water coil cooling* (see Figure 8-16).

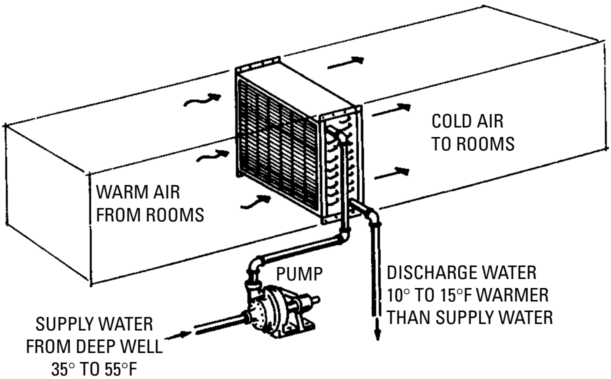


Figure 8-16 Cold-water coil cooling. *(Courtesy Honeywell Tradeline Controls)*

A water-cooled coil is effective only when there is a sufficient supply of cold water. The temperature of the water should range from 35° to 55°F, and the most common source is a deep well. A pump supplies the cold water to the coil where it picks up heat from the air passing through it. This warmer water is then discharged to a storm sewer, dry well, or some other outdoor receiver. The discharge water is approximately 10° to 15°F warmer than the supply water.

Gas Compression Refrigeration

A gas compression refrigeration air-conditioning system operates on the direct-expansion cooling principle. Basically the system consists of a compressor, condenser coil, receiver, expansion device, and evaporator coil. A refrigerant flowing through the system is affected by temperature and pressure acting simultaneously in such a way that heat is transferred from one place to another. In other words, heat is *removed* from the room air for cooling and added to it for heating.

Mechanical Refrigeration Cycle

The *mechanical refrigeration cycle* is illustrated schematically in Figure 8-17. The *liquid* refrigerant is contained initially in the

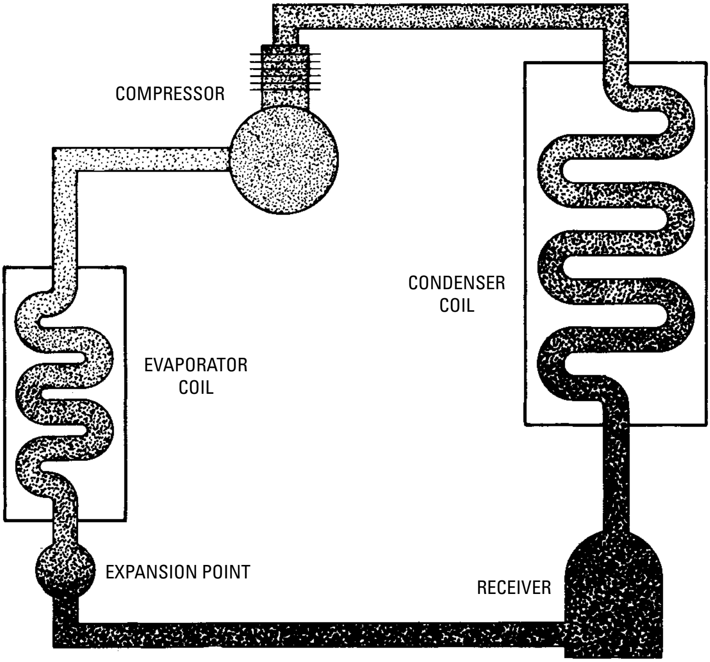


Figure 8-17 Mechanical refrigeration cycle. *(Courtesy Honeywell Tradeline Controls)*

receiver, which is usually located in the lower section of the condenser, although it can be a separate tank. The compressor, acting as a pump, forces the liquid refrigerant under high pressure through the liquid line to the expansion device.

The function of the expansion device is to regulate the flow of refrigerant into the evaporator coil. This expansion device may be in the form of an expansion valve or a capillary tube.

As the high-pressure liquid refrigerant is forced through the expansion device, it expands into a larger volume in the evaporator, thus reducing its pressure and consequently its boiling temperature. Under this low pressure, the liquid refrigerant boils until it becomes a vapor. During this change of state, the refrigerant absorbs heat from the warm air flowing across the outside of the evaporator.

After the refrigerant has boiled or vaporized, thus removing its quota of heat, it is of no more value in the evaporator coil and must be removed to make way for more liquid refrigerant. Instead of being exhausted to the outdoor air, the low-pressure heat-laden refrigerant vapor is pumped out of the evaporator through the suction line to the compressor. The compressor then compresses the refrigerant vapor, increasing its temperature and pressure and forces it along to the condenser.

At the condenser, the hot refrigerant vapor is cooled by lower temperature air passing over the condenser coils, thus absorbing some of the refrigerant heat. As a result, the air temperature increases and the refrigerant temperature decreases until the refrigerant is cooled to its saturation condition. At this condition, the vapor will condense to a liquid. The liquid, still under high pressure, flows to the expansion device, thus completing the cycle.

Note that cold is *never* created during the mechanical refrigeration cycle. Instead, heat is merely transferred from one place to another. When the refrigerant passes through the evaporator, it absorbs heat from the room air, thereby cooling it. When the higher-temperature refrigerant passes through the condenser, it gives up heat to the air entering the room, thereby warming it.

Gas Absorption Refrigeration

The *gas absorption refrigeration* method of cooling uses heat as its energy instead of electricity. This heat can be in the form of steam from a gas-fired or oil-fired atmospheric steam generator, or it can come from a gas or oil burner applied directly to the refrigeration generator. Normally, water is used as the refrigerant and lithium bromide as an absorbent. The absorption unit operates under a vacuum that gives the water a boiling temperature low enough for comfort cooling.

The absorption refrigeration system shown in Figure 8-18 is charged with lithium bromide and water, the lithium bromide being the absorbent and the water the refrigerant. This solution is contained within the refrigeration generator.

As steam heat is applied to the generator, a part of the refrigerant (water) is evaporated or boiled out of the solution. As this water vapor is driven off, absorbent solution is raised by vapor lift action to the separating chamber (5) above the generator.

Refrigerant (water) and absorbent separate in the vapor separating chamber (5), the refrigerant vapor rises to the condenser (6), and the separated absorbent solution flows down through a tube (8) to the liquid heat exchanger and thence to the absorber.

The refrigerant (water vapor) passes from the separating chamber to the condenser through a tube (6), where it is condensed to a liquid by the cooling action of water flowing through the condenser tubes. The cooling water that flows through the condenser is brought from some external source, such as a cooling tower, city main, or well.

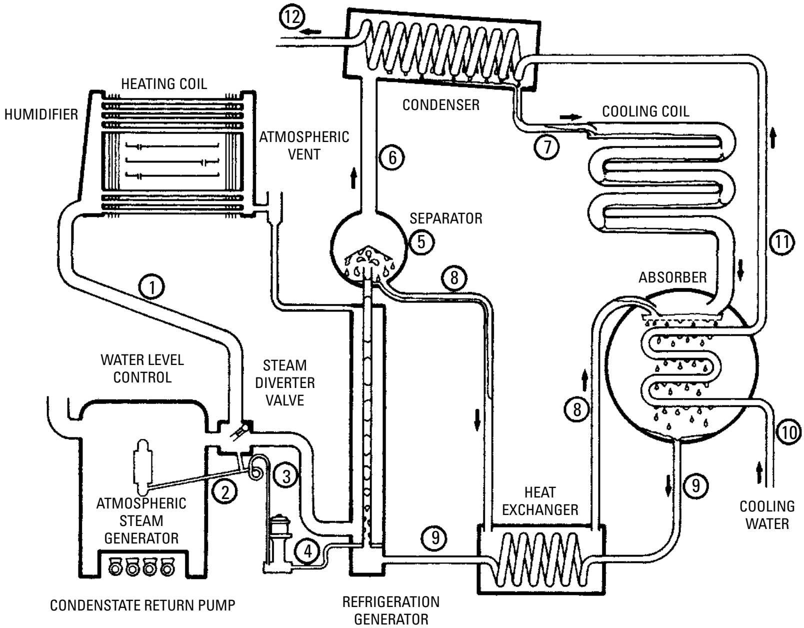


Figure 8-18 Gas absorption refrigeration unit.

The refrigerant vapor thus condensed to water within the condenser then flows through a tube (7) into the cooling coil. This tube contains a restriction that offers a resistance and therefore a pressure barrier to separate the slightly higher absolute pressure in the condenser from the lower pressure within the cooling coil. The refrigerant (water) entering the cooling coil vaporizes due to the lower absolute pressure (high vacuum) that exists within it. The high vacuum within the evaporator lowers the boiling temperature of water sufficiently to produce the refrigeration effect.

The evaporator or cooling coil is constructed with finned horizontal tubes, and the air being cooled flows horizontally over the coil surface. Evaporation of the refrigerant takes place within the cooling coil, the heat of evaporation for the refrigerant is extracted from the air stream, and cooling and dehumidifying are accomplished.

In the absorber, the solution absorbs the refrigerant vapors that were formed in the evaporator directly adjacent. To explain the presence of the absorbent at this point, it is necessary to divert attention back to the generator. The absorbent was separated from the refrigerant by boiling action. The absorbent then drains from the separator (5) down to the liquid heat exchanger and then to the absorber through the tube (8) designed for this purpose. The flow of solution in this circuit can actually exist by gravity action only because the absorber is slightly below the level of the separating chamber.

It must be understood at this point that lithium bromide in either dry or solution form has a very strong affinity for water vapor. It is because of this principle that the refrigerant vapor is absorbed back into solution again. Because the *rate* of absorption is increased at lower temperatures, a water-cooling coil is provided within the absorber shell.

The resultant mixture of refrigerant and absorbent drains back through the heat exchanger through another tube (9) to the refrigeration generator where it is again separated into its two component parts to repeat the cycle.

The liquid heat exchanger serves to increase operating efficiency. The absorbent solution leaves the refrigeration generator at a relatively high temperature. Because its affinity for water vapor is increased as its temperature is reduced, precooling is desirable before it enters the absorber. Conversely, the combined solution of refrigerant and absorbent leaving the absorber and flowing toward the generator is relatively cool.

Because heat is applied in the generator to drive off water vapor, it is desirable to preheat this liquid before it enters the generator. With counterflow action in the liquid heat exchanger, both precooling and preheating are accomplished within the solution circuit.

As stated previously, a high vacuum exists throughout all circuits. However, a slightly higher absolute pressure exists in the generator and condenser than in the cooling coil and absorber. This difference in pressure is maintained by a difference in height of the solution columns (or restrictor) in the various connecting tubes.

The effect of heat applied to the refrigeration generator raises the absorbent solution to the vapor separator located at the top of the generator. The absorbent solution is able to flow from the generator to the absorber by gravity, aided by the slight pressure differential between the two chambers.

In the absorber, water vapor is taken into the solution, which then flows back to the bottom of the generator. Because the pressure in the absorber is slightly below that in the generator, solution flow from a low-pressure area to one of relatively higher pressure is accomplished by the higher elevation of the absorber.

The water vapor (refrigerant) released from the generator rises to the condenser, where it is condensed to a liquid. Elevation of the condenser permits gravity flow of the refrigerant to the evaporator, aided by the slight pressure differential between the two chambers. Thus, by taking advantage of differences in fluid temperatures, density, and height of columns, continuous movement in the same direction throughout all circuits is accomplished without moving parts.

The cooling-water circuit can be traced in Figure 8-18 by noting that it enters the absorber coil at point 10. Flow is then directed through tube 11 to the condenser and leaves the unit at point 12.

Figure 8-19 shows a schematic sectional diagram of a typical absorption year-round air conditioner. Inlet air enters a plenum chamber that contains filter elements. The air, after having been

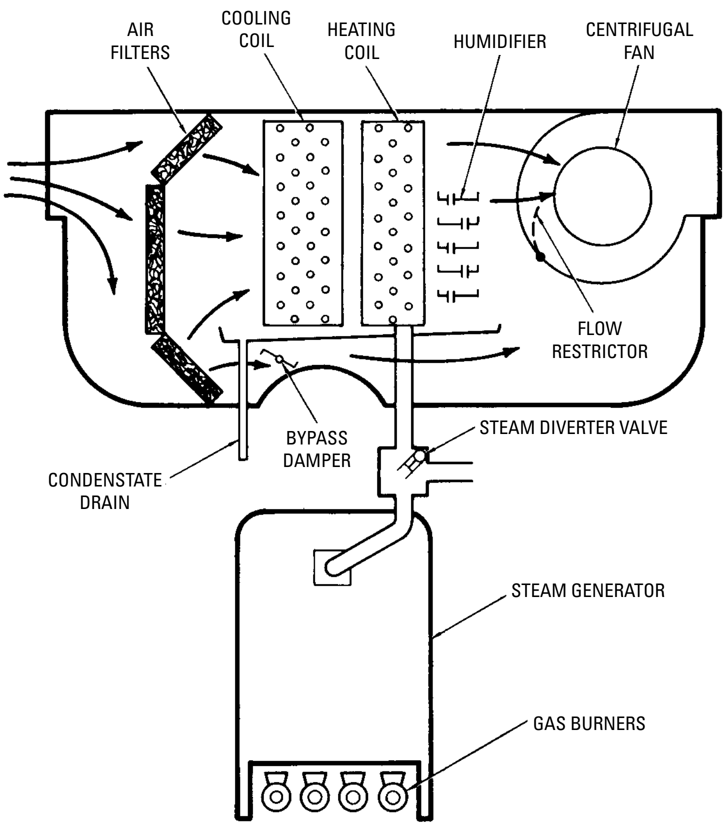


Figure 8-19 Typical absorption year-round air conditioner.

cleaned, passes through the cooling coil (evaporator) and heating coil, and is then returned to the rooms or spaces being cooled.

During the cooling cycle, the room air is cooled and dehumidified. Heat is extracted from the air and moisture is condensed on the cooling coil. Thus, both functions of cooling and dehumidification are performed simultaneously. During the heating cycle, the air is warmed by the steam heating coil, and moisture is added by the humidifier.

Steam is provided for both heating and cooling cycles by the steam generator located in the base of the conditioner. Steam at atmospheric pressure flows from the generator into a two-position steam diverter valve, which automatically directs the flow of steam to either the heating coil or the absorption refrigeration unit. The steam diverter valve is positioned by an electric motor governed by a remote heating and refrigeration switch.

After the air leaves the heating coil, it passes through the humidifier, which functions during the heating cycle only. The humidifier, in this installation, consists of a number of horizontal trays, each equipped with an overflow tube that feeds water to the next lower tray. This arrangement provides a large evaporative surface for positive humidification. Water is supplied at a predetermined and controlled rate of flow to the humidifier trays.

The air is drawn through the unit by a centrifugal fan that delivers the heated or cooled air through a duct-distributing system to the various rooms or spaces being conditioned. Because less air is normally required for winter heating than for summer cooling, a flow-restricting device is mounted in the fan scroll and functions on the heating cycle to automatically reduce the flow of air by adding resistance. This device usually consists of a pivoted blade, and its location is indicated by the dotted line in Figure 8-19.

When maximum air delivery is desired, the air-restricting device is positioned tightly against the inside column of the fan scroll. When the restrictor is pivoted toward the fan wheel, thereby reducing normal wheel clearance, a resistance is thus imposed which alters fan performance to reduce air delivery. The airflow-restricting device is moved automatically between predetermined summer and winter positions by the motor that governs its operation.

Correct air distribution practices dictate a need in some cases for the handling of a greater quantity of air on the cooling cycle than required by the refrigeration unit for full-rated cooling capacity. Should this excess air be needed, the amount in excess of rated quantity should be handled through the bypass, thus ensuring correct cooling coil performance. The bypass damper is located in the air circuit just beyond the cooling coil. During the heating season, the bypass damper will automatically be repositioned by the controlling motor to the closed position.

Thermoelectric Refrigeration

Thermoelectric refrigeration is a cooling method developed comparatively recently for use in residential air-conditioning, although the operating principle is not new. Thermoelectric refrigeration has been used for years as a cooling method for small refrigerators. It is also the cooling used on nuclear submarines.

Thermoelectric refrigeration is based on the thermocouple principle. In a thermoelectric refrigeration cooling system, electricity in the form of direct current power is applied to the thermocouple and heat is produced. The heat is transferred from one junction to the other producing a hot and cold junction. The direction of current flow determines which junction is hot and which is cold. If the power supply connections are reversed, the positions of the hot and cold junctions are also reversed.

The amount of cooling or heating that can be produced with a single thermocouple is small. For that reason, a number of thermocouples are wired in a series to produce the quantity of heating and cooling required by the installation.

The schematic of a typical thermoelectric cooling system shown in Figure 8-20 illustrates how direct current power is applied to a number of thermocouples wired in series. Heat is transferred from one side to the other depending on the direction of current flow.

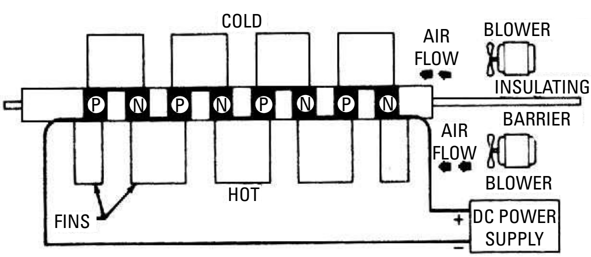


Figure 8-20 Typical thermoelectric refrigeration cooling system. *(Courtesy Honeywell Tradeline Controls)*

Cooling with Steam

Cooling with steam is based on the well-known fact that the boiling point of any liquid depends on the pressure to which it is subjected. By lowering the pressure, the boiling point is also lowered. When a liquid at a certain temperature and corresponding boiling point is sprayed into a closed vessel in which the pressure is lower, the entering liquid is above its boiling point at the new reduced pressure, and rapid evaporation takes place.

The basic components of a typical steam cooling system are shown in Figure 8-21. In operation, the water to be cooled, returning from the air-conditioning or other heat-exchanging apparatus at a temperature of 50°F, is sprayed into the evaporator. Because of the large surface of the spray, the boiling (or flashing) is very rapid and the unevaporated water falls to the bottom of the evaporator chilled to 40°F. At this temperature it is withdrawn from the evaporator by the chilled water pump and pumped to the heat-exchanging apparatus to again absorb heat, thus completing the cycle.

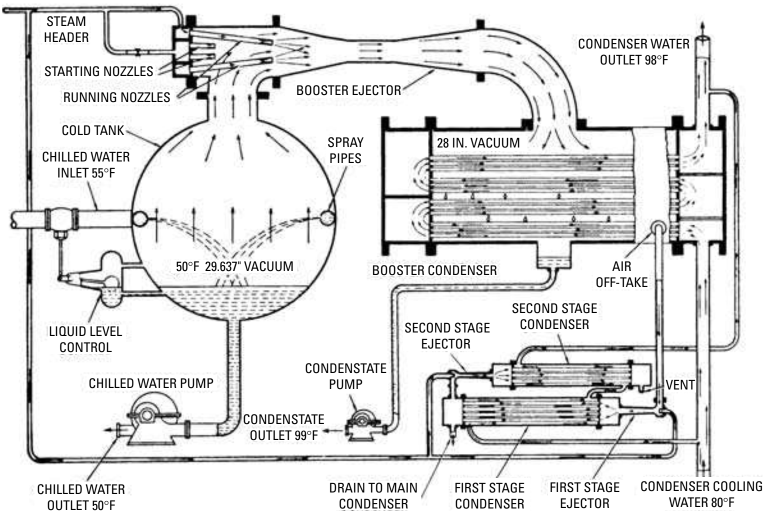


Figure 8-21 Basic components of a steam cooling system.
(Courtesy 1965 ASHRAE Guide)

In the booster ejector, steam flowing at high velocity through nozzles located in the ejector head is expanded in the venturi-shaped diffuser. The kinetic energy of the steam is in part utilized in imparting velocity to the water vapor liberated in the evaporator and in compressing this vapor over a compression range from the evaporator pressure to the condenser pressure. In this compression, the temperature of the water vapor is raised so that it can be readily condensed by condensing water at temperatures normally available.

The initial evacuation and constant purging of air and other noncondensable gases is handled by a secondary group of ejectors and condensers. These are relatively small in size, but of the greatest importance, and normally consist of two steam-operated ejectors in series, each with its own condenser in which condensing water condenses the propelling water and entrained vapor. Condensers used in a steam cooling system may be either of the surface type, with water passing through condenser tubes over which the mixture of operating steam and water vapor flows, or of the jet or barometric type, with condensing water sprayed directly into the steam mixture.

The amount of condensing water and condensing surface employed is such that the vapor temperature in the condenser is normally 5°F above the condensing water discharge temperature. This fixes the terminal pressure condition to which the steam mixture is compressed. The initial pressure condition (in the evaporator) is determined by the chilled water temperature desired. Variation in either of these two conditions affects the compression range and therefore the amount of operating steam required.

Central Air-Conditioning Applications

There are many different ways to apply central air-conditioning to a structure. The method used depends on a number of factors, but the type of heating system is probably the dominant one. The following are the most common types of cooling applications:

1. Water chiller cooling
2. Split-system cooling
3. Year-round air-conditioning
4. Central cooling packages
5. Cooling coils

Water Chiller Cooling

A water chiller is used to add cooling and dehumidification to steam or hot-water heating systems. A refrigeration-type water chiller consists of a compressor, condenser, thermal expansion valve, and evaporator coil. The water is cooled in the evaporator coil and pumped through the system.

A typical system in which a water chiller is used is shown in Figure 8-22. The boiler and water chiller are installed as separate units, each with its own circulator (pump), or with one circulator in the return line. Hot water from the boiler is circulated through the

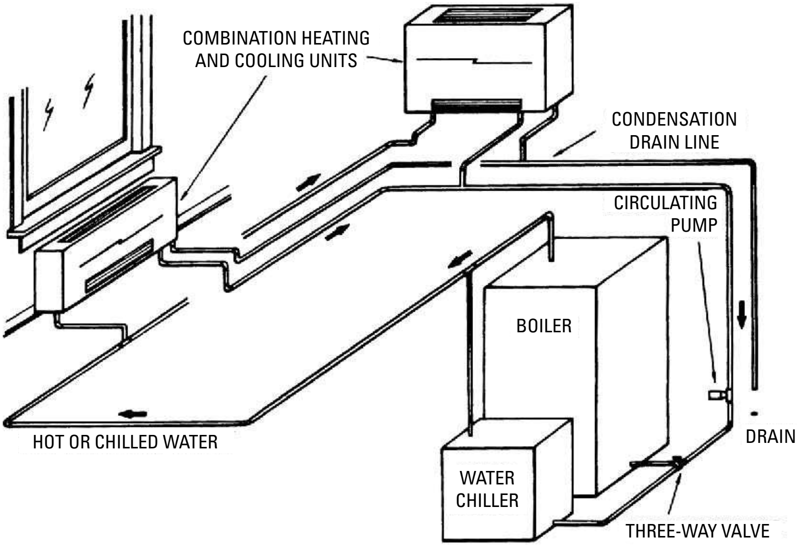


Figure 8-22 Water chiller and boiler installed as separate units.
(Courtesy 1965 ASHRAE Guide)

convectors for heating, and cold water is circulated through the same piping from the water chiller for cooling purposes.

Each convector unit contains a blower to force the air across the convector coil (see Figure 8-23). Water condensed from the coil during the cooling operation is trapped in a drip pan and discarded through a drain connected to the convector. Some convectors also contain a filter for air cleaning. The room convectors in a water chiller cooling system are usually designed for individual control.

The same piping carries both the chilled and hot water to the room convectors, but it must be insulated to minimize condensation during the cooling operation.

Water chillers are available as separate units or as a part of a complete package containing the boiler. Separate water chiller units are used when cooling must be applied to an existing steam or hot water heating system.

Split-System Cooling

Another method of applying central air-conditioning to a steam or hot-water heating system is to add forced-air cooling. This type of cooling application is sometimes referred to as a *split-system* installation—that is to say, a system split or divided between one type of heating (conventional steam or hot water) and another type of

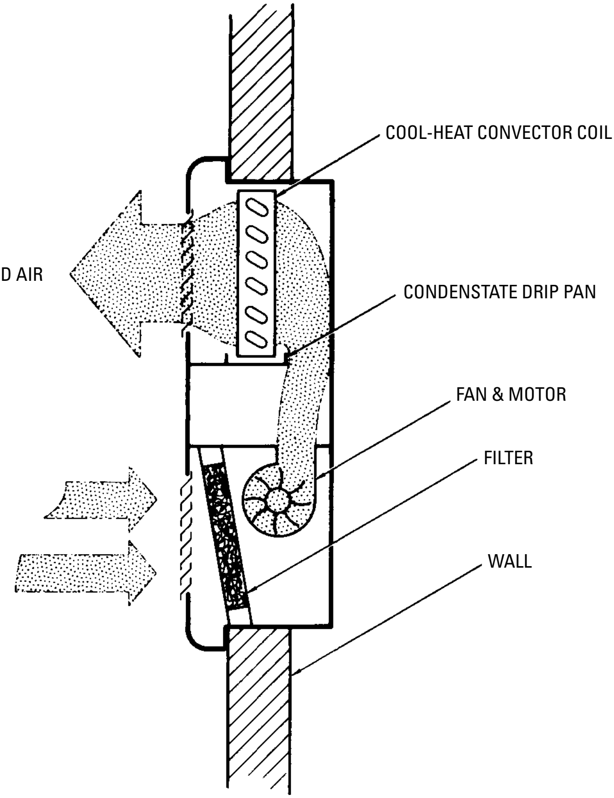


Figure 8-23 Air forced by convector across convector coil.
(Courtesy Honeywell Tradeline Controls)

cooling (forced air). This results in some confusion because the term split system is also used to refer to the separation of components in a year-round central air-conditioning system using forced warm-air heating and cooling (see *Location of Equipment*).

Three typical methods of applying forced-air cooling to a steam or hot-water heating system are shown in Figure 8-24.

Year-Round Air-Conditioning

In a year-round air-conditioning system, the heating and cooling units are combined in a single cabinet (see Figure 8-25). This combined package heats, cools, humidifies, dehumidifies, and filters the air in the structure as required. The unit may have an air-cooled, a water-cooled, or an evaporative-type condenser. The arrangement of the ductwork will depend in part on the type of condenser used in the unit.

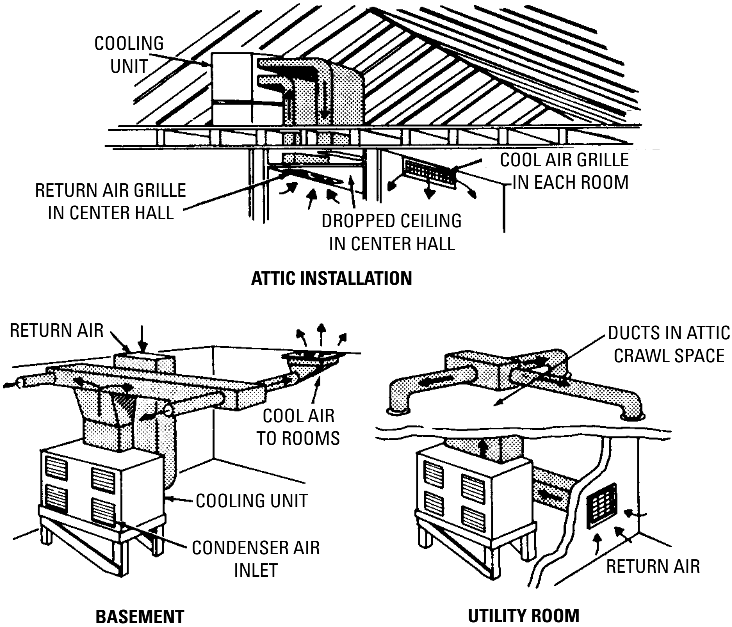


Figure 8-24 Methods of applying forced-air cooling to steam or hot-water heating systems. *(Courtesy Honeywell Tradeline Controls)*

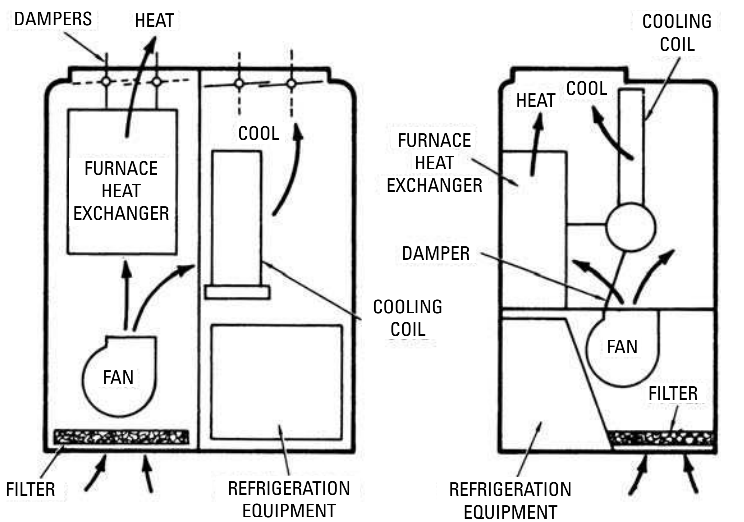


Figure 8-25 Heating and cooling units contained in a single cabinet. *(Courtesy Honeywell Tradeline Controls)*

Central Cooling Packages

A central cooling package is a unit designed for central air-conditioning applications. It consists of a cooling coil and the refrigeration equipment and will provide the necessary cooling and dehumidification as conditions require. These units are available with their own fans and filters, or they may be installed to use the filter and blower of the existing heating equipment (see Figure 8-26).

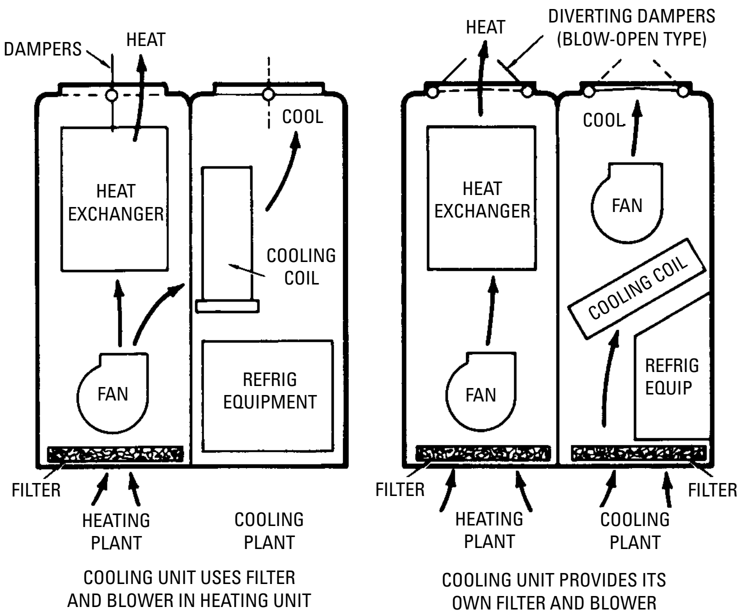


Figure 8-26 Central cooling package.

The method used to install a central cooling package will depend on whether the unit has an air-cooled or water-cooled condenser. If an air-cooled condenser is used, provisions must be made to carry outdoor air to and away from the condenser. Typical installations in which an air-cooled condenser is used are shown in Figure 8-27. Figure 8-28 illustrates some typical methods of applying a central cooling package in which a water-cooled condenser is used.

A typical remote or split system is shown in Figure 8-29. In this installation, the compressor and air-cooled condenser unit are located outdoors. The evaporator coil, fan, and heating appliance are located indoors in the conditioned space.

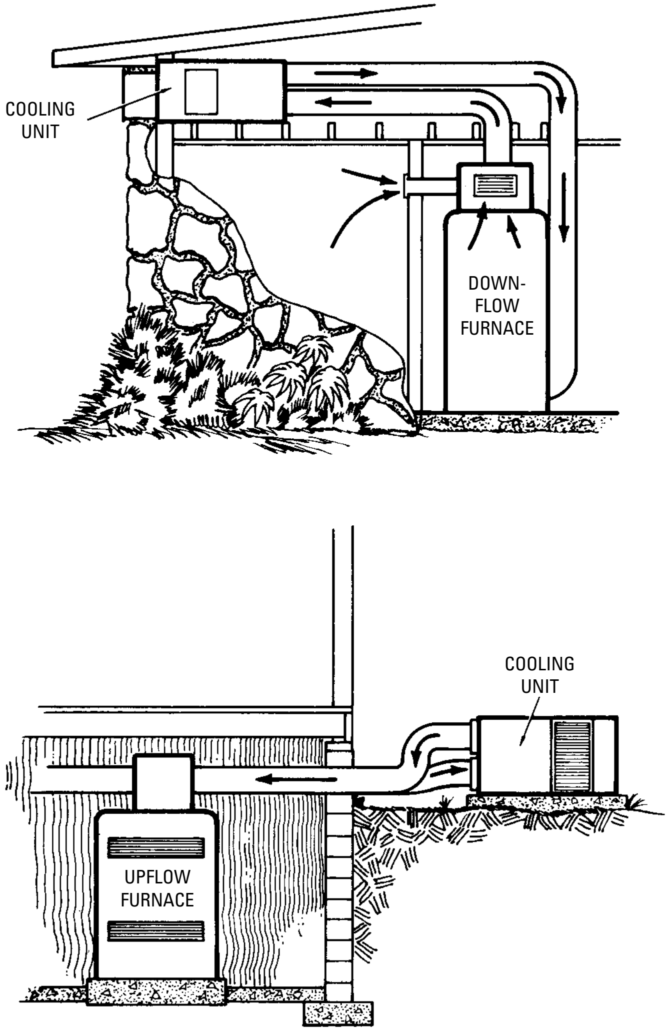
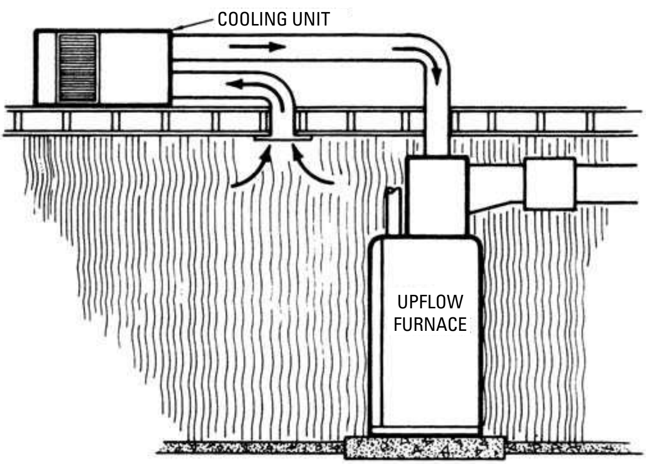


Figure 8-27 Applications of central cooling package having an air-cooled condenser. *(Courtesy Honeywell Tradeline Controls)*



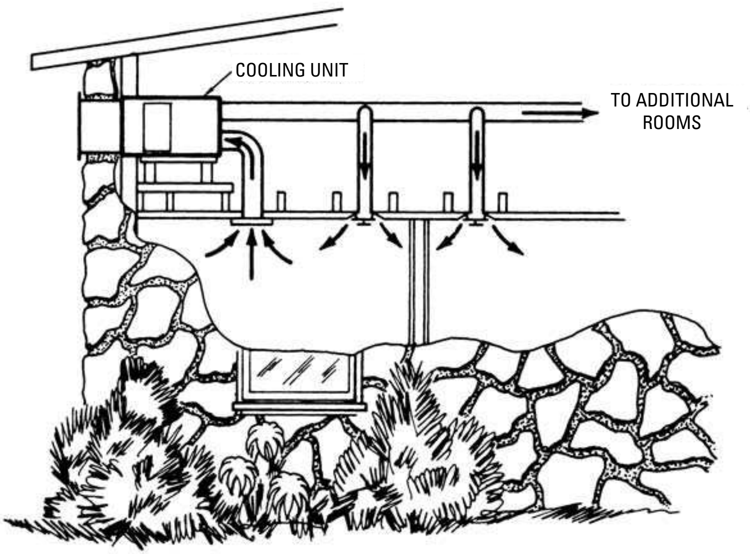


Figure 8-27 ***(continued)***

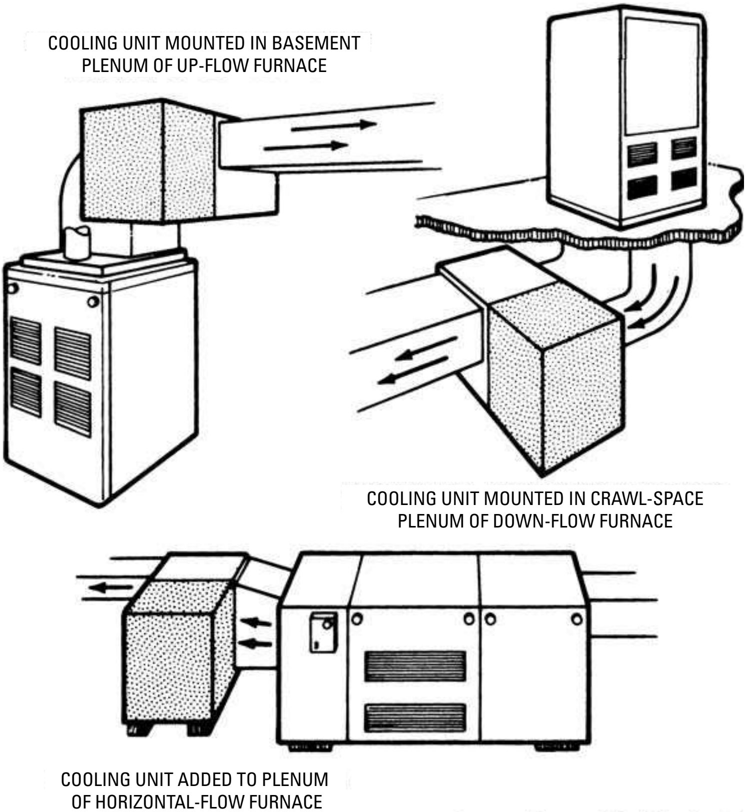


Figure 8-28 Applications of a central cooling package having a water-cooled condenser. *(Courtesy Honeywell Tradeline Controls)*

Cooling Coils

Cooling can be applied to a warm-air heating system by installing an evaporator coil or a cold-water coil in the ductwork. The evaporator coil is the low-side section of a mechanical refrigeration system. As shown in Figure 8-30, the evaporator coil is installed in the ductwork above the furnace. It is connected by refrigerant piping to the condenser coil and compressor installed outdoors.

A thermostatic expansion valve and condensation drip pan (with drain) are included with the evaporator coil. Sometimes a fan is added to the coil to supplement the furnace blower.

A cold-water coil may be used instead of an evaporator coil in the ductwork. Cold water is supplied to the coil by a water chiller,

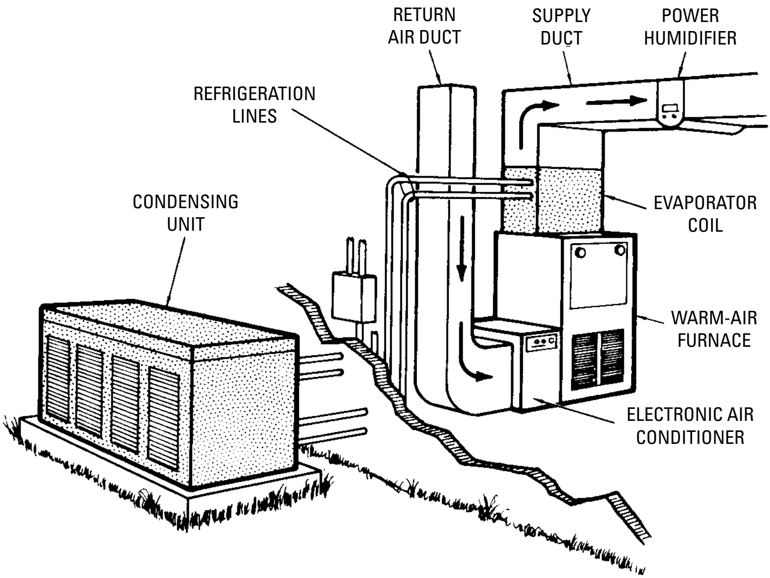


Figure 8-29 Typical remote split-type air-conditioning system.
(Courtesy Mueller Climatrol Corp.)

which can be located in the basement, a utility room, or outdoors. If the water chiller is installed outdoors, a gas engine can be used to drive the compressor (see Figure 8-31).

Hydronic Forced-Air Systems

In a hydronic forced-air system, the water is first heated in a boiler (sometimes called a *hydronic* furnace in these systems) or water heater and then circulated through the coils of a liquid-to-air heat exchanger connected to the furnace air handler. Heat is transferred from the water in the coils to the air inside the air-handler compartment. A blower forces the warm air through ducts to outlets inside the rooms. Cool air is produced by a chilled water or DX coil inside or on top of the blower cabinet. The cool air is distributed by the blower through the same ductwork used by the warm air. Condensation is collected by a condensate pump.

Hybrid Systems

A hybrid heating and cooling system consists of a radiant hydronic heating system working in conjunction with a separate cooling system. Hot water is produced by a hydronic boiler, water heater, or combination water heater. The cooling system is added to an existing

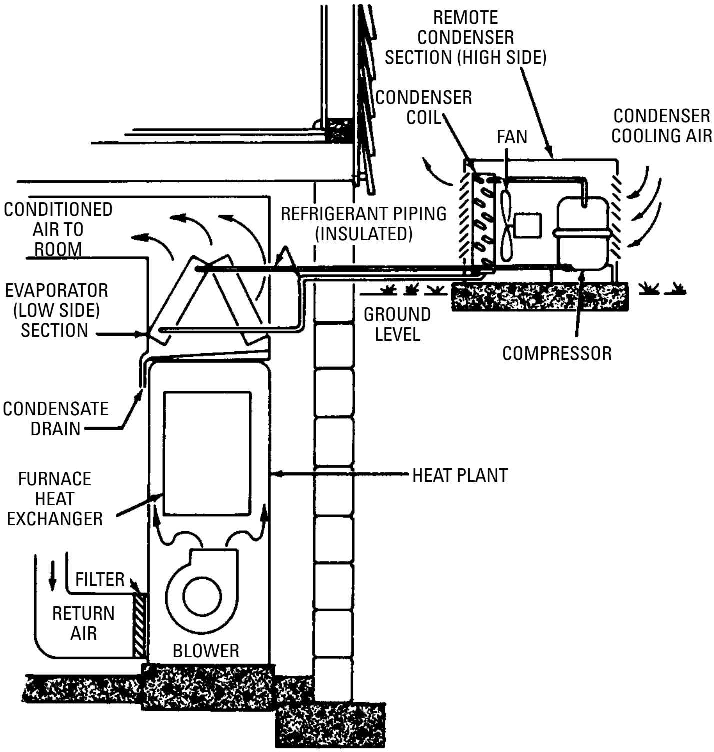


Figure 8-30 Evaporator coil installed in ductwork of a warm-air heating system. *(Courtesy Honeywell Tradeline Controls)*

hydronic system, when augmenting or upgrading the mechanical system of an older house or building. Some of the systems used to provide cool air to an existing hydronic heating system are described in the following paragraphs.

Indirect/Direct Evaporative Coolers

A high-efficiency indirect/direct evaporative cooler designed with a hydronic option can be used to supply cool air to a house with an existing hydronic heating system. The evaporative cooler has a Seasonal Energy Efficiency Ratio (SEER) of 36, which is three times the minimum SEER efficiency rating for air conditioners. Air cooled by direct and indirect evaporation can generate approximately the same amount of cooling as a 3-ton air conditioner. The cool air is delivered directly to the interior of the house or through a short duct.

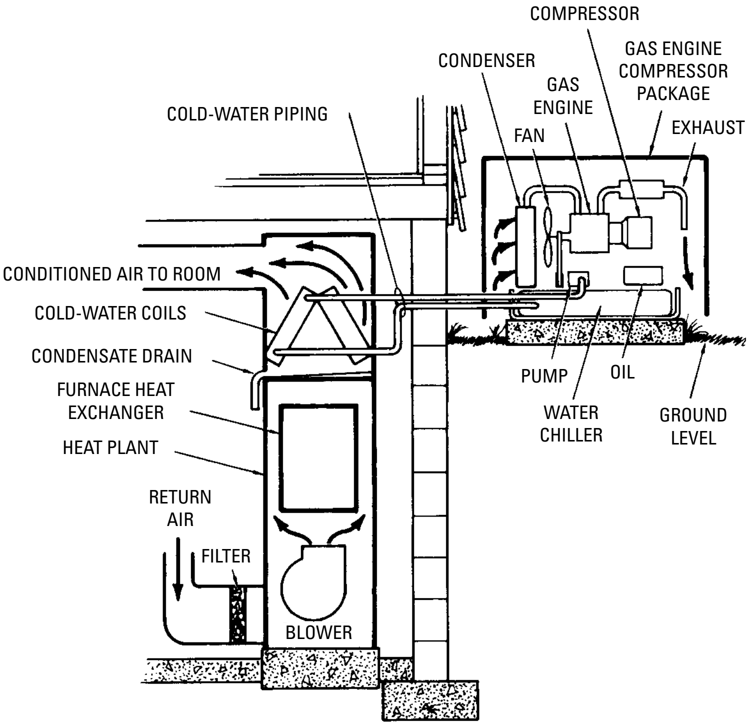


Figure 8-31 Cold-water coil used with outdoor gas engine compressor. *(Courtesy Honeywell Tradeline Controls)*

Ductless Split System

As the name suggests, the ductless split system does not require ductwork. The system consists of an indoor air handler and an outdoor condenser, connected by refrigerant tubing extending through a 3-inch hole in the wall. Decorative units can be mounted on the floor, wall, ceiling or recessed (drop) ceiling. The system can consist of a single zone with one condenser and one air handler, or a multizone system with one condenser containing two or more compressors connected to one, three, or four air handlers. The ductless split system is capable of producing 9000 Btu to 48,000 Btu, depending on the application.

Fan Coil and Flexible Ducts

The conditioned air is produced by a fan coil located in the attic, an attic crawl space, the basement, or a closet. If the air-conditioning unit is placed in the attic or an attic crawl space, a 5-ton one is small enough to insert between 16-inch on centers ceiling joists without cutting any framing. The distribution system consists of flexible 2-inch-diameter tubing running inside walls and floors and around internal framing obstructions. The conditioned air is delivered to the rooms through a 2-inch opening in the ceiling.

Residential Chiller with Ceiling-Mounted Panels

Chilled water is run through ceiling-mounted panels that exchange heat with the warm air in the room. The heated water is then carried down to the chiller where it is again cooled and returned to the ceiling. The system uses small ducts to feed fresh air directly into the house or building.

Room Air Conditioners

Room air conditioners are designed to cool a single room or space in a structure. The most commonly used type of room air conditioner is the window-mounted unit. These air conditioners are available for installation in single-hung windows, double-hung windows, horizontal sliding windows, and casement windows. Make sure to read carefully the specifications printed on the shipping container before purchasing a window air conditioner. The specifications should list the air conditioner's dimensions, the type of window installation, and its Btu output. Room air conditioners are also available for through-the-wall installation in exterior walls. A sleeve is provided for the wall mounting.

Chapter 9

Air-Conditioning Equipment

The gas compression method of mechanical refrigeration used in conjunction with an air-cooled condenser is probably the most common cooling system used in residences and small commercial buildings. For that reason, this chapter is devoted almost exclusively to a description of mechanical refrigeration equipment.

A typical central air-conditioning system cools the house with an indoor coil (evaporator) working in conjunction with an outdoor coil (condenser) and a pump (compressor). The evaporator and condenser coils are commonly constructed of copper tubing and aluminum fins. A pump (compressor) forces a refrigerant (heat transfer fluid) through the tubing coils and fins. When the refrigerant reaches the indoor coil (evaporator), it evaporates and pulls the heat out of the indoor air. At this point, the refrigerant fluid has changed to a gas. The hot refrigerant gas is then pumped back through the copper tubing and aluminum fins of the outdoor condenser where it changes (condenses) back into a liquid, releasing its heat to the air passing over the metal tubing and fins.

Mechanical Refrigeration Equipment

The equipment of a gas compression mechanical refrigeration system can be divided into mechanical and electrical components. The electrical components are described below (see *Electrical Components*) and in Chapter 6 ("Other Automatic Controls") in Volume 2. The principal mechanical components include the following:

1. Compressor
2. Condenser
3. Receiver
4. Evaporator
5. Liquid refrigerant controls

Air Conditioner Efficiency Ratings

The energy efficiency of an air conditioner is determined by the number of Btu per hour (Btu/h) removed for each watt of power drawn. The method used to rate the energy efficiency of a central air conditioner differs from that used for a room air conditioner. *(continued)*

Air Conditioner Efficiency Ratings *(continued)*

- **Central Air Conditioners.** The energy efficiency of the cooling equipment used in a residential or light commercial central air-conditioning system is expressed in terms of its Seasonal Energy Efficiency Ratio (SEER). In other words, the efficiency of the central air-conditioning equipment is defined in terms of the cooling effect in Btu per hour divided by the power use in watts for the seasonal average day (SEER). New air-conditioning equipment should have a SEER rating of 10 or better. The ratings go as high as 17. The ratings of equipment manufactured before the new efficiency ratings went into effect were 8 or lower.
- **Room Air Conditioners.** The energy efficiency of a room air conditioner is expressed in terms of its Energy Efficiency Ratio (EER); that is to say, it is defined in terms of the cooling effect in Btu per hour divided by the power use in watts for the peak day (EER). An energy-efficient room air conditioner will have an EER rating of 8 or higher. One with a 10 rating is recommended for hot climates.

Some air conditioner manufacturers also participate in the voluntary EnergyStar labeling program. Air-conditioning equipment with an EnergyStar label means that they possess high EER and SEER ratings.

Energy efficiency ratings are posted on an energy guide label, which is attached to the equipment.

Compressors

A *compressor* is a pumping device used in a mechanical refrigeration system to receive and compress low-pressure refrigerant vapor into a smaller volume at higher pressure. Thus, the primary function of a compressor is to establish a pressure difference in the system to create a flow of the refrigerant from one part of the system to the other.

Compressors are manufactured in many different sizes for a variety of different applications. Most residential compressors are reciprocating-type, scroll-type units, or rotary-type units, depending on how the refrigerant is compressed. The scroll compressors are a more recent design.

A *reciprocating compressor* (also sometimes called a *piston compressor*) uses a piston moving inside a cylinder to compress the refrigerant (see Figures 9-1 and 9-2). The operation of a piston compressor is similar to that of the reciprocating pistons in an automotive engine. It is a positive-displacement compressor with the piston (or pistons) moving in a straight line but alternately in opposite directions. Both open and hermetic reciprocating compressors are manufactured for use in refrigeration systems.

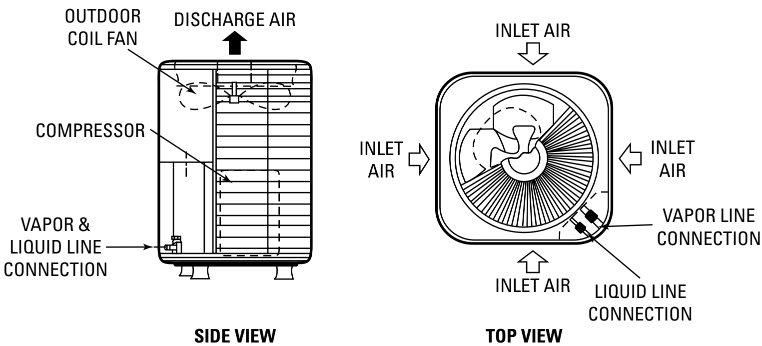


Figure 9-1 Side and top views of Lennox HP29 reciprocating compressor. *(Courtesy Lennox Industries Inc.)*

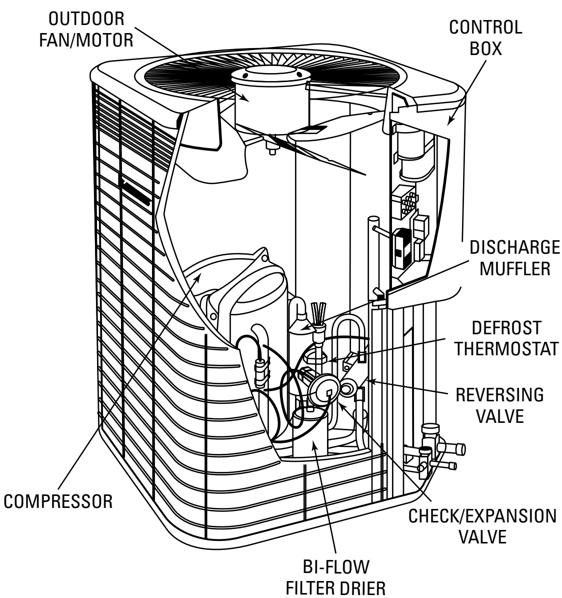


Figure 9-2 Cutaway view of Lennox HP29 reciprocating compressor. *(Courtesy Lennox Industries Inc.)*

A *scroll compressor* uses two spiral-shaped scrolls to compress the refrigerant (see Figures 9-3 and 9-4). One scroll remains stationary while the other orbits around it in a rotary motion. The moving scroll compresses the refrigerant by forcing it into an increasingly smaller space. At this point, the gas, now compressed to a high pressure, is discharged from a port in the stationary scroll to the condenser. Scroll compressors are quieter than piston compressors because they contain only one moving part (the single rotating scroll).

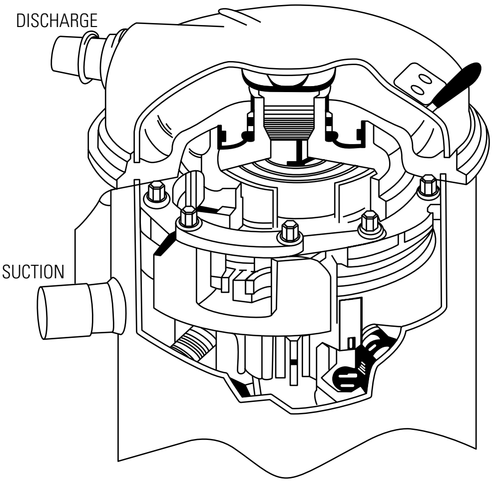


Figure 9-3 Details of scroll compressor. *(Courtesy Lennox Industries Inc.)*

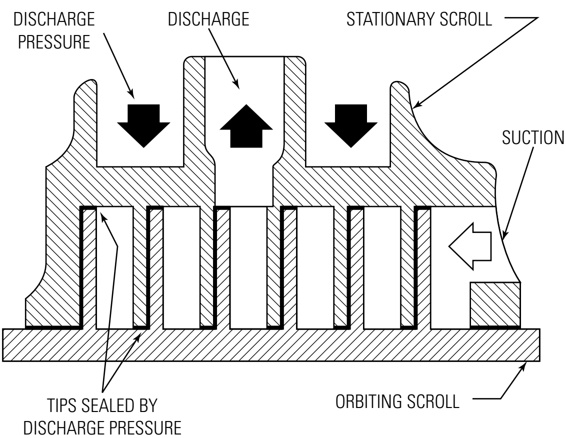


Figure 9-4 Cross-section of scrolls. *(Courtesy Lennox Industries Inc.)*

A *rotary compressor* is a hermetically sealed, direct-drive compressor that compresses the gas by movement of the roll in relation to the pump chamber. Rotary compressors are manufactured in large quantities for use in residential cooling systems (see Figures 9-5 and 9-6).

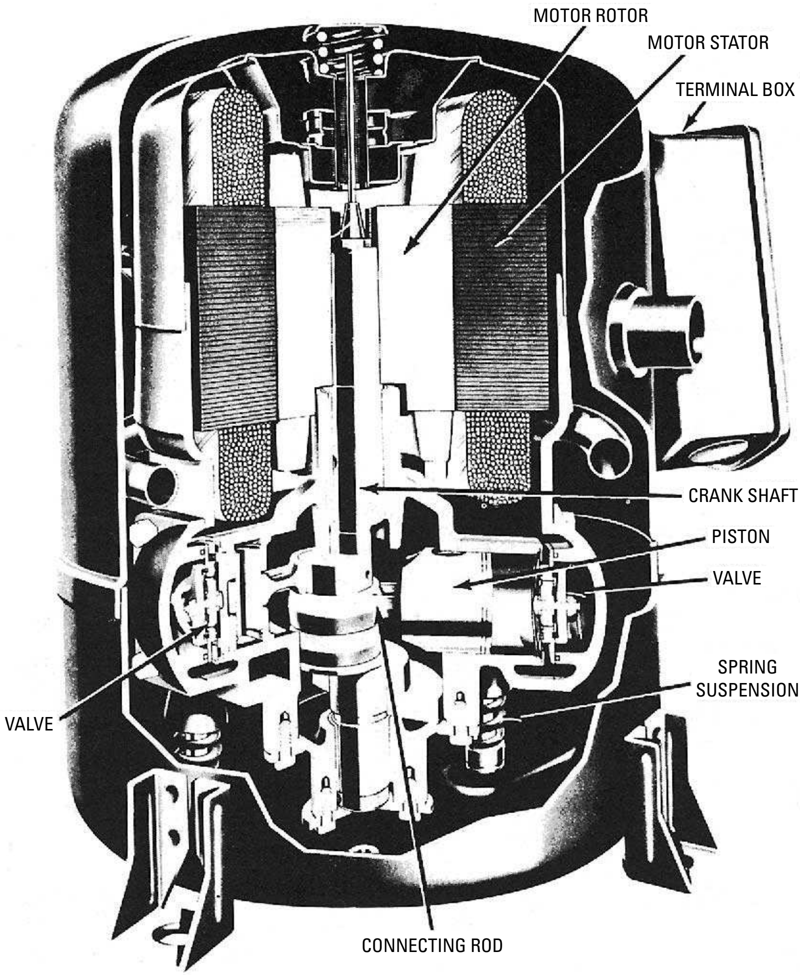


Figure 9-5 Cutaway view of a typical rotary compressor.
(Courtesy Trane Co.)

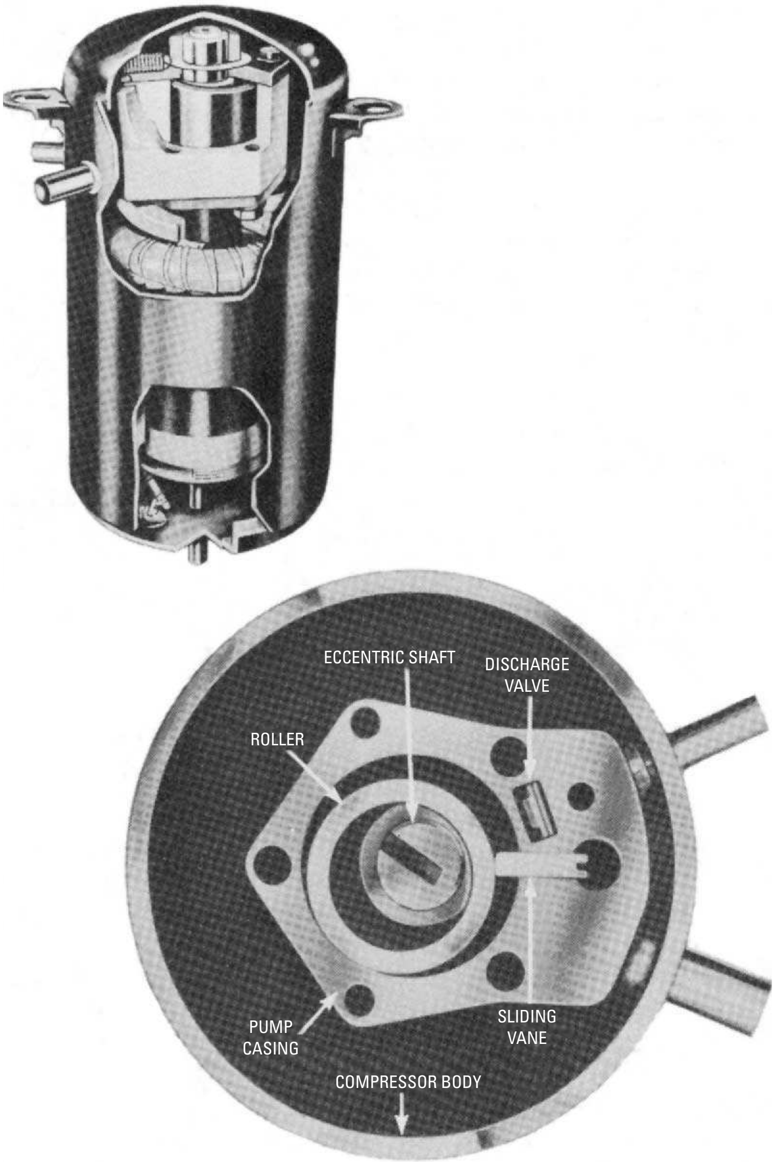


Figure 9-6 Eccentric shaft and roller of a rotary compressor.
(Courtesy Mueller Climatrol Corp.)

A *centrifugal compressor* is a non-positive-displacement compressor that relies in part on centrifugal effect for pressure rise. Compression of the refrigerant is accomplished by means of centrifugal force. As a result, this type of compressor is generally used in installations having large refrigerant volumes and low pressure differentials. The compressors used in residential and light commercial cooling systems may be classified on the basis of how accessible they are for field service and repair. The following three types are recognized:

1. Open-type compressors
2. Hermetic compressors
3. Semihermetic compressors

As shown in Figure 9-7, an *open-type compressor* is usually driven by a separately mounted electric motor. Both the compressor and motor are easily accessible for field service and repair.

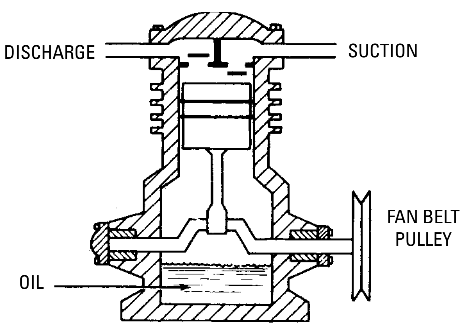


Figure 9-7 Diagram on an open-type compressor. *(Courtesy Honeywell Tradeline Controls)*

The *hermetic compressor* shown in Figure 9-8 differs from the open type in being *completely* sealed, usually by welding. No provision is made for service access. The compressors used in residential and light-commercial construction are hermetic compressors. A hermetic compressor is so called because its components are sealed inside a welded housing. The housing (or *can*) contains an electric motor and a pump. Compressors can be reciprocating, scroll, rotary, disc, or screw types.

Note

A sealed (*hermetic*) compressor must be replaced if it fails because it cannot be repaired on site. After it is replaced, filter dryers must be installed to remove any moisture and/or acid in the system.

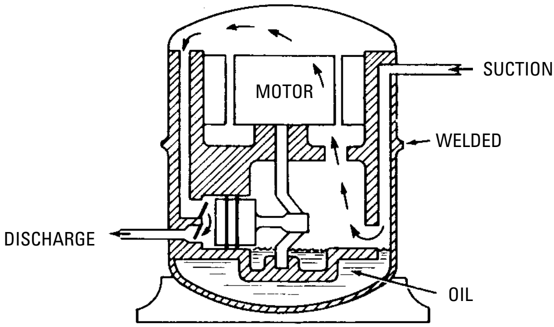


Figure 9-8 Diagram of a hermetic compressor.
(Courtesy Honeywell Tradeline Controls)

Both single-speed and two-speed compressors are used in residential heat pumps. A single-speed compressor is the most common type. It operates at full capacity regardless of the actual heating and cooling needs of the structure. A two-speed compressor, on the other hand, operates at a capacity that approximates the actual heating and cooling needs at any given moment. A two-speed compressor is, therefore, much more energy efficient than a single-speed one. It also is subject to less wear because its operation is not continuous.

The *semihermetic compressor* is similar in construction to the hermetic type, except that field service and repairs are possible on the former through bolted access plates.

Both the compressor and electric motor are sealed in the same casing in hermetic and semihermetic compressors. As a result, the motors are cooled by a refrigerant that flows through and around the motors. Quick-trip overload relays provide additional protection against overheating should the refrigerant flow be cut off.

Semihermetic and hermetic compressor motors of a given size are designed and constructed to operate on a heavier current without overheating. Hermetically sealing the compressor and electric motor in the same casing also results in a greater output. The principal disadvantage of a hermetic compressor is that it must be replaced with a new unit when it malfunctions. Because this usually occurs in the cooling season, the homeowner may be without air-conditioning for a day or so when it is most needed.

Troubleshooting Compressors

When a compressor is suspected of being defective, a complete analysis should be made of the system before the compressor is replaced. In some cases, the symptoms encountered in servicing an air conditioner may lead the serviceperson to suspect the compressor when actually the trouble is in another section of the system. For example, noise and knocking are often attributed to a faulty compressor when the trouble may be a loose compressor flywheel, incorrect belt alignment, air in the system, or a large quantity of oil being pumped through the compressor because of liquid refrigerant in the crankcase.

Table 9-1 lists the most common operating problems associated with air-conditioning compressors. For each observable symptom, a possible cause and remedy are suggested.

Table 9-1 Troubleshooting Compressors

Symptom and Possible Cause	***Possible Remedy***
Compressor does not start; no hum.	
(a) Open power switch.	(a) Close switch.
(b) Fuse blown.	(b) Replace fuse.
(c) Broken electrical connection.	(c) Check circuit and repair.
(d) Overload stuck.	(d) Wait for reset; check current.
(e) Frozen compressor or motor bearings.	(e) Replace the compressor.
(f) High head pressure; cut out open due to high pressure.	(f) Push high-pressure button and check for air circulation in condenser.
(g) Central contacts in open position.	(g) Repair and check control.
(h) Open circuit in compressor stator.	(h) Replace the compressor.
(i) Thermostat set too high.	(i) Reset to proper level.
(j) Solenoid valve closed.	(j) Examine holding coil; if burned out, replace.
Compressor starts but motor will not get off of starting windings; high amperage and rattle in the compressor.	
(a) Compressor improperly wired.	(a) Check wiring against wiring diagram; rewire if necessary.
(b) Low line voltage.	(b) Check line voltage and correct (decrease load on line or increase wire size).
(c) Relay defective.	(c) Replace relay.
(d) Run capacitor defective.	(d) Replace run capacitor.

(continued)

Table 9-1 (continued)

Symptom and Possible Cause	*Possible Remedy*
(e) Compressor motor starting and running windings shorted.	(e) Replace compressor.
(f) High discharge pressure.	(f) Correct excessive high pressure.
(g) Starting capacitor weak.	(g) Check capacitor; replace if necessary.
(h) Tight compressor.	(h) Check oil level and correct, or replace compressor.
Compressor will not start; hums and trips on overload.	
(a) Compressor improperly wired.	(a) Check wiring against wiring diagram; rewire if necessary.
(b) Low line voltage.	(b) Check line voltage and correct.
(c) Starting capacitor defective.	(c) Replace capacitor.
(d) Relay contacts not closing.	(d) Check contact points; replace if defective.
(e) Grounded compressor motor or motor with open winding.	(e) Replace compressor.
(f) High discharge pressure.	(f) Check excessive high pressure. Check air.
(g) Tight compressor.	(g) Check oil level and correct, or replace compressor.
Compressor starts and runs but short cycles.	
(a) Low line voltage.	(a) Check line voltage; correct.
(b) Additional current passing through overload protector.	(b) Check wiring diagram; fan motors may be connected to the wrong side of the protector.
(c) Suction pressure high.	(c) Check compressor for possibility of misapplication.
(d) High discharge pressure.	(d) Correct excessive high pressure.
(e) Run capacitor defective.	(e) Check capacitor and replace.
(f) Compressor too hot; inadequate motor cooling.	(f) Check refrigerant charge; add if necessary.
(g) Compressor motor windings shorted.	(g) Replace compressor.

(continued)

Table 9-1 *(continued)*

Symptom and Possible Cause	*Possible Remedy*
(h) Overload protector defective.	(h) Check current, give reset time; if it does not come back, replace compressor.
(i) Compressor tight.	(i) Check oil level and correct, or replace compressor.
(j) Discharge valve defective.	(j) Replace compressor.
Compressor short cycling.	
(a) Thermostat differential set too closely.	(a) Widen differential.
(b) Dirty air filter.	(b) Replace.
(c) Refrigerant charge too low.	(c) Recharge system with correct charge.
(d) Dirty strainer or dryer in liquid line.	(d) Replace.
(e) Restricted capillary tube or expansion valve.	(e) Replace.
(f) Dirty condenser.	(f) Clean condenser.
(g) Too much refrigerant.	(g) Discharge some refrigerant.
(h) Air in system.	(h) Purge system.
(i) Compressor valve leaking.	(i) Replace compressor.
(j) Overload protector cutting out.	(j) Check current and give reset time; if it does not come back, replace compressor.
Compressor runs continuously.	
(a) Shortage of refrigerant.	(a) Test at refrigerant test cock; if short of gas, add proper amount. Test for leaks.
(b) Compressor too small for load.	(b) Increase capacity by increasing speed or using larger compressor.
(c) Discharge valve leaking badly.	(c) Test valve; if leaking, remove head of compressor and repair or service.
Compressor noisy.	
(a) Vibration because unit not bolted down properly.	(a) Examine bolts and correct.

(continued)

Table 9-1 (continued)

Symptom and Possible Cause	*Possible Remedy*
(b) Too much oil in circulation, causing hydraulic knock.	(b) Check oil level and check for oil in refrigerant test cock; correct.
(c) Slugging due to flooding back of refrigerant.	(c) Expansion valve is open too wide. Close.
(d) Wear of parts such as piston, piston pins.	(d) Locate cause. Repair or replace compressor.
High suction pressure.	
(a) Overfeeding of expansion valve.	(a) Regulate expansion; check bulb attachment.
(b) Compressor too small for evaporator or load.	(b) Check capacity. Try to increase speed or replace with larger-size compressor.
(c) Leaky suction valves.	(c) Remove head and examine valve discs or rings; replace if worn.
Low suction pressure.	
(a) Restricted liquid line and expansion valve or suction screens.	(a) Pump down; remove, examine, and clean screens.
(b) Compressor too big for evaporator.	(b) Check capacity against load; reduce speed if necessary.
(c) Insufficient gas in system.	(c) Check for gas shortage at test cock.
(d) Too much oil circulating in system.	(d) Remove oil.
(e) Improper adjustment of expansion valves.	(e) Adjust valve to give more flow. If opening valve does not correct, increase size to give greater capacity.

Each compressor should be equipped with internal devices to provide protection against the following operating problems:

1. Motor overload
2. Locked rotor
3. Extreme voltage supply
4. Excessive winding temperature

5. Excessive pressure
6. Loss of refrigerant charge
7. Compressor cycling

If these devices are operating properly, the compressor will provide efficient and trouble-free service.

Compressor Replacement

Before replacing a hermetic compressor, be sure to check other possible causes of system malfunction (see *Troubleshooting Compressors*). Do not replace the compressor unless you are absolutely certain it is the source of the trouble.

Many manufacturers will provide instructions for replacing the compressor along with their installation, servicing, and operating literature. Carefully read these instructions before attempting to disconnect the compressor.

Disconnect the power supply, remove the fuses, and check the liquid refrigerant for oil discoloration or an acrid odor. These are indications that a compressor burnout has contaminated the system. If the system is not properly cleaned up, the replacement compressor will also burn out.

The system can be checked for contamination by discharging a small amount of refrigerant and oil through the high-side port onto a clean white cloth and checking it for discoloration and odor. Perform the same test on the low-side gauge port. If the system shows signs of contamination, discharge the remainder of the refrigerant through the liquid line gauge port (on a factory-charged system) or the high-side gauge port (on a field-charged system). Inspect the refrigerant lines to determine the exact extent of contamination.

Examine the refrigerant lines connected to the evaporator for contamination. A rapid compressor burnout will usually leave the evaporator coil unaffected. If the burnout has been particularly slow and the refrigerant and oil have been circulated through the system, the evaporator will also be contaminated. A contaminated evaporator can be cleaned by flushing it with a refrigerant.

Electric Motors

The electric motors used to power mechanical refrigeration equipment are commonly of the following two types:

1. Single-phase induction motors
2. Three-phase induction motors

The single-phase induction motors are usually classified by the method used to start them. Among the more common ones are the following:

1. Split-phase motors
2. Capacitor-start motors
3. Permanent-split capacitor motors
4. Capacitor-start, capacitor-run motors

Capacitor-start and capacitor-start, capacitor-run motors are described in Chapter 6 ("Other Automatic Controls") in Volume 2.

Either capacitor-start, capacitor-run or three-phase induction motors can be used to power compressors. The latter are normally used when three-phase current is available.

Troubleshooting Electrical Motors

Table 9-2 lists the most common operating problems associated with electric motors. For each symptom, a possible cause and remedy are suggested.

Table 9-2 Troubleshooting Electrical Motors

Symptom and Possible Cause	*Possible Remedy*
Motor blows fuses, trips overload.	
(a) Fuses and/or overload too small.	(a) Install larger sizes if necessary within safe limit for motor.
(b) Poor switch contacts.	(b) Check and replace contacts. Replace entire switch if necessary.
(c) Low voltage.	(c) Check voltages with meter; if more than 10 percent low, notify power company to correct condition.
(d) Leaky discharge valve.	(d) Replace.
(e) Overloaded motor.	(e) Check bhp load against back-pressure and compressor speed; if motor is too small, increase size.
Motor hot.	
(a) Low voltage.	(a) Check voltage with meter; if more than 10 percent low, notify power company to correct condition.

(continued)

Table 9-2 *(continued)*

Symptom and Possible Cause	*Possible Remedy*
(b) Bearings need oil.	(b) Oil bearings to reduce friction.
(c) Overloaded motor.	(c) Check bhp load against back-pressure and compressor speed; if motor is too small, increase size.

Gas Engines

A four-cylinder water-cooled gas engine using natural gas as the fuel can be used to power the compressor (and sometimes the condenser fan). It is normally mounted in a weatherproof cabinet outside the residence where venting is not a problem. Because an internal combustion engine must be vented, electric motors are by far the most popular type used for powering mechanical refrigeration equipment.

Electrical Components

The principal electrical components of a mechanical refrigeration system include the following:

1. Electric compressor motor
2. Compressor contactor or relay
3. Compressor starter
4. Overload protector
5. Capacitor
6. Potential relay
7. Pressure switch
8. Evaporator fan motor
9. Condenser fan motor
10. Evaporator fan relay

The wiring diagram in Figure 9-9 illustrates the relationship of these various components. Switches, relays, and capacitors have already been described in considerable detail in Chapter 6 ("Other Automatic Controls") in Volume 2.

The room thermostat is sometimes included when the electrical components of a refrigeration system are listed. The reader is referred to Chapter 4 ("Thermostats and Humidistats") in Volume 2 for detailed information about thermostats.

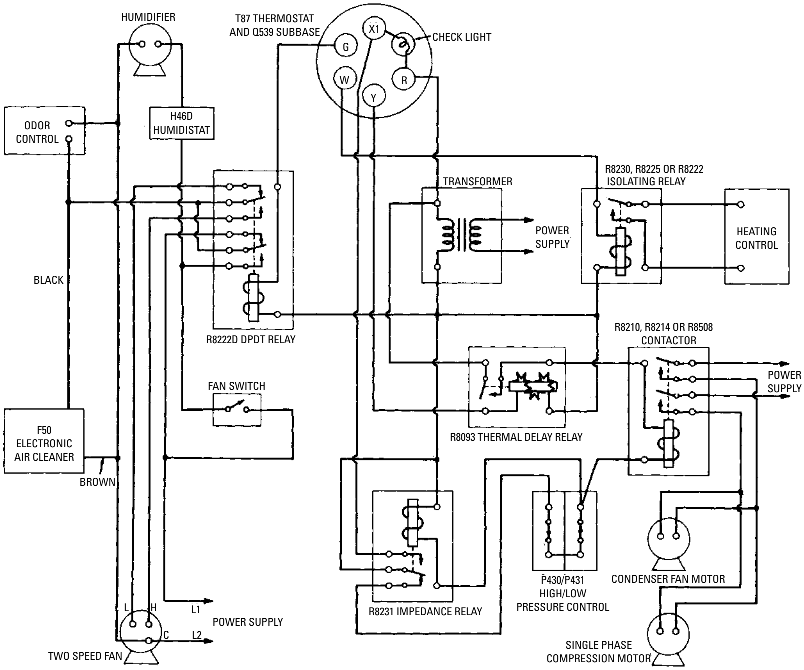


Figure 9-9 Impedance relay, thermal delay relay, isolating relay, heat control, electronic air cleaner, and humidity controls added to a basic cooling control system. *(Courtesy Honeywell Tradeline Controls)*

Troubleshooting Electrical Components

Table 9-3 lists the most common problems associated with the operation of the electrical components in air-conditioning equipment. For each symptom, a possible cause and remedy are suggested.

Table 9-3 Troubleshooting Electrical Components

Symptom and Possible Cause	*Possible Remedy*
Starting capacitor is open, shorted, or burned out.	
(a) Relay contacts not operating properly.	(a) Clean contacts or replace.
(b) Improper capacitor.	(b) Check for proper MFD rating and voltage.
(c) Low voltage.	(c) Check and correct.
(d) Improper relay.	(d) Check and replace.
(e) Short cycling.	(e) Replace starting capacitor.

(continued)

Table 9-3 (continued)

Symptom and Possible Cause	*Possible Remedy*
Running capacitor is open, shorted, or burned out.	
(a) Improper capacitor.	(a) Check for proper MFD rating and voltage.
(b) Excessive high line voltage.	(b) Correct line voltage to not more than 10 percent of rated motor voltage.
Relay is shorted or burned out.	
(a) Line voltage is too low or too high.	(a) Check and correct.
(b) Incorrect running capacitor.	(b) Replace with correct MFD capacitor.
(c) Loose relay.	(c) Tighten relay.
(d) Short cycling.	(d) Replace relay.

Condenser

A *condenser* is a device that is used to liquefy gas by cooling. In operation, hot discharge gas (refrigerant vapor) from the compressor enters the condenser coil at the top and, as it is condensed, drains out of the condenser to a receiver located at a lower level.

The condenser coil is located along with the compressor and controlling devices in the *condensing unit*. In a remote or split-system air-conditioning installation, the condensing unit is located outdoors (see Figure 9-10). Condensers are available in a variety of designs, including plain tube, finned tube, and plate type, and as series-pass and parallel-pass units. A number of different condensers are illustrated in Figures 9-11, 9-12, 9-13, and 9-14.

Condensers may be classified with respect to the cooling method used into the following three types:

1. Air-cooled condensers
2. Water-cooled condensers
3. Combined air- and water-cooled condensers

An *air-cooled condenser* consists of a coil of ample surface across which air is blown by a fan or induced by natural draft (see Figure 9-15). This type of condenser is universally used in small-capacity refrigerating units.

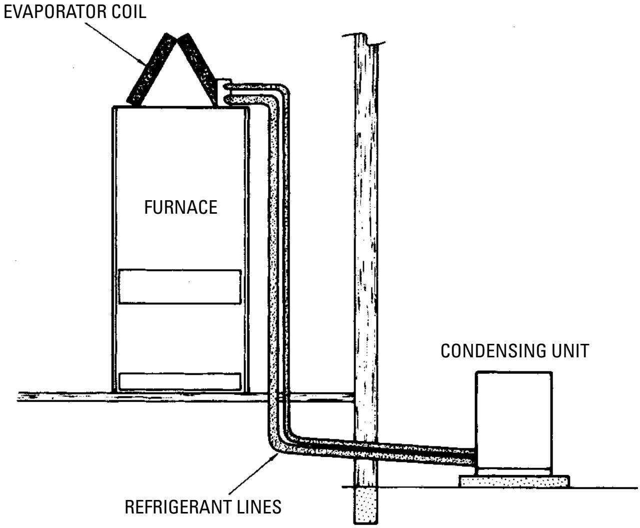


Figure 9-10 Location of the condensing unit in a remote or split-system air-conditioning installation.

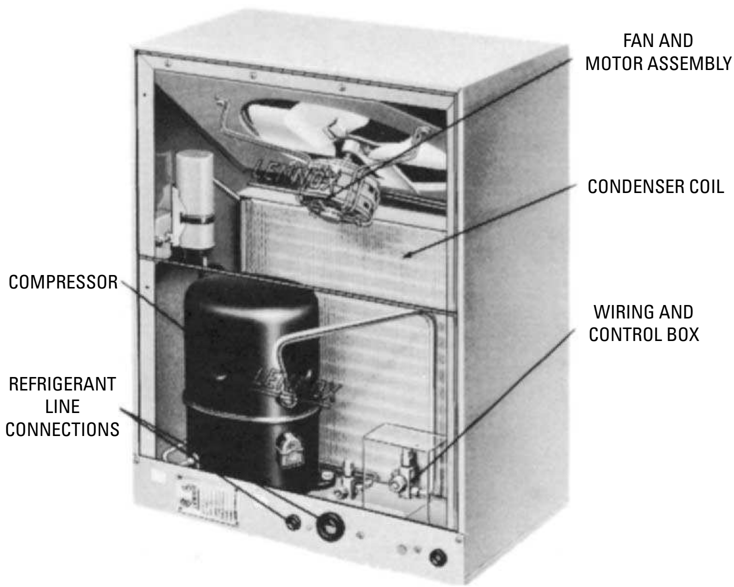


Figure 9-11 Lennox HSW4 series air-conditioning condenser unit. *(Courtesy Lennox Air Conditioning and Heating)*

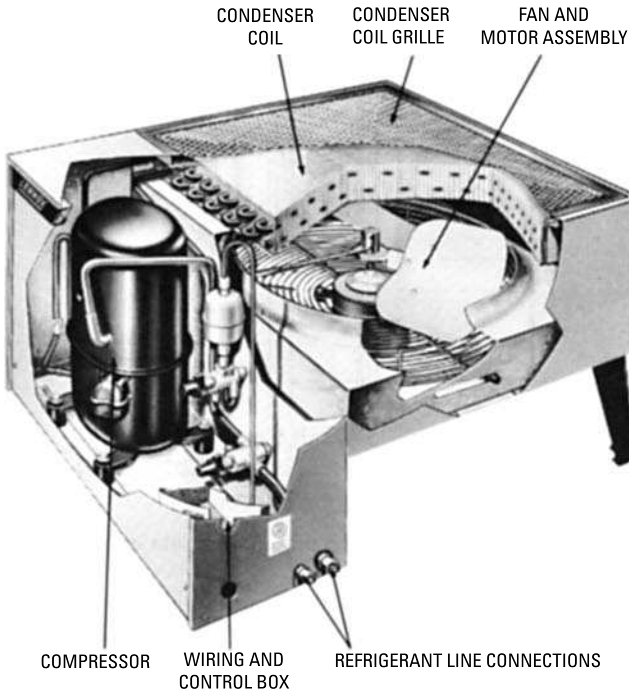


Figure 9-12 Lennox HS8 series air-conditioning condenser unit.
(Courtesy Lennox Air Conditioning and Heating)

A *water-cooled condenser* is similar to a steam surface condenser in that cooling is accomplished by water alone that circulates through tubes or coils enclosed in a shell. The refrigerant circulates through the annular space between the tubes or coils. Because of its construction, a water-cooled condenser is also sometimes called a *double-pipe condenser* (see Figure 9-16).

Maximum temperature differences can be obtained by connecting the condenser for counterflow. This type of arrangement usually gives the best operating results.

Shell-and-tube construction is recommended for a small condensing unit. In medium-size units, shell-and-coil construction works very well (see Figures 9-17 and 9-18).

A *combined air- and water-cooled condenser*, more commonly known as an *evaporative condenser*, consists of a coil cooled by water sprayed from above and cold air entering from below (see Figure 9-19).

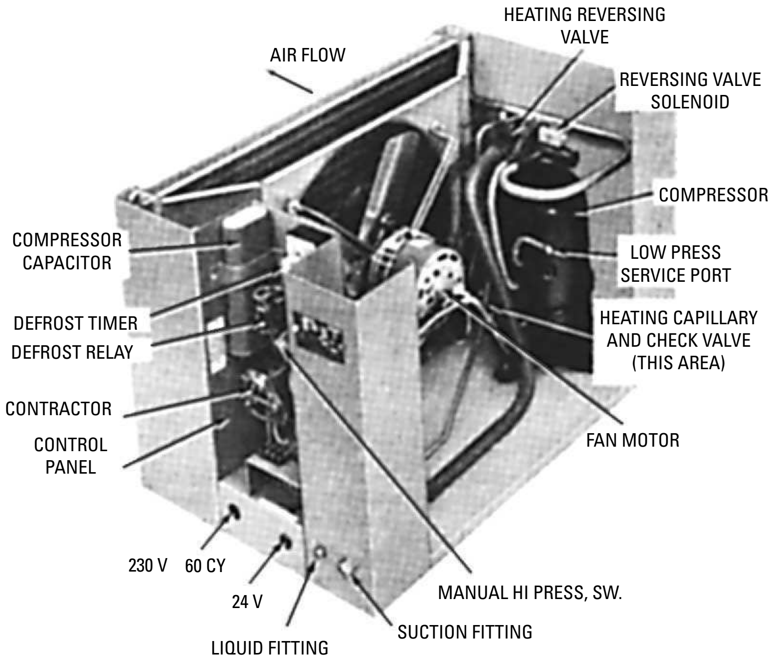


Figure 9-13 Bard 36HPQ1 condensing unit. *(Courtesy Bard Mfg. Co.)*

As water evaporates from the coil, it brings about a cooling effect, which condenses the refrigerant within the coil. The hot refrigerant gas within the coil is thus changed to the liquid state by the combined action of the sprayed water and the large volume of moving air supplied by the fan. The water that does not evaporate is recirculated by means of a pump.

Because an evaporative condenser is not wasteful of water, large compressor installations are possible in areas where water is scarce. Tests have shown that the amount of water required will not exceed 0.03 gpm per ton of refrigeration. Evaporative condensers also eliminate wastewater disposal problems and provide the most economical means of cooling refrigerant gases.

Air-cooled condensers, like evaporators, should be kept free from dirt, lint, and other foreign materials because they tend to reduce the airflow around tubes and fins if they are allowed to accumulate.

Condenser Service and Maintenance

The aluminum fins on condenser coils are easily bent and can block airflow through the coil. A tool called a fin comb is available at

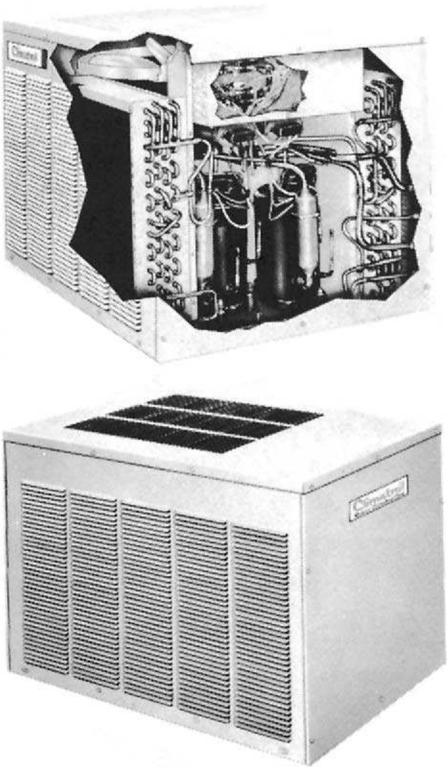


Figure 9-14 Climatrol 938-1 dual-compressor condensing unit.

(Courtesy Mueller Climatrol Corp.)

air-conditioning equipment wholesalers that will comb these fins back into nearly original condition.

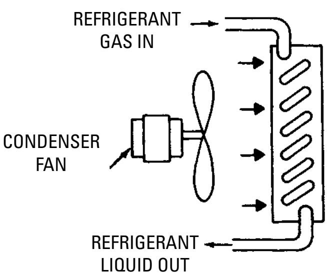


Figure 9-15 Air-cooled condenser.

(Courtesy Honeywell Tradeline Controls)

Troubleshooting Condensers

Common operating problems associated with air-conditioning condensers are listed in Table 9-4. For each symptom, a possible cause and remedy are suggested.

Receiver

As the name suggests, the *receiver* is the reservoir for any excess liquid refrigerant not being used in the system. The liquid receiver must be large enough to hold the *total* amount of

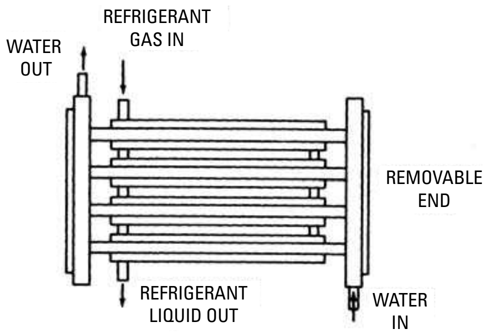


Figure 9-16 Double-pipe condenser.

(Courtesy Honeywell Tradeline Controls)

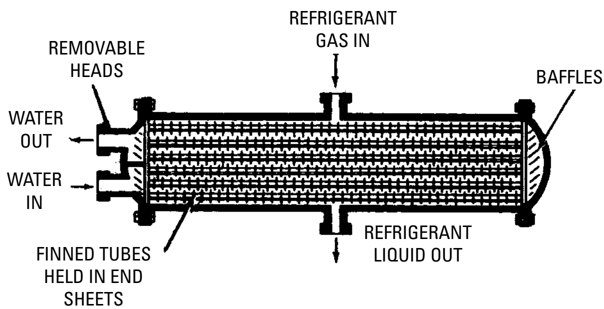


Figure 9-17 Shell-and-tube condenser.

(Courtesy Honeywell Tradeline Controls)

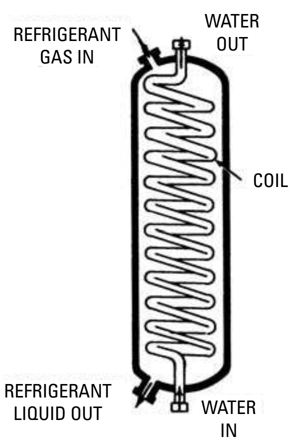


Figure 9-18 Shell-and-coil condenser.

(Courtesy Honeywell Tradeline Controls)

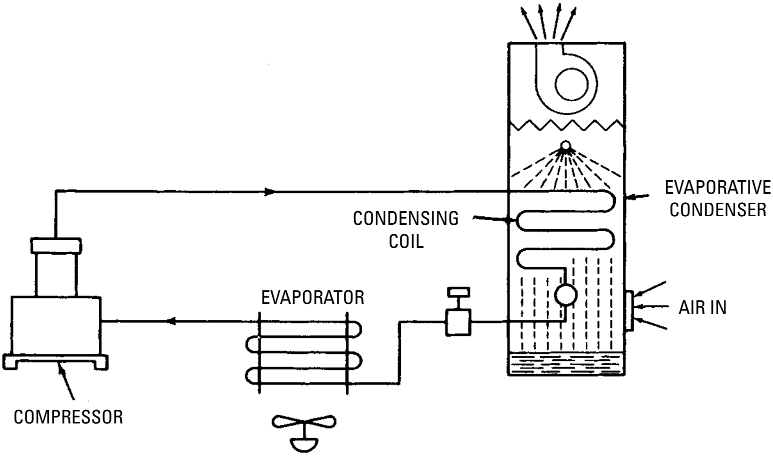


Figure 9-19 Evaporative condenser. *(Courtesy Honeywell Tradeline Controls)*

Table 9-4 Troubleshooting Condensers

Symptom and Possible Cause	***Possible Remedy***
Compressor pressure too high.	
(a) Air in system.	(a) Purge system.
(b) Dirty condenser.	(b) Clean condenser.
(c) Refrigerant too high.	(c) Discharge some refrigerant.
(d) Unit location too hot.	(d) Change unit location.
(e) Condenser air off.	(e) Check condenser motor connections for burnout.
Condenser pressure too low.	
(a) Refrigerant charge too low.	(a) Check for leak, repair, and recharge with correct amount of refrigerant.
(b) Compressor discharge or suction valves defective.	(b) Replace compressor.
(c) Entering temperature to evaporator low.	(c) Raise temperature.

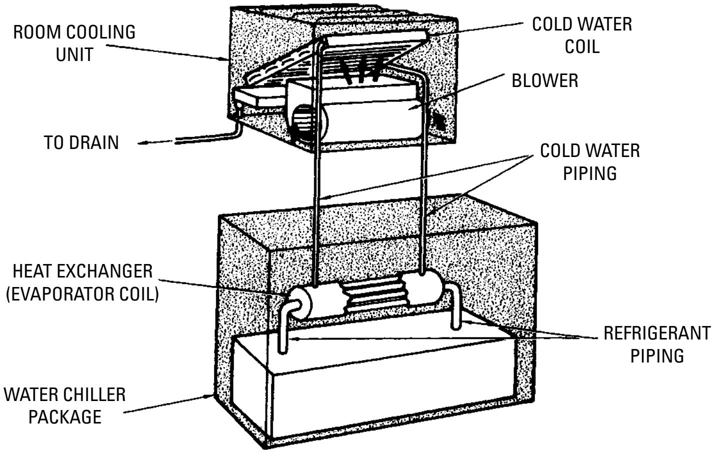


Figure 9-20 Evaporator coil. *(Courtesy Coleman Co.)*

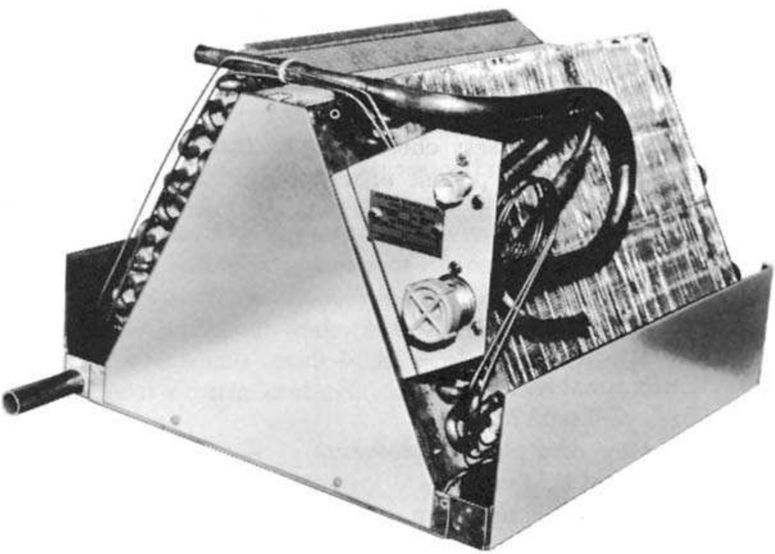


Figure 9-21 Evaporator coil and water chiller.
(Courtesy Honeywell Tradeline Controls)

refrigerant used in the system. Receivers are commonly constructed of drawn steel shells welded together to form a single unit.

Evaporator

An *evaporator* is a device used in either mechanical- or absorption-type refrigeration systems to transfer or absorb heat from the air surrounding the evaporator to the refrigerant. In so doing, the liquid refrigerant is evaporated or boiled off as it passes through the evaporator.

Evaporators are made of copper tubing with or without closely spaced aluminum fins designed to increase the heat transfer surface. Because of its function (that is, removing heat from room air) and construction, an evaporator is also referred to as an *evaporator coil*, *cooling coil*, *blower coil*, or *direct-expansion coil*.

Figure 9-20 illustrates a typical evaporator coil used in the bonnet or plenum of a warm-air furnace. The coil capacity must be matched to the condensing unit for efficient cooling. This is particularly important to remember when converting an existing heating system to year-round air-conditioning.

An evaporator coil may also be placed in the heat exchanger of a water chiller as shown in Figure 9-21. The water cooled in the water chiller is piped to the cold-water coil over which the room air is circulated. The coil may be duct mounted (in a warm-air heating system) or located in a room cooling unit (in a forced hot-water heating system).

Evaporator Service and Maintenance

The aluminum fins on evaporator coils, like those on the condenser coils, are also easily bent. If bent, they can block the flow of air through the coil. The same tool used to straighten the fins on the condenser tubing can be used to return the evaporator fins to their original position.

Troubleshooting Evaporators

An evaporator must be kept clean and free of dirt and dust so that the flow of air through the tubes remains unrestricted. If the evaporator is damaged or leaking to such an extent that it cannot be successfully repaired, it should be replaced by a new assembly. If repairs or replacement are necessary, the complete coil assembly must be removed from the system.

Before removing a damaged or leaking evaporator, the refrigerant lines must first be disconnected and the evaporator retaining bolts (if used) loosened and removed.

The new evaporator is bolted or otherwise secured in place and connected to the refrigerant lines. After all connections are made, the entire system is evacuated, recharged with refrigerant, and tested for leaks.

Refrigerants

A *refrigerant* is any substance that produces a refrigerating effect by absorbing heat as it expands or vaporizes. A desirable refrigerant should possess chemical, physical, and thermodynamic properties that permit efficient and safe operation in refrigerating systems. Among the properties possessed by a good refrigerant are the following:

1. Low boiling point
2. Nontoxic and nonirritating
3. Nonexplosive
4. Nonflammable
5. Mixes well with oil
6. Operation on a positive pressure
7. High latent heat value
8. Not affected by moisture

Two of the most commonly used refrigerants in older equipment are R-12 (Freon 12) and R-22 (Freon 22). These are clear, almost colorless liquids at temperatures below their boiling points.

R-12 has a boiling point of –21.8°F at atmospheric pressure and is characterized by moderate pressure differentials between suction and discharge. A moderate volume of R-12 is required per ton of refrigeration.

R-22 has a boiling point of –41.4°F at atmospheric pressure. In contrast to R-12, it has a considerably higher pressure differential between suction and discharge. As a result, it requires a smaller volume of refrigerant per ton of refrigeration.

R-410A is gradually replacing older refrigerants because it does not possess the ozone-depleting chemical properties of the latter. Refrigerant R-410A is known by such trade names as PuronTM, Dupont Suva, and Genetron AZ20. Many HVAC manufacturers are already using the new refrigerant in new air-conditioning equipment.

Older air-conditioning equipment and systems cannot be retrofitted with R-410A. If an older refrigerant was used, it must be removed, cleaned, and reused. Because R-410A runs operating pressures higher than older refrigerants, new sets of hoses and refrigerant gauges are required for installation, service, and repair.

Note

The efficiency of an air conditioner is greatest when the refrigerant charge exactly matches the manufacturer's specification and is neither undercharged nor overcharged. If the air conditioner is on refrigerant (undercharged) and not leaking, refrigerant should be added by a trained HVAC technician. If the air conditioner is leaking refrigerant, do not add refrigerant. Have a trained HVAC technician fix the leak, test the repair, and then charge the system with the correct amount of refrigerant.

Liquid Refrigerant Control Devices

Each refrigeration system may be described in terms of a low side and a high side of operating pressure. The *low side* is that part of the refrigeration system that normally operates under low pressure (as opposed to the high side). It is identified as that part of a refrigeration system lying between the expansion valve and the intake valve in the compressor, and includes the evaporating or cooling surface, the intake line, and the compressor crankcase—in other words, that part of the refrigeration equipment under intake pressure. The term low side is sometimes used to designate the evaporator coils.

The *high side* is that part of the refrigeration system operating under high pressure. The term high side is sometimes used to designate the condensing unit.

Some form of expansion device is necessary to control the flow of liquid refrigerant between the low and high sides of a refrigeration system. The following expansion devices are designed to provide automatic control of refrigerant flow:

1. Automatic expansion valves
2. Thermostatic expansion valves
3. Float valves
4. Capillary tubes

Automatic Expansion Valves

An *automatic expansion valve* is a pressure-actuated diaphragm valve used to maintain a constant pressure in the evaporator of a direct-expansion mechanical refrigeration system (see Figure 9-22). It accomplishes this function by regulating the flow of refrigerant from the liquid line into the evaporator. In this way, the evaporator is always supplied with the proper amount of refrigerant to meet conditions. An automatic expansion valve does not respond well to load fluctuations. For this reason, it is not recommended for use in air-conditioning (see *Thermostatic Expansion Valves*).

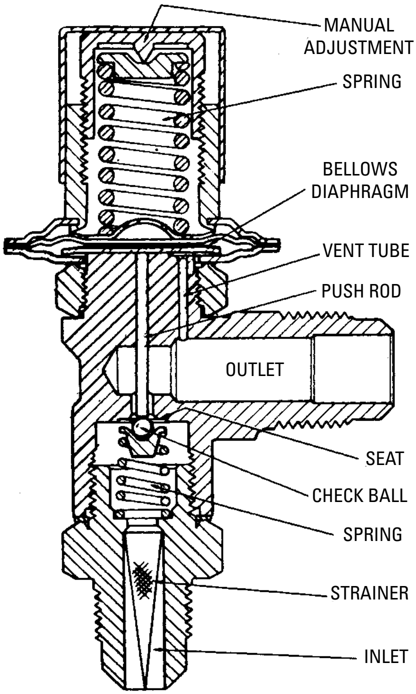


Figure 9-22 Automatic expansion valve.

Thermostatic Expansion Valves

The *thermostatic expansion valve* is designed to automatically control the flow of liquid refrigerant entering the evaporator coil. The valve mechanism must operate freely and without restriction in order to allow the proper amount of refrigerant to enter the evaporator (see Figures 9-23 and 9-24).

Failure of any part of the thermostatic expansion valve will affect the refrigerating capacity of the unit and the cooling capacity of the system. Faulty operation of the expansion valve may be caused by mechanically frozen internal parts clogging the strainer or valve orifice, or by failure of the regulating sensor bulb, which operates the needle valve.

If the expansion valve is frozen partly open, the capacity of the unit will be affected because the flow of refrigerant is restricted. If the expansion valve is frozen in a fully open position, the liquid refrigerant may flow through the entire system, causing very cold inlet line, high inlet pressure, pounding of the compressor, and a cold compressor head.

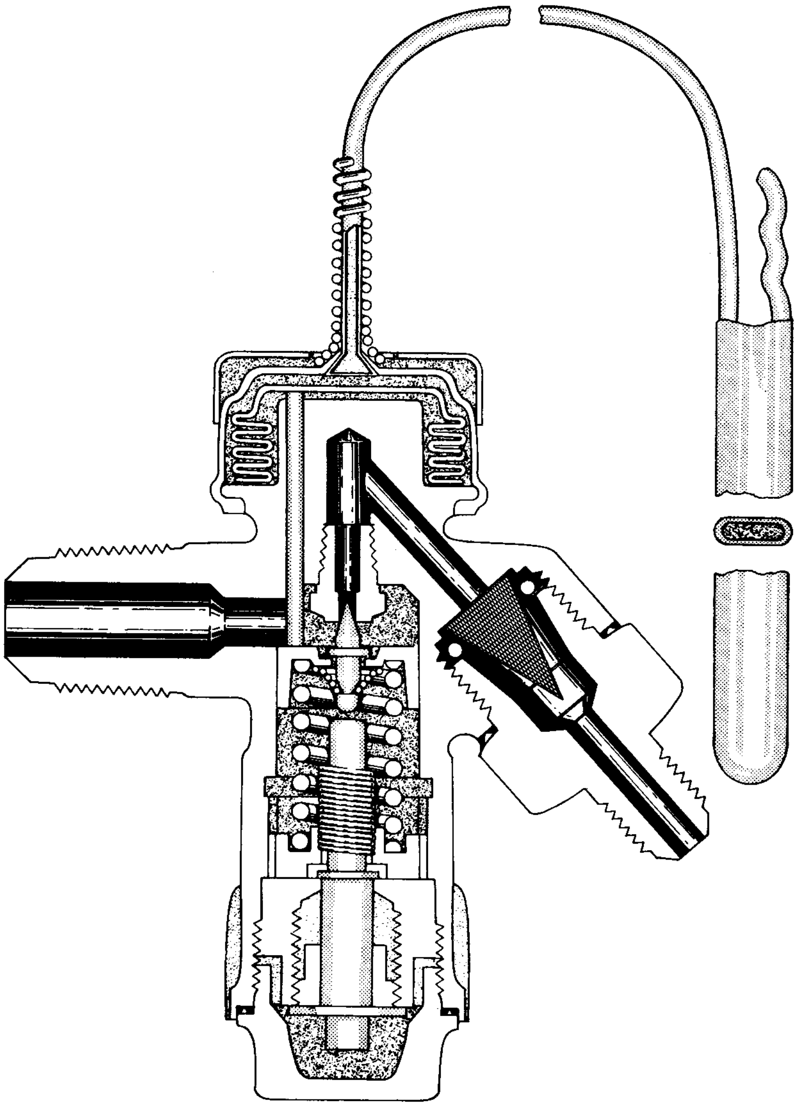


Figure 9-23 Typical thermostatic expansion valve.

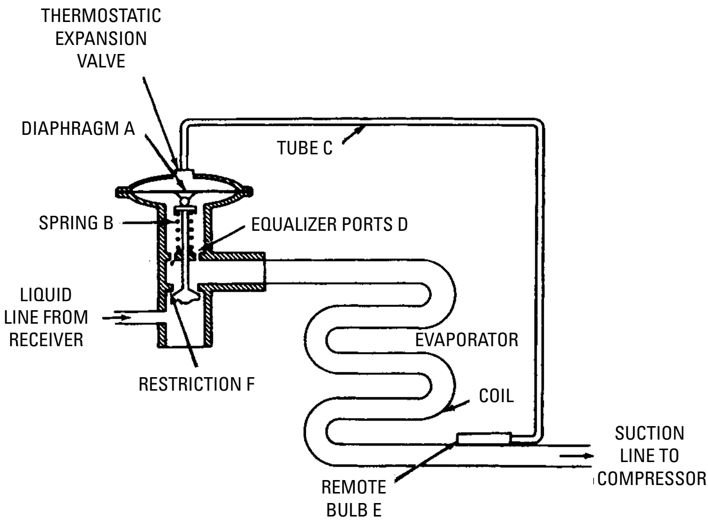


Figure 9-24 Thermostatic expansion valve operating principle.
(Courtesy Honeywell Tradeline Controls)

The pressure in the sensor bulb or feeler of the expansion valve must be somewhat higher than the pressure in the evaporator, which means that the inlet line where the bulb is clamped must be at a higher temperature than that within the evaporator. Accordingly, the vapor in the inlet line at this point must be in a somewhat superheated state. This superheat should be at the minimum that will allow the valve to regulate the flow of refrigerant.

For higher-temperature work, such as comfort cooling work, the amount of superheating will vary between 5° and 10°. For lower-temperature work, such as product cooling work, the superheating will vary between 4° and 6° or in some cases even lower.

Excessive superheat indicates a lack of sufficient refrigerant flowing through the expansion valve, a condition that reduces the capacity of the evaporator.

The sensitivity and response of the thermostatic expansion valve is largely dependent on the proper installation of the sensor (feeler) bulb. The sensor bulb should always be firmly attached to the inlet line.

When properly installed and adjusted, the thermostatic expansion valve will maintain all the evaporator surface effective and in contact with the boiling refrigerant regardless of the change in load on the evaporator, provided of course that the evaporator valve has sufficient capacity for peak loads.

Under normal operating conditions, the sensor (feeler) bulb will cause the thermostatic expansion valve to close during the shutdown period. There are, however, certain conditions that will affect this and may cause overflooding of the evaporator. For this reason, the inlet lines should be trapped.

If the evaporator in an air-conditioning system is connected to outside air or where it may receive air at a temperature lower than that surrounding the sensor (feeler) bulb, the difference in temperature between the evaporator and the bulb will cause the valve to open and overflood the low side. Under such conditions, it is essential that the liquid line be equipped with a solenoid valve to positively shut off the refrigerant during the shutdown period.

Float Valves

A *float valve* is one actuated by a float immersed in a liquid container (see Figure 9-25). Both low-side and high-side float valves are used to control the flow of liquid refrigerant in a refrigeration system.

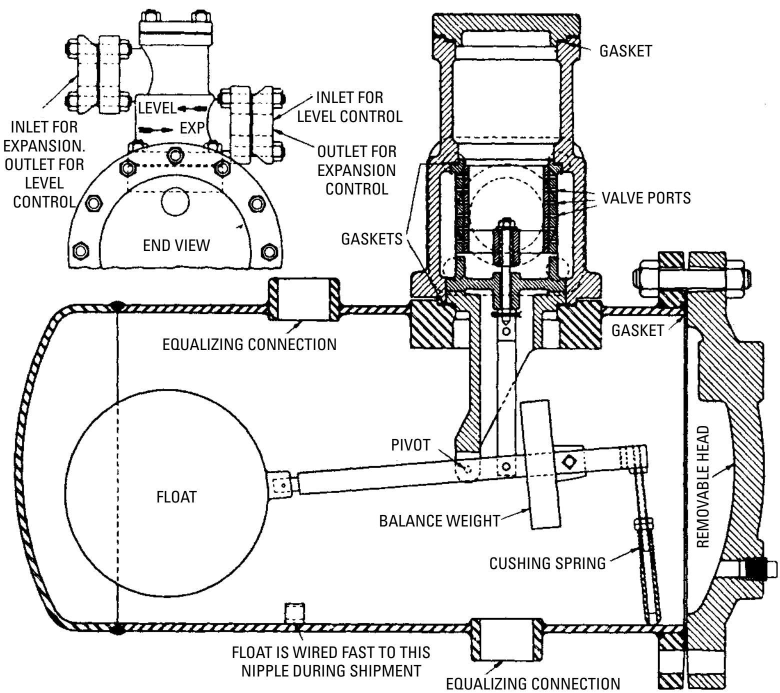


Figure 9-25 Float valve construction details. *(Courtesy Frick Company)*

A *low-side* float valve is one that is operated by a low-pressure liquid. It opens at a low level and closes when the liquid is at a high level. In other words, when there is no liquid in the evaporator, the float and lever arm are positioned so that the valve is left open. When liquid refrigerant under pressure from the compressor again enters the float chamber, the float rises until a predetermined level is reached and the valve is closed.

A *high-side* float valve is one that is operated by a high-side pressure. The valve opens on an increase of the liquid level in the float chamber and admits liquid to the low side.

Capillary Tubes

A *capillary tube* is a tube of small internal diameter used in refrigeration air-conditioning systems as an expansion device between the high-pressure and low-pressure sides. It can also be used to transmit pressure from the sensor bulb of some temperature controls to the operating element (see Figure 9-26).

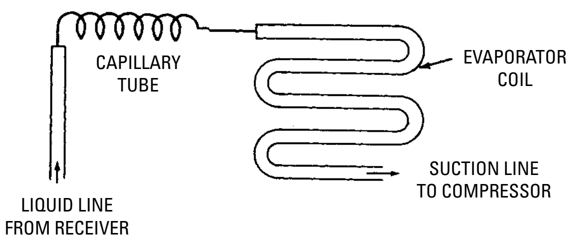


Figure 9-26 Capillary tube and connections to mechanical refrigeration system. *(Courtesy Honeywell Tradeline Controls)*

The use of a capillary tube as a liquid refrigerant expansion device is largely limited to completely assembled factory refrigeration units because the bore diameters and the length of the tube are critical to its efficiency. The pressure reduction that occurs between the condenser and evaporator results from the pressure drop or friction loss in the long, small-diameter passage provided by the capillary tube. No pressure-reducing valve is necessary between the high-side and low-side pressure zones when a capillary system is used.

Refrigerant Piping

The refrigerant travels between the various components of a mechanical refrigeration unit or system in small-diameter copper tubing sometimes referred to as the *refrigerant lines*.

The *suction line* is the piping between the evaporator and compressor inlet. Its function is to carry the refrigerant vapor to the compressor. It is important that the suction line be correctly sized for a practical pressure drop at full load. Under minimum load conditions, the suction line should be able to return oil from the evaporator to the compressor. Two other desirable features that should be incorporated in the design of a suction line are the following:

1. The prevention of oil drainage into a non-operating evaporator from an operating one.
2. The prevention of liquid drainage into a shut-down compressor.

The *liquid line* is the piping that carries the liquid refrigerant from the condenser or receiver to a pressure-reducing device.

The refrigerant piping (lines) should be carefully checked to make certain they will function properly. All connections should be examined for leaks, and all bends should be checked to make certain the tubing has not been squeezed together. A squeezed or pinched line will restrict the flow of refrigerant.

The *slope* of the suction line is also important in remote or split-system installations. When the evaporator coil is higher than the condensing unit, the suction line should be sloped with a continuous fall of at least ¼ inch per foot toward the condensing unit.

If the evaporator coil is higher than the condensing unit and the excess line is coiled, the excess tubing must be coiled horizontally in such a way that the flow of refrigerant is from the top to the bottom of the coil and toward the condensing unit in a continuous fall (see Figure 9-27).

Refrigerant Piping Service and Maintenance

Check the liquid and suction lines to make certain that they do not contact one another. Heat will transfer to the suction line if there is bare contact between the two.

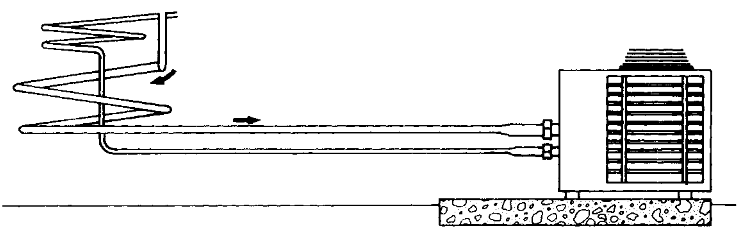


Figure 9-27 Flow of refrigerant toward the condensing unit.
(Courtesy Coleman Co.)

Check refrigerant line connections for proper seat at the evaporator coil. These are nonreusable connecting valves that must be 100 percent seated for effective operation. If these valves have not been 100 percent seated, then the metal diaphragm will obstruct the line and restrict the flow of refrigerant. If this condition is suspected, use a wrench on the stationary fitting of the valve as shown in Figure 9-28 while tightening the nut with another wrench.

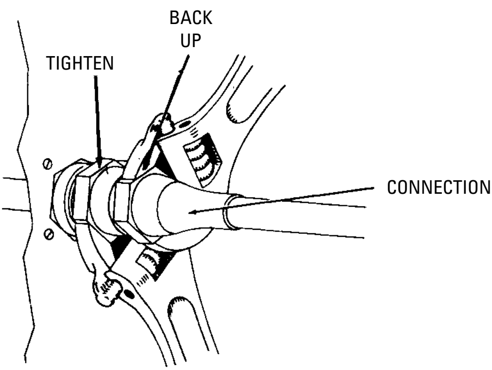


Figure 9-28 Using wrenches to tighten connection. *(Courtesy Coleman Co.)*

Troubleshooting Refrigerant Piping

Table 9-5 lists the most common operating problems associated with the refrigerant piping. For each observable symptom, a possible cause and remedy are suggested.

Table 9-5 Troubleshooting Refrigerant Piping

Symptom and Possible Cause	*Possible Remedy*
Frosted or sweaty suction line.	
(a) Capillary tube or expansion valve passes excess refrigerant.	(a) Check the size and bore of capillary tube. Readjust the expansion valve.
(b) Expansion valve is stuck.	(b) Clean valve; replace if necessary.
(c) Evaporator fan not running.	(c) Repair or replace.
(d) Overcharge of refrigerant.	(d) Correct.
(e) Ambient temperature too low.	(e) Block the condenser to increase the suction pressure or stop the unit.

(continued)

Table 9-5 (continued)

Symptom and Possible Cause	*Possible Remedy*
Hot liquid line.	
(a) Low refrigerant charge.	(a) Fix leak and recharge.
(b) Expansion valve stuck or open too wide.	(b) Clean valve and replace if necessary.
Frosted or sweating liquid line.	
(a) Restriction in dryer.	(a) Replace dryer.
Frost on expansion valve or on capillary tube.	
(a) Ice plugging capillary tube or expansion valve.	(a) Apply hot wet cloth to capillary tube or expansion valve; a suction pressure increase indicates moisture present. Replace dryer.

Filters and Dryers

Filters and dryers are devices that provide very important functions in a mechanical refrigeration system. A *filter* is a device used to remove particles from the liquid refrigerant and from the oil by straining the fluid. For this reason, it is also sometimes referred to as a *strainer.* If a filter or strainer were not used, these particles trapped in the fluid could block small passages in the thermostatic valve or capillary tube, thereby seriously affecting the operation of the cooling system, or they could eventually damage mechanical parts.

A *dryer* is a device designed to remove moisture from the refrigerant in a mechanical refrigeration system. It is also referred to as a *dehydrator* or a *drier* (a spelling variant used by some authorities).

A typical combination filter-dryer is shown in Figure 9-29. The desiccant surrounding the filter core is usually a silica gel and functions as a drying agent. This unit is usually installed in the liquid line (either at the liquid receiver outlet or at the expansion valve outlet).

Filters and dryers are not included with small-capacity cooling units (residential types) that are filled and hermetically sealed at the factory. Filters and dryers are usually installed in systems where the refrigerant circuit is designed for field service.

Pressure-Limiting Controls

Certain pressure-limiting controls are used in cooling systems to protect them from extremes in refrigeration suction and discharge line pressures. Whenever the pressures in the system deviate from

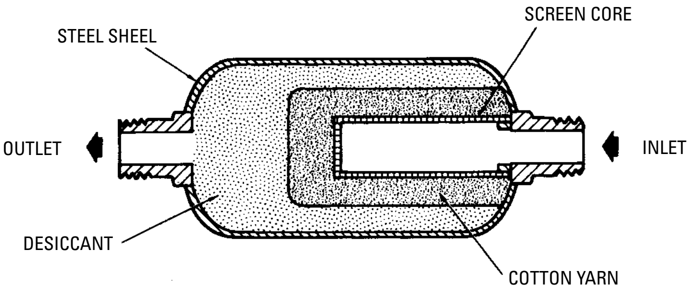


Figure 9-29 Combination filter-dryer. *(Courtesy Honeywell Tradeline Controls)*

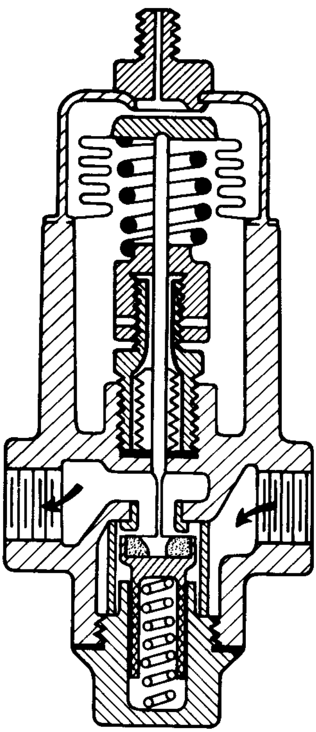


Figure 9-30 Diagram of a direct-acting water-regulating valve.

the normal operating range, the pressure control breaks the circuit to the compressor until the pressure returns to normal. High-side and low-side pressure switches are described in Chapter 6 ("Other Automatic Controls") in Volume 2.

Water-Regulating Valves

Temperature-actuated water-regulating valves are used on water-cooled condensers to maintain condensing pressures within the desired range. This is accomplished by increasing or decreasing the rate of water flow as required by conditions in the system. Most water-regulating valves may be classed as either *direct acting* or *pilot operated.*

In the case of a direct-acting valve, the deflection of the bellows caused by an increase in refrigerant pressure overcomes the force of the springs and pushes the disc away from the seat, allowing water to flow. When the unit shuts down, the refrigerant pressure becomes less than the spring pressure and the water valve closes off (see Figure 9-30).

In the pilot-operated valve, the main plunger to which the disc is attached is actuated by water pressure. Opening and closing the pilot port causes the differential pressure across the hollow plunger to vary. The amount of water that will flow through any given size and type of orifice will depend on the pressure differential across the orifice.

Water-regulating valves are rated at a certain quantity of flow under a given pressure differential and the amount of valve opening. The amount of opening is controlled by refrigerant pressure, but if the pressure differential is insufficient, no amount of opening will provide the necessary water for the condenser.

Automatic Controls

Refrigeration and air-conditioning systems consist of refrigeration equipment and an electrical control circuit. These components are interconnected to produce and control the required cooling. Wiring diagrams of some typical automatic cooling control circuits used in refrigeration and air-conditioning systems are illustrated in Figures 9-31 and 9-32.

A cooling control circuit can be divided into the following principal components:

1. Basic controller or thermostat
2. Limit control
3. Primary control
4. Power supply

The relationships and functions of these various control system components are illustrated in Figure 9-31. Detailed descriptions of these components are given in a number of different chapters, especially Chapters 4 and 6 in Volume 2. Refer to the index for additional information.

Note

> The compressor and fan controls are subject to early failure in an oversized air-conditioning system because the air conditioner is forced to turn on and off frequently. The corrosion of wires and terminals is also a problem in many systems. Regularly check all electrical wiring and contacts for loose connections, corrosion, and damage.

System Troubleshooting

Table 9-6 lists the most common operating problems associated with the system as a whole. For each problem and symptom, a possible cause and remedy are suggested.

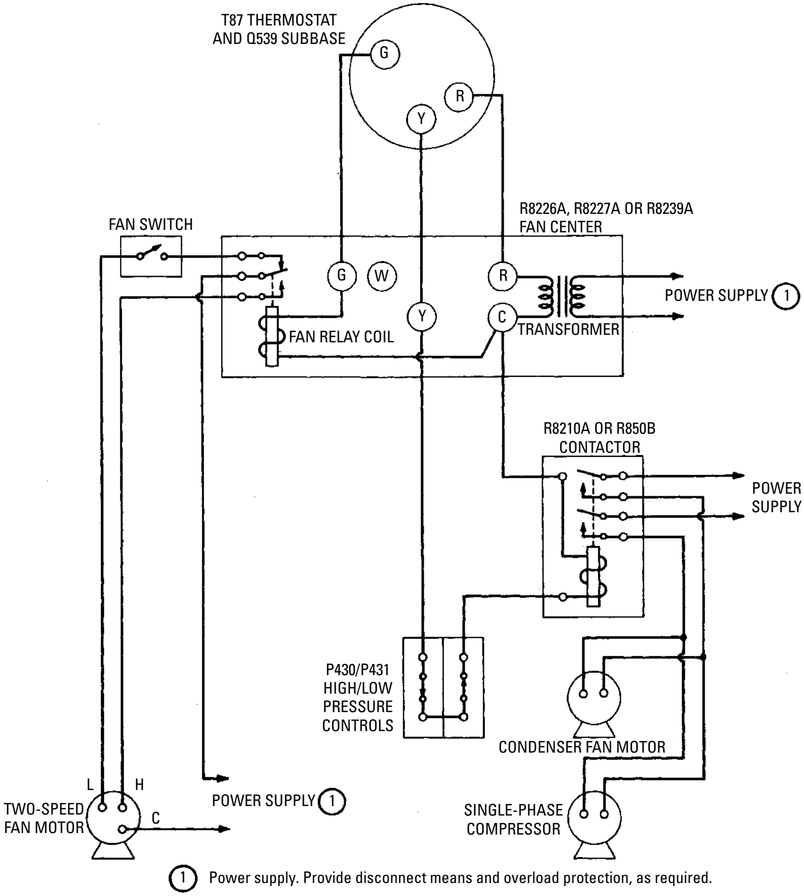


Figure 9-31 Basic cooling control system with system power supplied by fan center transformer. *(Courtesy Honeywell Tradeline Controls)*

General Servicing and Maintenance

It must be thoroughly understood that the greatest precautions must be taken to exclude air and moisture from a refrigeration system and that it should not be opened to the atmosphere without first removing the refrigerant from that part of the system to be serviced or repaired.

Caution

> Always shut off the electrical power to the air conditioner at the disconnect switch before performing any maintenance or repairs. The air conditioner may have multiple power supplies.

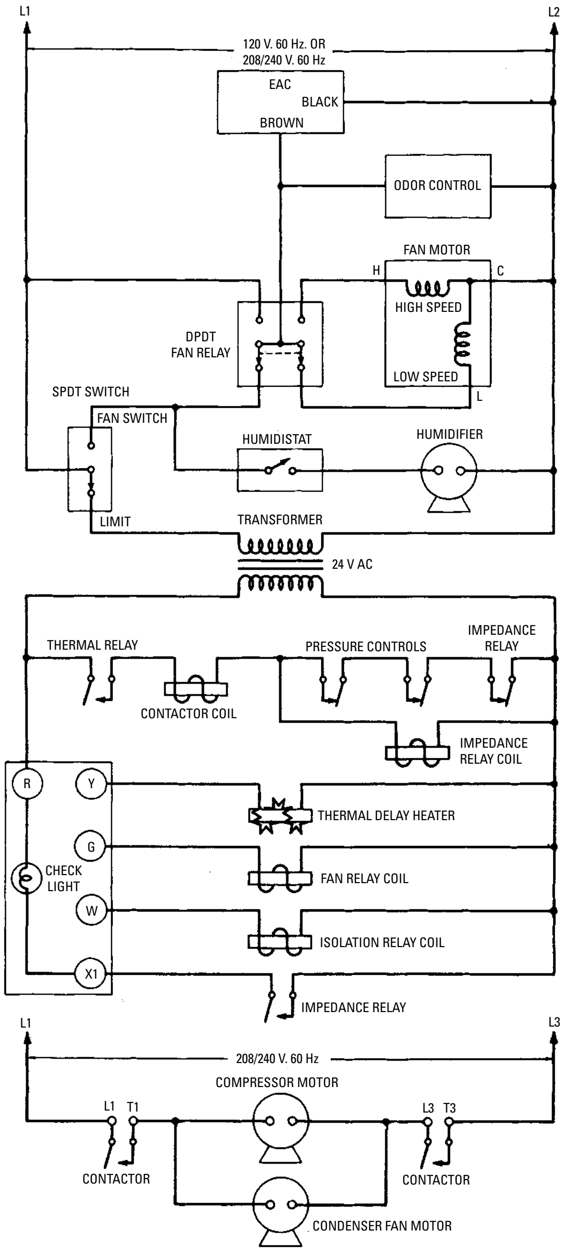


Figure 9-32 Ladder diagram of basic cooling system control circuit. *(Courtesy Honeywell Tradeline Controls)*

Table 9-6 System Troubleshooting

Symptom and Possible Cause	*Possible Remedy*
Unit operates continuously.	
(a) Shortage of refrigerant.	(a) Fix leak and recharge.
(b) Control contacts frozen or stuck closed.	(b) Clean points or replace.
(c) Insufficient air or dirty condenser.	(c) Check and correct.
(d) Air conditioner space poorly insulated or excess load in structure.	(d) Replace with larger unit.
(e) Compressor valves defective.	(e) Replace compressor.
(f) Restriction in refrigerant system.	(f) Check and correct.
(g) Filter dirty.	(g) Clean or replace.
(h) Air bypassing the coil or service load.	(h) Check return air; keep windows and doors closed.
Space temperature too high; not enough cooling.	
(a) Refrigerant charge low.	(a) Check for leaks and recharge.
(b) Control set too high.	(b) Reset control.
(c) Cap tube, expansion valve, or dryer plugged.	(c) Repair or replace.
(d) Iced or dirty coils.	(d) Defrost or clean.
(e) Unit too small.	(e) Replace with larger unit.
(f) Insufficient air circulation.	(f) Correct air circulation.
(g) Cap tube or expansion valve not allowing enough refrigerant.	(g) Reset or replace.
(h) Cooling coils too small.	(h) Replace.
(i) Restrictions or small gas lines.	(i) Correct restrictions; increase line size.
(j) High and low pressures approaching each other; defective compressor valves.	(j) Replace compressor.
(k) Low line voltage.	(k) Check line voltage and correct.
(l) Dirty air filter.	(l) Replace.
(m) Dirty condenser.	(m) Clean condenser.
(n) Air circulator size too small.	(n) Replace with larger air ` circulator.
(o) Ductwork too small.	(o) Increase size of ductwork.

(continued)

Table 9-6 *(continued)*

Symptom and Possible Cause	*Possible Remedy*
Noisy unit.	
(a) Tubing rattle.	(a) Fix so it is free from contact.
(b) Fan blade causing vibration.	(b) Check for bend; replace if necessary.
(c) Refrigerant overcharged or oil too high.	(c) Check for correct refrigerant charge and maintain oil level. If necessary, replace expansion valves or capillary tube.
(d) Loose parts or mountings.	(d) Fix and tighten.
(e) Motor bearings worn.	(e) Replace motor.
(f) Lack of oil in the compressor.	(f) Add required oil.
No air delivery out of register.	
(a) System not set for summer cooling.	(a) Read operating instructions and make required adjustment.
(b) Fan motor not operating.	(b) Repair or replace.
(c) Open power switch.	(c) Close switch.
(d) Fuse blown.	(d) Replace with same-size fuse.
(e) Broken connection.	(e) Check circuit and repair.
(f) Register closed.	(f) Open register.
(g) Evaporator fan motor leads not connected to line voltage.	(g) Connect the leads.

Regular Maintenance

Extend the service life and operating efficiency of the air-conditioning equipment and system by providing regular maintenance. A regular maintenance schedule should include the following:

- Clean the indoor evaporator coils.
- Clean the outdoor condenser coils. Use a water hose to flush the outdoor condenser coils.
- Check the coils for leaks with a leak detector.
- Clean or replace the indoor unit filter.
- Check wiring and contacts for loose connections, corrosion, and/or damage.
- Check the amp draw at the outdoor fan motor and the indoor blower motor and compare the values to those on the unit nameplate.

- Check the voltage at the indoor and outdoor units *with the units operating*.
- Check the system for the correct amount of refrigerant.
- Inspect the condensate drain line for blockage and clean as necessary.
- Check the ducts for leaks and repair if found.
- Oil motors and check belts for tightness and wear.
- Check for the correct electrical control sequence.

Pumping Down

Whenever a refrigeration system is to be opened to the atmosphere for service operations or repairs, it is necessary to remove the refrigerant from that part of the system to be opened. By *pumping down* the system prior to servicing, the refrigerant can be saved.

The manufacturer of the equipment will usually include detailed instructions concerning the pump-down procedure. Read and follow these instructions carefully.

Pumping down the system usually involves confining the refrigerant to the receiver by closing off the liquid line stop valve and (with a gauge attached to the intake stop valve) operating the compressor. By doing this, all the gas is drawn back to the compressor and condensed in the condenser but is prevented from going further by the liquid line stop valve.

The compressor should be run until the suction pressure is reduced to holding steady at approximately 2 to 5 lbs pressure. Do *not* draw a vacuum on the system. A vacuum will cause moisture to be drawn into the system when it is opened.

Purging

Purging refers to the release of air or noncondensable gases from a system, usually through a cock placed on or near the top of the receiver. This term is also applied to the sweeping of air out of a newly installed part or connection by releasing refrigerant gas into the part and allowing it to escape from the open end, thus pushing the air ahead of it.

Follow the instructions for purging contained in the manufacturer's installation and operating literature.

Evacuating the System

Sometimes it becomes necessary to remove the *entire* refrigerant charge from the system. This operation is referred to as *evacuating the system* and is accomplished as follows:

1. Close the discharge service valve stem by turning it clockwise and remove the gauge connection plug.
2. Open the inlet service valve by turning the stem counterclockwise and attach a compound gauge to the inlet service valve.
3. Close the valve ½ turn clockwise and start the unit discharging through the open gauge connection in the discharging service valve.

Warning

Capture the evacuated refrigerant. It is illegal to release the refrigerant to the atmosphere.

If a vacuum is pumped too rapidly, the compressor will have a tendency to pump oil out of the compressor crankcase. Attach a copper tube to the gauge port and bend it so that any oil pumped out may be drained into a container. During this operation, the compressor may knock.

If knocking occurs, stop the compressor for about a minute and then restart. Continue the process until the gauge indicates a 20-inch vacuum or better. At this point, leaks in the system may be detected by putting sufficient oil in the container to cover the end of the tubing and continuing the pumping operation. When the system is entirely evacuated, no more bubbles should appear in the oil container. After the system is fully evacuated, replace the discharge gauge connection plug or attach a pressure gauge as desired.

Charging

Charging is the addition of refrigerant to a system from an external drum. There are a number of ways to add a refrigerant charge to a system, but the safest method usually is to introduce the refrigerant through the liquid line. The procedure may be outlined as follows:

1. Connect the refrigerant cylinder to the liquid line port at the condenser or compressor.
2. Purge the connecting line and tighten the last connection.
3. Disconnect the compressor so that it will not run during the charging operation.
4. Turn on the blower to the condenser.
5. Warm the refrigerant cylinder by placing it in a bucket of warm water (see Figure 9-33). Do *not* immerse any refrigerant connections.

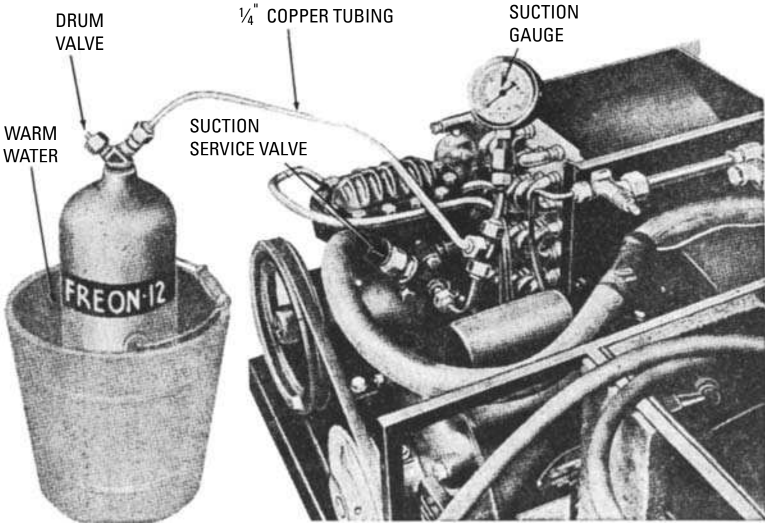


Figure 9-33 Warming the refrigerant cylinder.

6. Remove the cylinder from the water when you are satisfied it has been thoroughly warmed.
7. Wipe the cylinder dry and invert it.
8. Open the cylinder valve and the charging port valve.

The refrigerant should flow very readily into the high-pressure side of the system if steps 1–8 were carefully followed.

After the system has been charged, close the refrigerant cylinder valve, allow 2 or 3 minutes to pass, and disconnect the cylinder. Reconnect the compressor and operate the unit, using gauges to determine if the charge is sufficient.

Always exercise caution when making connections or disconnections on the liquid line. This line is under high pressure, and the refrigerant is in a liquid form. Guard against refrigerant spraying into the face and eyes. Any minor leakage that may occur around the refrigeration hose in disconnection will be cold and at high pressure. To minimize pressures, liquid line disconnections should be made *after* the unit has been shut down for at least 5 minutes.

If the refrigerant charge is introduced in the low-pressure side of the system, the charging cylinder should always be kept in a vertical position. This precaution prevents the refrigerant liquid from flowing into the crankcase of the compressor.

Never heat a refrigerant cylinder with a torch or any other type of flame. Warming a cylinder in this manner generates excessive pressures, which can result in an explosion. *Always* use warm water to heat a refrigerant cylinder.

Silver-Brazing Repairs

For the repair of tubing condensers, evaporators, and parts made of light metal, *silver brazing* is the ideal process. It was formerly known as silver soldering, a term still frequently used. The term silver soldering is used to avoid confusing the use of silver-brazing alloys with the soft solders. Some silver-brazing alloys contain a certain amount of silver alloyed with copper and zinc. Others contain silver, copper, and phosphors. These alloys are available in forms having melting temperatures ranging from 1175°F to 1500°F.

The use of silver-brazing alloys enables the serviceperson to obtain strong joints without danger of burning or overheating the base metals. Apart from the skill acquired through practice, the two most important requirements of a good silver-brazing job are clean surfaces and enough heat to make the silver flow freely, but not so much that the silver burns to form scale. The best source of heat is an oxyacetylene or compressed-air and illuminating gas torch.

The various operations to be performed in silver brazing are as follows:

1. Preparation
2. Preparing swaged joints
3. Preparing different-size tubing for connection
4. Applying the flux
5. Applying the brazing alloy

Silver brazing has very little tensile strength of its own. The total strength of the joint is derived from the union of the two surfaces as a result of the action of the alloys used. Accordingly, surfaces must fit together tightly.

The tubing should be expanded or swaged to a depth at least equal to its diameter for tubes up to ½ inch and not less than ½ inch deep for tubes of larger diameter. Special swaging blocks and drifts that accurately size and shape the inside of the tube and the outside of the expanded section are recommended for this operation where there is sufficient volume to warrant the investment. For occasional jobs, the tube can be held on a flare block and a swaging drift driven into it to form the bell end.

Where two tubes of different sizes, such as 3⁄8 inch and 1⁄2 inch, are to be joined, the smaller tube can be expanded by the previously described method until the outside diameter of the smaller tube is sized to fit snugly into the inside of the larger tube.

When the surfaces of the tube ends to be joined have been thoroughly cleaned with steel wool or sandpaper, they should be fitted together and clamped, or firmly held together so that no movement will occur while they are being brazed (see Figure 9-34).

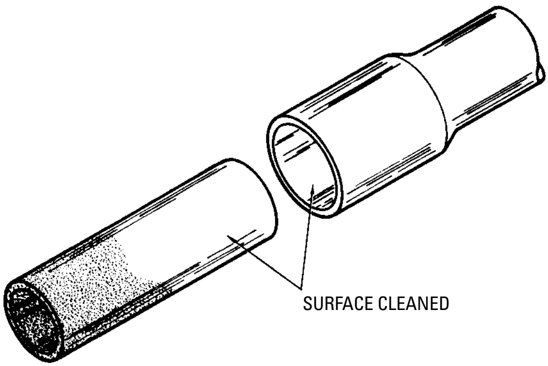


Figure 9-34 Surface preparation. The surface must be clean.

Apply enough flux with a brush to cover the surfaces to be joined, but not so much that it will run down the tubing. Make certain, however, that the flux is inside the joint all the way around (see Figure 9-35).

After the flux has been applied, the heat should be concentrated on one side of the joint and the silver brazing applied (see Figures 9-36 and 9-37). The temperature of the parts to be joined should be high enough to melt the silver by touching it to the heated surfaces near the flame. When the silver melts, apply it to the heated surfaces near the flame, but not under the flame. Move the flame around the heated surface, following it with silver until silver has been applied to the entire joint. Do not use too much silver, and try to keep it from running down inside the tubing. Apply only enough heat to cause the silver-brazing alloy to flow freely in order to avoid the formation of scale or the burning of the surfaces.

Most of the heat should be applied to the heavier parts of the joint where it will be conducted through the metal to the location where the silver alloy is to be applied.

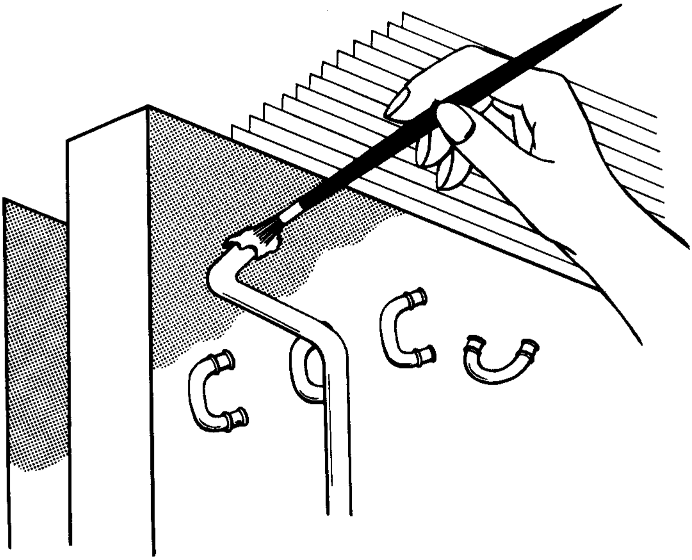


Figure 9-35 Applying flux with brush.

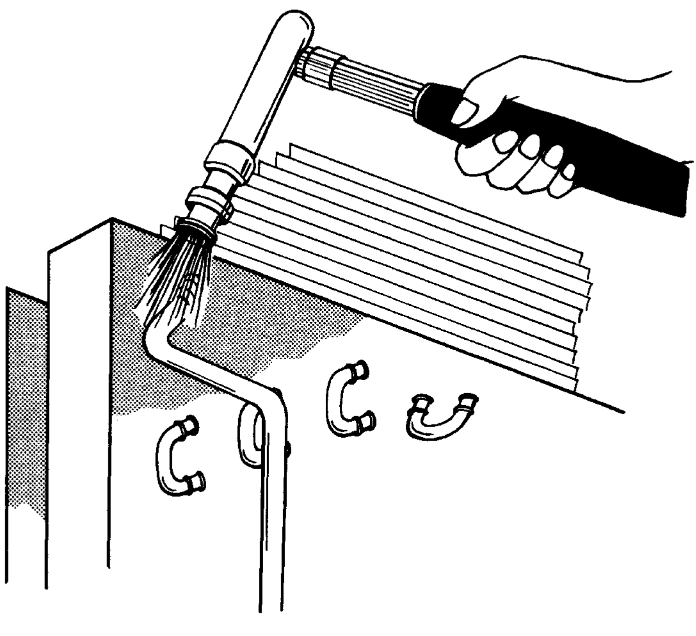


Figure 9-36 Applying heat.

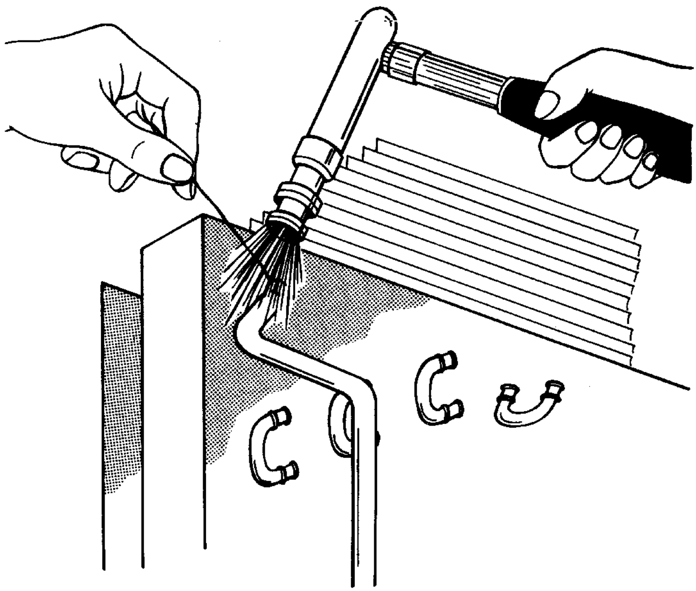


Figure 9-37 Applying brazing alloy.

Flames should never be applied directly to the point where brazing is being done. For thorough inspection of the joint, all flux must be carefully removed. Pinholes may exist under the film of melted brazing flux and are not readily noticed until the flux has been removed.

Cleaning the joint can be done either by washing it with water while the joint is still hot or by thoroughly brushing and scraping it with a wire brush or emery cloth after the joint has cooled.

Where silver brazing is being done near an enameled or painted surface, or such materials as wood, insulating material, and other combustible surfaces, the surface should be protected with sheet asbestos during the brazing operation.

Valves, controls, or other apparatus to which a tube is being joined by silver brazing must be protected from damage by heat. Either remove the internal parts of the valve or protect the entire assembly with a wet cloth.

If a joint has previously been soldered with soft solder, all traces of the soft solder must be removed because the tin in soft solder amalgamates with copper at the temperature necessary for a silver-brazing operation.

Chapter 10

Heat Pumps

A *heat pump* is a refrigeration device used to transfer heat from one room or space to another. The heat pump is designed to take heat from a medium-temperature source, such as outdoor air, and convert it to higher-temperature heat for distribution within a structure. By means of a specifically designed reversing valve, the heat pump can also extract heat from the indoor air and expel it outdoors.

Because a heat pump system uses the reverse-cycle principle of operation, its operating principle is sometimes referred to as *reverse-cycle conditioning* or *reverse-cycle refrigeration*. The latter term is not correct because there are fundamental differences between the operating principles of a heat pump and a true refrigeration unit. The confusion probably stems from the fact that during the cooling cycle, the operation of a heat pump is identical to that of the mechanical refrigeration cycle in a packaged air-conditioning unit. The indoor coil functions as an evaporator, cooling the indoor air. The outdoor coil is a condenser, in which the hot refrigerant gas releases heat to the outside air.

Heat Pump Operating Principles

The two principal phases of heat pump operation are the heating and cooling cycles. A third phase, the defrost cycle, is used to protect the coils from excessive frost buildup.

Heating Cycle

The heating cycle of a heat pump begins with the circulation of a refrigerant through the outdoor coils (see Figure 10-1). Initially, the refrigerant is in a low-pressure, low-temperature liquid state, but it soon absorbs enough heat from the outdoor air to raise its temperature to the boiling point. Upon reaching the boiling point, the refrigerant changes into a hot vapor or gas. This gas is then compressed by the compressor and circulated under higher pressure and temperature through the indoor coils, where it comes into contact with the cooler room air that circulates around the coils. The cooler air causes the gas to cool, condense, and return to the liquid state. The condensation of the refrigerant vapor releases heat to the interior of the structure. After the refrigerant has returned to a liquid state, it passes through a special pressure-reducing device (an

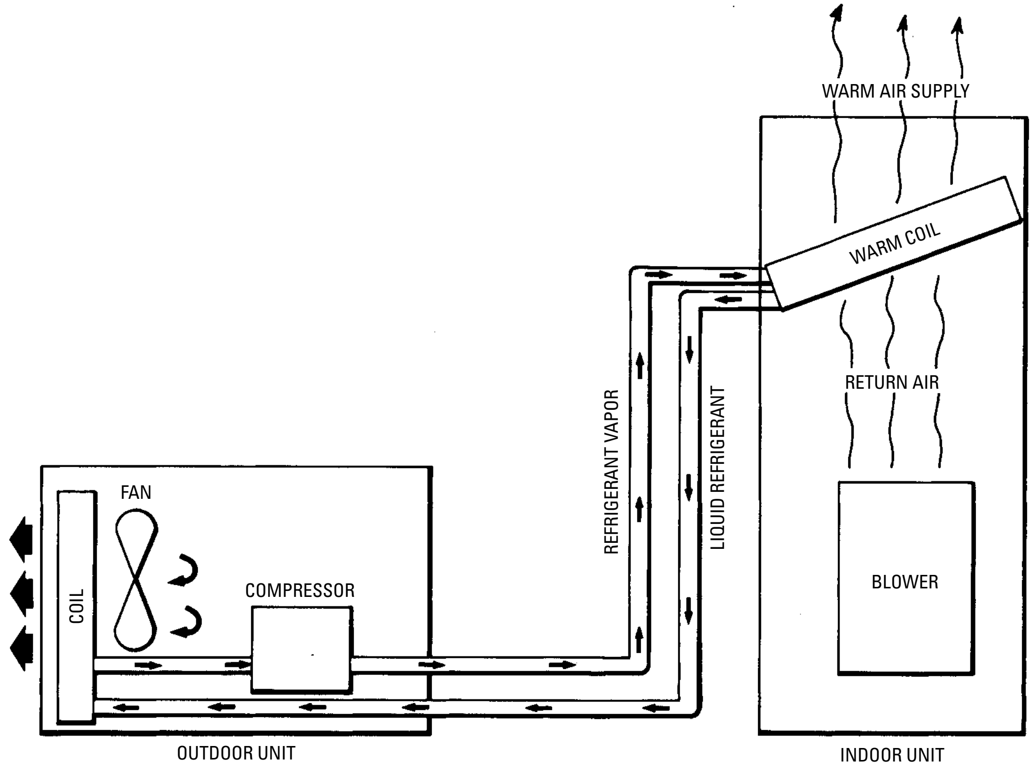


Figure 10-1 Heat pump heating cycle. *(Courtesy Lennox Air Conditioning and Heating)*

expansion valve) and then back through the outdoor coils where the heating cycle begins all over again. The temperature of the room air that originally cooled the higher-temperature refrigerant vapor is itself increased by the process of heat transfer and recirculated throughout the room to provide the necessary heat.

Note

A heat pump is designed to reverse the action or direction of heat transfer depending on whether heating or cooling is desired. As a result, the indoor and outdoor coils change their functions based on the heating or cooling cycle. The outdoor coil becomes the condenser in the cooling cycle and the evaporator in the heating cycle. The indoor coil, on the other hand, becomes the evaporator in the cooling cycle and the condenser coil in the heating cycle.

Cooling Cycle

In the cooling cycle, the reversing valve causes the flow of the refrigerant to be reversed. As a result, the compressor pumps the refrigerant in the opposite direction so that the coils that heat the building or space in cold weather cool it in warm weather. In other words, the heat is extracted from the interior, cycled through the heat pump, and then expelled outside the building or space during the condensation of the refrigerant (that is, its change from a gaseous to a liquid state) (see Figure 10-2).

Heat Sink

The heat given off by the process of condensation is received by the *heat sink*. This is true for both the heating and cooling cycles. In the former, the air of the rooms or spaces functions as the heat sink. In the cooling cycle, the outside air, a water source (for example, a well, a pond, or a sewage pipe) or the ground commonly serve as heat sinks outside the structure.

Defrost Cycle

Because the outdoor air is relatively cool when the heat pump is on the heating cycle, and the outdoor coil is acting as an evaporator, frost forms on the surface of the coil under certain conditions of temperature and relative humidity. Because this layer of frost on the coils interferes with the efficient operation of the heat pump, it must be removed. This is accomplished by putting the heat pump through a defrost cycle.

In the *defrost cycle*, the action of the heat pump is reversed at certain intervals and returned to the cooling cycle. This is done to

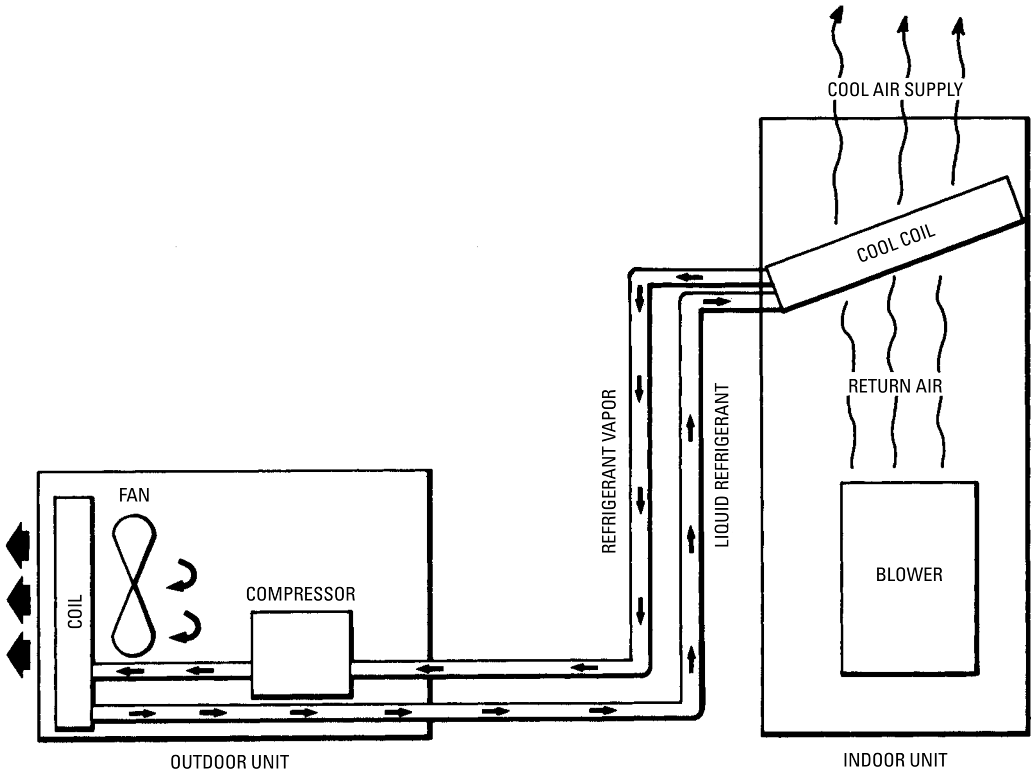


Figure 10-2 Heat pump cooling cycle. *(Courtesy Lennox Air Conditioning and Heating)*

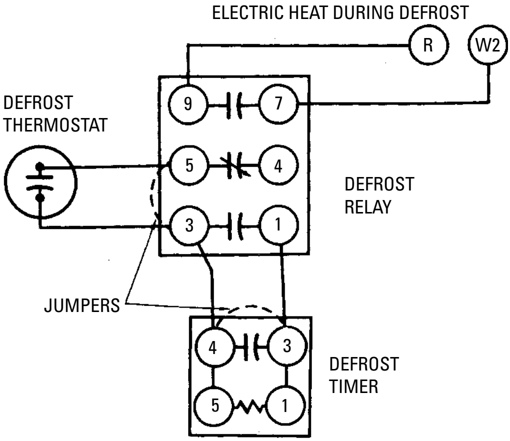


Figure 10-3 Defrost system wiring diagram. *(Courtesy Bard Mfg. Co.)*

temporarily heat the outdoor coil and melt the frost accumulation. The temperature rise of the outdoor coil is hastened because the operation of the outdoor fan stops when the system switches over to the cooling cycle.

The system will remain in the cooling cycle until the coil temperature has risen to 57°F. The time of the defrost cycle will vary, depending on how much frost has collected on the coil. During this period, the indoor motor continues to operate and blow cool air. This cold condition can be eliminated by installing an electric heating element (see *Auxiliary Electric Heating Elements* in this chapter). The heating element is wired in conjunction with the second stage of a two-stage thermostat and will come on automatically when the heat pump is in the defrost cycle (terminals 9 and 7 on the defrost relay in Figure 10-3).

The defrost cycle control system consists of a thermostat, timer, and relay. The defrost thermostat is located at the bottom of the outdoor coil where it can respond to temperature changes in the coil. It makes contact (closes) when the temperature of the outdoor coil drops to 32°F. This action of the thermostat causes the timer motor (located in the unit electrical box) to start. After the accumulative running periods reach either 30 minutes or 90 minutes (depending on the type of cam installed in the timer), the timer energizes the defrost relays, which reverses the reversing valve and stops the *outdoor* fan motor. The unit remains in the defrost cycle (cooling cycle) until the temperature of the outdoor coil reaches 57°F. At that temperature the coil is free of frost and the frost thermostat opens to

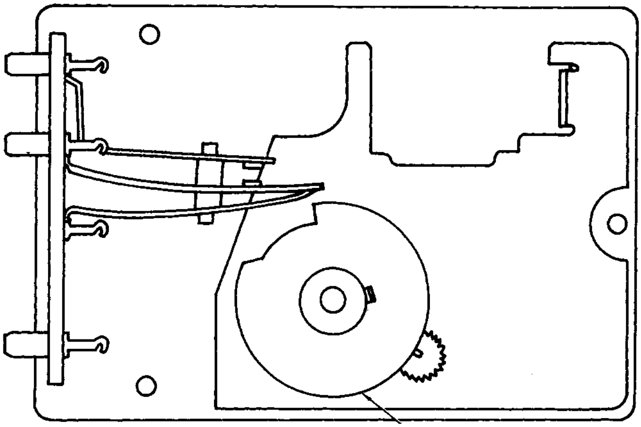


Figure 10-4 Thirty-minute cam. *(Courtesy Heat Controller, Inc.)*

stop the timer and return the unit to the heating cycle. The timer will not run again until the outdoor coil temperature drops to 32°F. The timer runs *only* when the thermostat contacts are closed.

A defrost timer is shipped with a 30-minute cam installed (see Figure 10-4). With this cam, the unit will defrost once every 30 minutes (of accumulated running time) when the outdoor coil temperature is below 32°F. If there is little or no frost on the coil, the defrost cycle will be correspondingly short (approximately 45 seconds to 1 minute). A 90-minute cam is recommended.

Types of Heat Pumps

Heat pumps are often classified according to their heat source. The three principal types used in residential and light commercial heating/cooling systems are: (1) air-source heat pumps, (2) ground-source heat pumps, and (3) water-source heat pumps.

Air-Source Heat Pumps

An *air-source heat pump* (also sometimes called an *air-to-air heat pump*) relies on the outdoor air as the heat source. In other words, it extracts the heat from the outdoor air and transfers it to the rooms and spaces inside the structure. A major technical problem associated with earlier air-source heat pumps was that the temperature of the outdoor air is commonly lowest when heat requirements are highest—that is, during the cold winter months. When outdoor temperatures drop below 0°F, the heat pump is largely ineffective. For this reason, some sort of supplementary radiant heating system was usually employed until outdoor air temperatures rose to a level suitable for effective use of the heat pump.

Note

Air-source heat pumps operate most efficiently in areas where the winter temperatures usually remain above 30°F. In climates where the winter temperatures frequently drop below freezing, a backup auxiliary heater must be used with an air-source heat pump. Ground-source heat pumps are more efficient and economical to operate than conventional air-source units in areas with similar heating and cooling loads.

Split-System Heat Pumps

Most air-source heat pumps used in residential and light-commercial heating and cooling systems are split-system heat pumps. A *split-system heat pump* is so called because its components are divided into two sections, one located indoors and the other outdoors. The two sections are connected by refrigerant tubing. In most split-system heat pumps, the evaporator coil, blower, and filter section are located inside the structure, and the compressor, condenser coil, and fan are located outdoors (see Figures 10-5, 10-6, and 10-7).

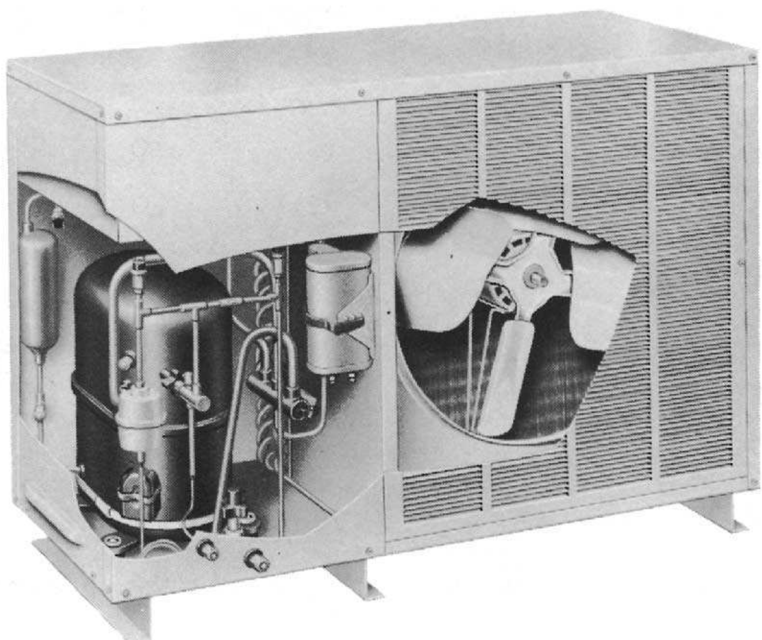


Figure 10-5 Outdoor heat pump unit. *(Courtesy Lennox Air Conditioning and Heating)*

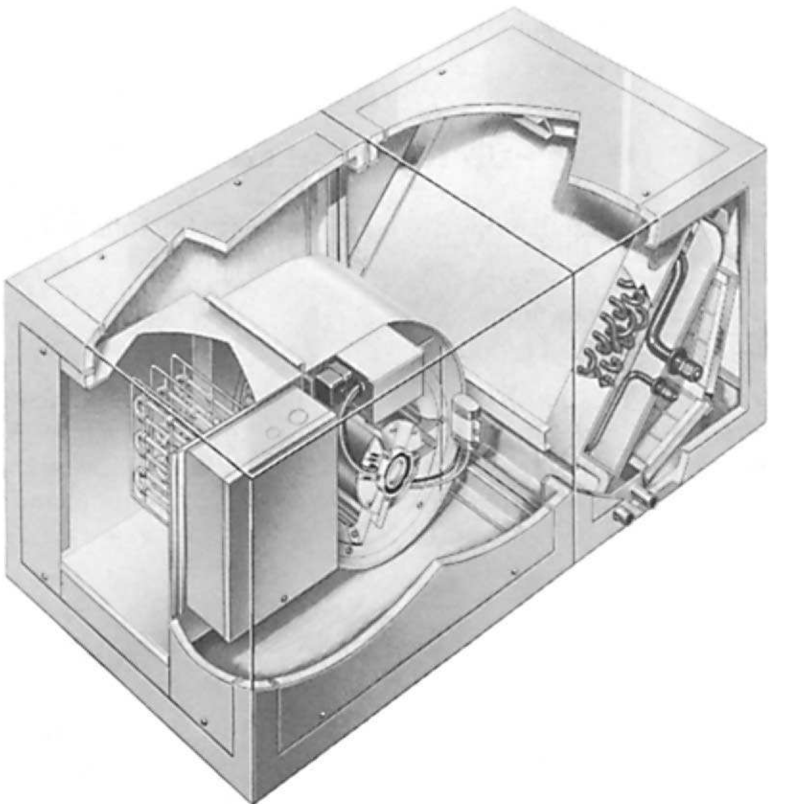


Figure 10-6 Indoor heat pump unit. *(Courtesy Lennox Air Conditioning and Heating)*

Sometimes the outdoor condensing section is installed on the roof and the indoor section is suspended from the ceiling. This is a very common type of installation in commercial buildings.

In residential installations, the outdoor section is usually placed on a concrete slab next to the house and the indoor section is located either in the attic (installed horizontally) or in a closet space (installed vertically) on the same level as the outdoor unit.

Packaged Heat Pumps

Some air-source heat pumps are packaged units. A *packaged heat pump* differs from the split-system heat pump by having the condenser coil, evaporator coil, compressor, blower and motor,

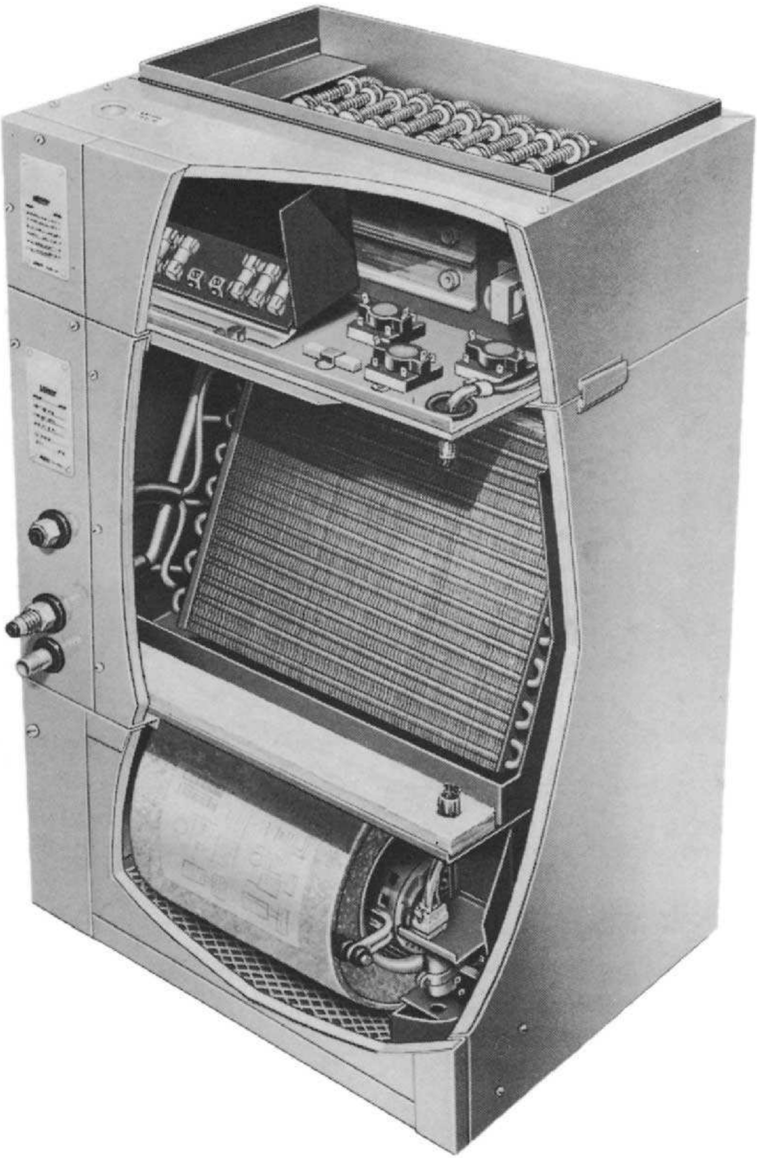


Figure 10-7 Indoor unit for split system. *(Courtesy Lennox Air Conditioning and Heating)*

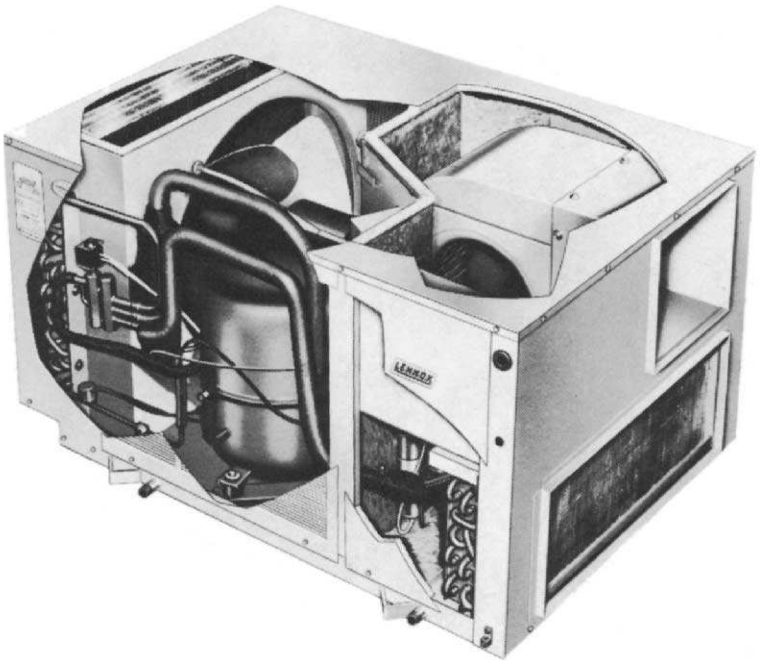


Figure 10-8 Packaged heat pump unit. *(Courtesy Lennox Air Conditioning and Heating)*

automatic controls, and filter all located in the same box (see Figure 10-8). Some packaged heat pumps are used with ductwork to heat and cool the entire house; others do not use ductwork because they are designed to heat and cool only a single room and do not require ducts. These heat pumps are also referred to as *single-packaged units, through-the-wall units,* or *self-contained heat pumps* by various manufacturers.

Advantages and Disadvantages of Air-Source Heat Pumps

Most residential heat pumps are the air-source type installed as a split system with the compressor and outdoor coil installed outside the structure and the indoor coil installed inside. Because their use is so widespread, replacement parts are easy to acquire and trained, certified technicians are readily available in most areas of the country.

The air-source heat pump is less expensive to install than the ground-source or water-source heat pumps. On the other hand, it is noisier than either of the other types, is more difficult to conceal, and requires more maintenance.

Ground-Source Heat Pumps

A *ground-source heat pump* uses the constant temperature of the earth instead of the outdoor air as the heat-exchange medium (that is, the heat source or heat sink depending on the heating or cooling cycle). During the summer when cool interior temperatures are required, the fluid circulating through the indoor coil of the heat pump collects the heat from inside the structure and pumps it outdoors into a pipe system located below ground. The heat is then absorbed into the ground through the piping and the fluid is recirculated back to the unit. In the winter, the process is reversed. The system is based on the principle of heat transference, whereby heat is transferred from one object (the underground pipe) to another object (the ground) through direct contact. The temperature of the ground is a constant 55°F.

Ground-Source Heat Pump Terminology

Ground-source heat pump technology has made spectacular advances in recent years through research and development by various HVAC equipment manufacturers. The HVAC trade associations, as well as the government, have also conducted extensive research in this technology. As a result, the ground-source heat pump is identified by many different names, which can be a bit confusing. The two most widely used names for this appliance are *ground-source heat pump* and *geothermal heat pump*. Other less commonly used names include the following:

- Water-source heat pump
- Well-water heat pump
- Direct-expansion heat pump
- Geo-exchange heat pump
- Groundwater heat pump
- Earth-coupled heat pump
- Ground-coupled heat pump
- Open-loop heat pump
- Closed-loop heat pump

The use of so many different names for the same appliance results from attempts to accurately identify the appliance and its operating principle or, in many cases, to exclusively associate a name with a specific equipment manufacturer. Eventually, only one name will emerge as the industry standard. At this point, the names ground-source heat pump and geothermal heat pump have the widest usage. Both are also used to include water-source heat pumps, which are described separately in this chapter.

Ground-Source Coupling System

A ground-source (geothermal) heat pump uses a closed-loop ground coupling system as a heat exchanger. In a closed-loop ground coupling system, a heat transfer fluid is circulated by a pump through a network of buried high-strength plastic pipe. Because the loop system is closed, there is no mixing of the fluid with groundwater and no buildup of contaminating mineral deposits in the heat pump heat exchanger.

The configuration of the ground coupling will depend primarily on installation cost and the available space. The following three closed-loop systems are illustrated in Figure 10-9:

- Horizontal closed-loop system
- Spiral closed-loop system
- Vertical closed-loop system

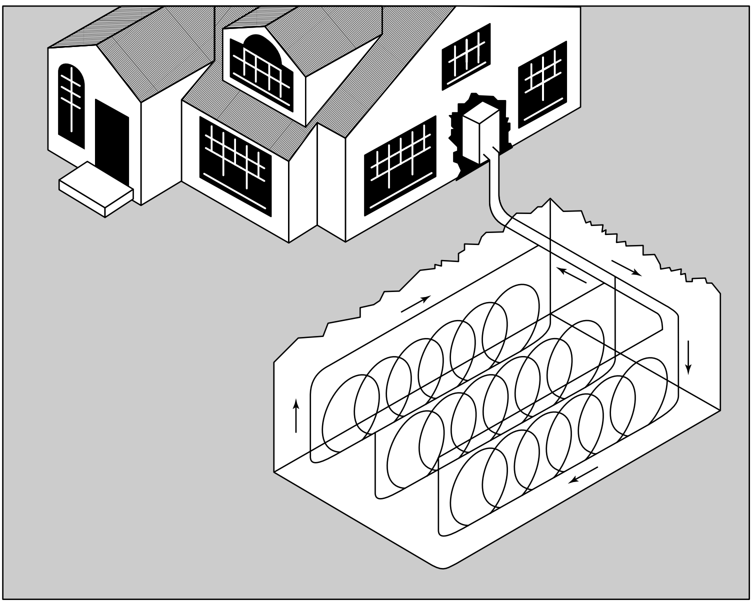


Figure 10-9 Closed-loop ground coupling systems.

(Courtesy U.S. Department of Energy)

The horizontal loop is used only when there is adequate space. The space surrounding the house or building must be great enough to bury the pipe network without extending onto the neighbor's property. One to six pipes are buried at least 4 ft beneath the surface in trenches.

Horizontal loops are most commonly used in residential heat pump systems where there is adequate space beneath lawns to bury the pipes. They are not recommended for large-tonnage commercial applications because the land area required for the ground loops is much larger than the area of most city properties.

The spiral loop is a variation of the horizontal loop configuration. In this configuration, the pipe is unrolled in spirals and placed in horizontal trenches. In the vertical closed-loop system, the pipe loops are inserted in 75- to 300-ft-deep vertical dry wells.

Advantages and Disadvantages of Ground-Source Heat Pumps

The U.S. Environmental Protection Agency (EPA) rates the ground-source heat pump as being the most energy efficient and environmentally clean of all the heating and cooling systems available for residential use. It is quieter and less costly to operate than an air-source heat pump. It also has lower maintenance requirements because the outside elements (piping loops) are buried in the ground and not exposed to weather extremes.

Ground-source heat pumps do not require defrost cycles or crankcase heaters because there is not the same danger of outdoor coil freezing as there is with air-source heat pumps. Furthermore, there is less of a need for supplemental resistance heaters than is required with air-source heat pumps.

Ground-source heat pumps obtain their heat from the ground during the heating cycle. Because subsurface ground temperatures remain fairly constant and uniform throughout the year, ground-source heat pumps are very efficient all year long.

The two principal disadvantages of a ground-source heat pump are its high installation costs and the requirement for large areas in which to bury the outdoor piping loops.

Water-Source Heat Pumps

Water-source heat pumps use water for both the heat source and the heat sink. The water serves as a direct heat transfer medium in contrast to the heat transfer fluid used in closed-loop systems. The steady cool temperature of the water offsets the seasonal temperature variations by serving as a reservoir of heat in the winter and as a drain of heat in the summer. The compressor and controls of a water-source heat pump are identical to those in a ground-source heat pump.

Water-Source Coupling System

A water-source heat pump uses both the open-loop and closed-loop coupling systems. The open-loop coupling system uses local groundwater from extraction wells or extraction and reinjection wells (see Figure 10-10). In some systems, a single standing column

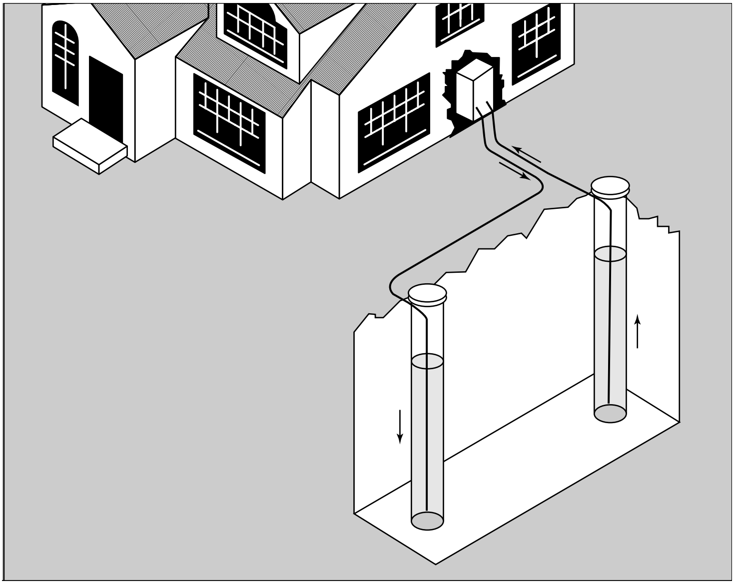


Figure 10-10 Water-source heat pump open-loop coupling system.
(Courtesy U.S. Department of Energy)

well is used as the water source. A standing column well allows the major part of the discharge water from the heat pump to be reinjected into the source well. This method eliminates the need for a separate reinjection well.

A submerged closed-loop piping system is used with a water-source heat pump if the heat source and discharge area is a lake, pond, or stream. Using a closed-loop system avoids the problem of discharging the water back into the lake, pond, or stream, which can be an environmental concern.

The water in the pipes of a water-source closed-loop system is circulated between the source (that is, the lake, pond, or stream) and a refrigerant-to-water heat exchanger and then back to the source. The compressor pumps a refrigerant through separate coils in the refrigerant-to-water heat exchanger. The heat transfer occurs in the heat exchanger.

Advantages and Disadvantages of Water-Source Heat Pumps

Installing a water-source heat pump can be a problem in many areas of the country because there are no uniform regulations governing the discharge of the water after the heat has been extracted. It could be an important environmental concern. Always check any existing federal, state, and local codes and requirements governing the installation and use of water-source heat pumps. Some of the requirements governing their use include the following:

- Local ordinances may require the water to be discharged through a sewer or a second well. The former method requires a hookup fee (which commonly includes the cost of trenching and pipe laying) and an increased monthly sewer bill. The latter method requires the expense of drilling a return well. Water discharged to a return well also may require an EPA reporting procedure.
- Return wells for discharge water must be installed by licensed drillers. The drillers must submit well logs and well locations to the Bureau of Topographic and Geologic Survey at the Department of Conservation and Natural Resources.
- Water discharged to a lake, pond, or stream may require a National Pollutant Discharge Elimination System (NPDES) permit.
- A well used as a water source must have sufficient flow and adequate temperature for the heat pump.

The principal advantage of a water-source heat pump is that water temperatures are warmer and more stable than air during the cold winter months, which makes it more efficient than the air-source heat pump. The two principal disadvantages of this type of pump are its higher installation cost and the lack of uniformity among federal, state, and local codes and regulations.

Other Types of Heat Pumps

Heat pumps and heat pump systems may also be defined by how the compressor is driven, whether the heat pump is a dual-fuel unit, and other factors.

Gas-Fired Heat Pumps

A gas-fired heat pump is driven by a small natural gas or propane engine which, in turn, drives the compressor. One advantage of a gas-fired heat pump is that the waste heat produced by the engine can be used to supplement the heat output of the heat pump and also to heat the domestic hot water.

Gas-fired heat pumps are available for both residential and commercial applications. They are about as efficient as an air-source heat pump, but they are not widely available and their use is cost-effective only in areas where natural gas or propane cost less than electricity.

Dual-Fuel Heat Pump System

A *dual-fuel heat pump system* combines an air-source heat pump with a gas furnace in the same heating and cooling system. Instead of using electric resistance heaters, this system uses a gas furnace to back up the heat pump when outdoor temperatures become excessively cold. A conventional gas furnace provides more heat while consuming less energy than electric resistance heating. As a result, a dual-fuel system provides year-round comfort with reduced energy use.

The dual-fuel heat pump system operates just like a typical air-source heat pump under ordinary conditions. In the winter, the air-source heat pump extracts the heat from the outside air, compresses it, and transfers it to an inside coil and blower located inside the house. In the summer, the cycle is reversed. The heat is extracted from the indoor air and sent to the outdoor coil where it is released to the atmosphere. The gas furnace operates as a backup heater to the heat pump only when the outdoor temperature drops below a preset temperature setting.

Dual-Source Heat Pumps

A *dual-source heat pump* combines a geothermal heat pump and an air-source heat pump in the same unit. This results in a heat pump almost as efficient as the geothermal heat pump but with the advantage of being much less expensive to install.

Instead of using only one outdoor heat source and heat sink (that is, air or ground), the dual-source heat pump uses both air and ground sources for the condensing process in the cooling mode and the evaporating process in the heating mode. In the cooling mode, the liquid refrigerant discharging from an air-source condenser is subcooled by using a ground-source-cooled fluid. This fluid is then reused after the subcooler to desuperheat, that is, to remove some of the superheat from the hot gas before it goes into the air-source condenser.

The ground loop requirements are much smaller than for a conventional ground-source system, which reduces the initial installation cost. Some dual-source heat pump systems are installed with dual compressors to provide additional heat during the coldest outdoor temperatures.

Dual-source heat pumps are of limited availability in the United States. As a result, it is difficult to find contractors with the necessary experience to install and service them.

Ductless Heat Pumps

A *ductless heat pump* (also sometimes called a *mini-split-system heat pump*) is essentially a heat pump without distribution ducts (see Figure 10-11). The ductless heat pump is used primarily for cooling, although in some applications both heating and cooling are possible.

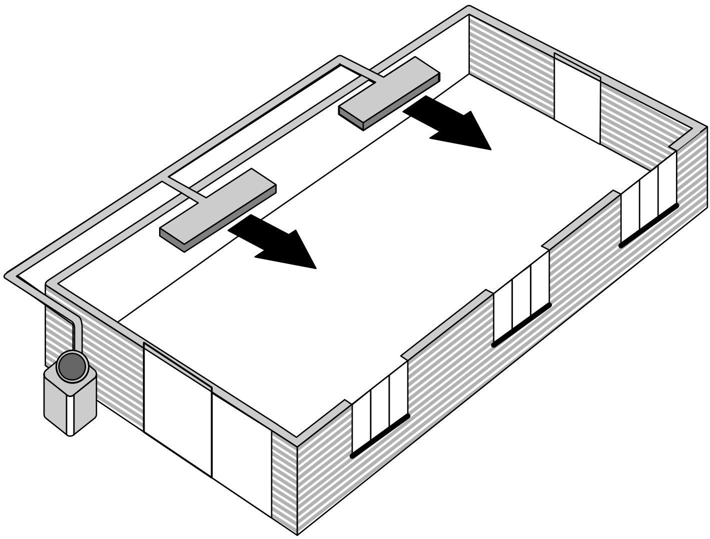


Figure 10-11 Ductless heat pump system.

A typical ductless heat pump system consists of one outdoor unit (and compressor) connected by refrigerant lines to more than one small indoor unit. Refrigerant is piped from the outdoor unit through small-diameter insulated refrigerant lines directly to individual rooms or zones. Cooled air is blown into the room by fans located in the individual evaporator units. It is called a mini split system because of the multiple small ("mini") indoor units.

The indoor units are about 6 to 8 in deep and are commonly mounted flush to the inside surface of an exterior wall. They can also be mounted on a ceiling or inside a dropped ceiling. Wiring, refrigerant lines, control cables, and the condensate drain all pass through a small 3-in-diameter hole in the wall or ceiling.

Heat Pump Performance and Efficiency Ratings

A number of different methods are used to rate the performance and efficiency of heat pumps. The two methods used to measure the cooling and heating efficiency of the heat pump are the Seasonal Energy Efficiency Ratio (SEER) and the Heating Season Performance Factor (HSPF).

Note

> These rating methods were conducted under ideal laboratory conditions; the ratings will commonly be lower on-site in different parts of the country for the same types of equipment.

Seasonal Energy Efficiency Ratio (SEER)

The *Seasonal Energy Efficiency Ratio* is a measure of the cooling efficiency of a heat pump. The higher the SEER number, the more efficient the system is at converting electricity into cooling power. The higher the SEER ratio, the higher the energy efficiency rating of the heat pump. The U.S. Department of Energy has established a minimum SEER rating for cooling of 10.0.

Heating Season Performance Factor (HSPF)

The *Heating Season Performance Factor* (HSPF) is a measure of the overall heating efficiency of a heat pump. The higher the HSPF number, the more efficiently the heat pump heats the house.

Coefficiency of Performance (COP)

The *Coefficiency of Performance* (COP) measures the rate of heat output to the amount of energy input. The highest possible COP number is 3. A heat pump with a COP of 3 would mean that for every $1.00 of energy input, the heat pump would produce $3.00 worth of heat.

Energy Efficiency Rating (EER)

The *Energy Efficiency Rating* (EER) measures the cooling efficiency of the heat pump. The higher the EER number, the higher the cooling efficiency of the heat pump.

Energy Star Rating

The *Energy Star Rating* is a voluntary rating system for HVAC manufacturers whose heat pumps meet or exceed the EPA guidelines for energy efficiency.

Heat Pump System Components

Figures 10-12 and 10-13 illustrate the components in the outdoor unit of two Lennox residential heat pumps. They can be grouped into four categories:

1. Compressor section (outdoor unit).
2. Air-handler section (indoor unit).

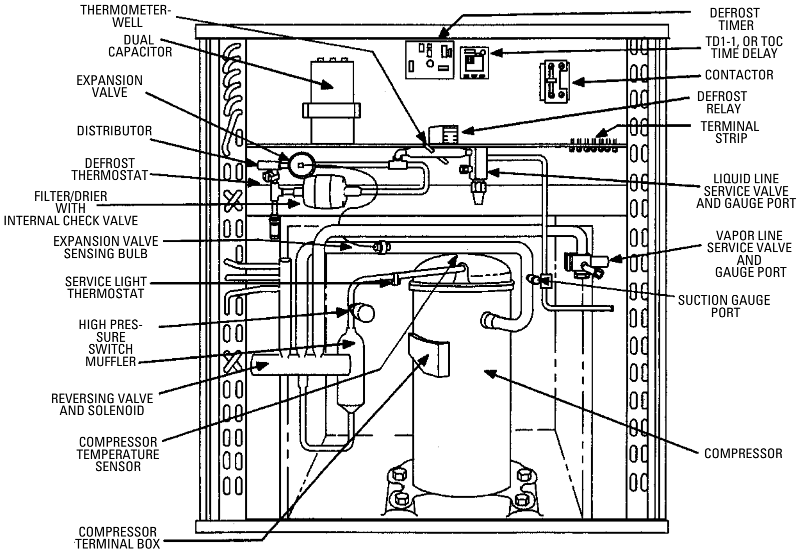


Figure 10-12 Lennox HP26 outdoor unit (early model).

(Courtesy Lennox Industries Inc.)

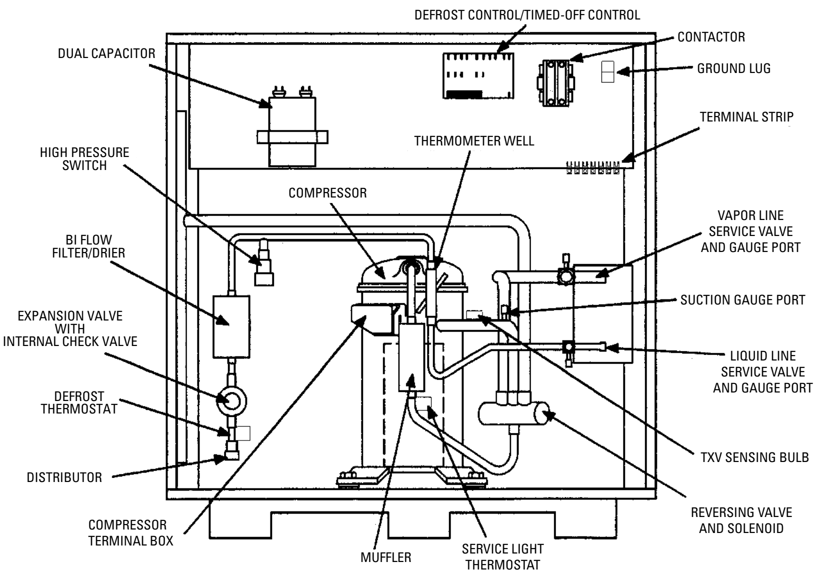


Figure 10-13 Lennox HP26 outdoor unit (late model).

(Courtesy Lennox Industries Inc.)

3. Refrigerant lines.
4. Heat pump controls.

The *compressor section* of a heat pump contains the compressor (or compressors), outdoor coil, fan(s) and motor(s), control system box, and reversing valve. In addition, the compressor section will also contain a refrigerant-distributing device and the defrosting controls (automatic timer and terminating thermostat). The compressor section of a remote, or split-system, heat pump is located outdoors.

The *air-handler section* consists of the indoor coil, blower and blower motor, check valve, thermal expansion valve, refrigerant distributing device, and the air filter(s).

The refrigerant lines are divided into a *liquid line* containing the refrigerant in a liquid state and a *vapor* or *suction line* containing the refrigerant vapor. During the cooling cycle, cool refrigerant vapors are moving through the line to the compressor section. During the heating cycle, hot vapors are moving in the opposite direction.

The heat pump controls include the thermostat, reversing valve, expansion/check valves, safety switches, and other components that ensure safe operation and which direct and regulate the flow of the liquid refrigerant.

Compressor

The compressor is used to receive the refrigerant vapor at low pressure and compress it into a smaller volume at higher pressure and temperature. It then pumps the refrigerant vapor to one of the coils for either the heating cycle or the cooling cycle operation.

The compressors used in residential and light-commercial construction are hermetic compressors. A hermetic compressor is so called because its components are sealed inside a welded housing. The housing (or *can*) contains an electric motor and a pump.

Note

A sealed (*hermetic*) compressor must be replaced if it fails because it cannot be repaired on-site. After it is replaced, filter dryers must be installed to remove any moisture and/or acid in the system.

Compressors can be reciprocating, scroll, rotary, disc, or screw types. The reciprocating and scroll compressors are the types used most commonly in residential and light-commercial heat pump installations. See Chapter 9 ("Air-Conditioning Equipment") for additional information on compressors.

Indoor Coil and Blower

The indoor coil is the part of a split-system heat pump located indoors. During the cooling cycle, the indoor coil cools and dehumidifies the air by converting liquid refrigerant into a gas, which absorbs the heat from the air. The warmed refrigerant is then carried through a tube to the outdoor unit.

Note

> During the cooling cycle, the heat pump draws heat from the air inside the house or building. Moisture in the air will condense on the indoor coil and must be drained to the outdoors through a condensate drain. A condensate pump should be installed to assist drainage because reliance on gravity alone will not provide efficient drainage. Do NOT allow the condensate to drain into the crawl space. Doing so will eventually result in water damage to the floor joists and other wood framing members.

During the heating cycle, heat is extracted from the outdoor air and released by the indoor coil. The heat is blown into the interior rooms and spaces by a fan, which is sometimes called an *air handler* or *blower*. Both direct-drive and belt-drive motors are used.

Outdoor Coil and Fan

The outdoor coil is the part of a split-system heat pump located outdoors in the same cabinet housing the compressor. The outdoor fan is a direct-drive unit.

Refrigerant Lines

The refrigerant lines are divided into a *liquid line* containing the refrigerant in a liquid state and a *vapor* or *suction line* containing the refrigerant vapor. During the cooling cycle, cool refrigerant vapors are moving through the line to the compressor section. During the heating cycle, hot vapors are moving in the opposite direction.

The lines should be reasonably straight. Any excess lines that need to be coiled should be coiled horizontally so that they don't form an oil trap. Vertical coils may prevent needed lubricant from returning to the compressor.

Both refrigerant lines should be insulated. Reducing unwanted heat loss and heat gain through the refrigerant lines saves energy.

Reversing Valve and Solenoid

A refrigerant reversing valve with an electromechanical solenoid coil is used to reverse refrigerant flow during unit operation (see Figure 10-14). It allows the heat pump to operate in either the heating

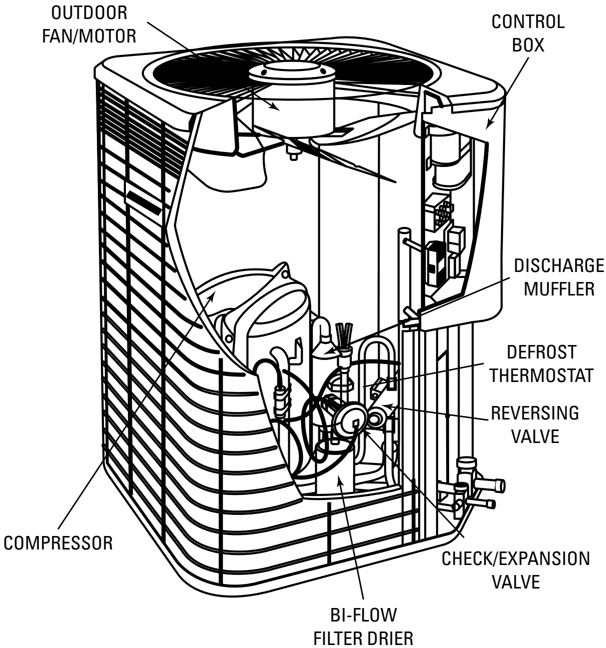


Figure 10-14 Schematic of a four-way reversing valve.
(Courtesy Ranco Incorporated)

or cooling mode by changing the direction of the refrigerant between the indoor and outdoor coils. The operation of a four-way reversing valve is shown schematically in Figures 10-15 and 10-16.

Whenever the reversing valve changes the direction of refrigerant flow, it also changes the functions of the indoor and outdoor coils. During the heating mode, the indoor coil functions as an evaporator and is sometimes referred to as an evaporating coil. This is true only as long as the system is in the heating mode. If the system is in the cooling mode, the direction of the refrigerant reverses and the indoor coil becomes a condenser (that is, a condenser coil). The reversing valve also changes the function of the outdoor coil when it changes the direction of refrigerant flow.

Conventional refrigerant reversing valves cause pressure drops and undesired heat exchange that leads to a 5 to 10 percent degradation of heat pump performance. A newly designed four-way reversing valve has been developed to solve this problem.

As mentioned, the four-way reversing valve is operated by a solenoid coil. When the room thermostat calls for heat, the solenoid

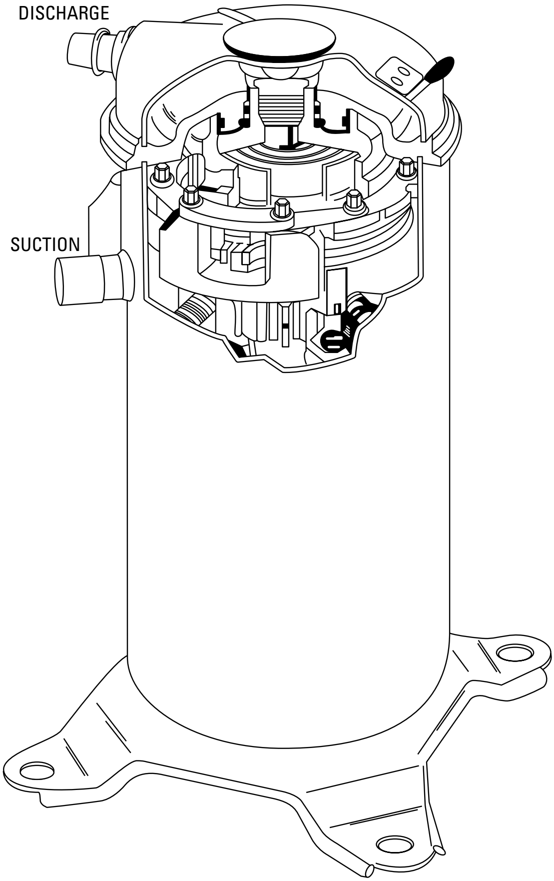


Figure 10-15 Heat cycle piping diagram. *(Courtesy Bard Mfg. Co.)*

coil is energized. This action causes a nylon slide in the vale cylinder to move to the right and allow the high-pressure refrigerant to flow through capillary tubes to the left piston side of the main valve. The low-pressure refrigerant on the left side flows back to the compressor. When the system calls for cooling, the valve operation is reversed.

Thermostatic Expansion Valve

The thermostatic expansion valve (TXV) was developed to provide more precise control of the refrigerant flow to the indoor coil. The valve meters the exact amount of refrigerant required to

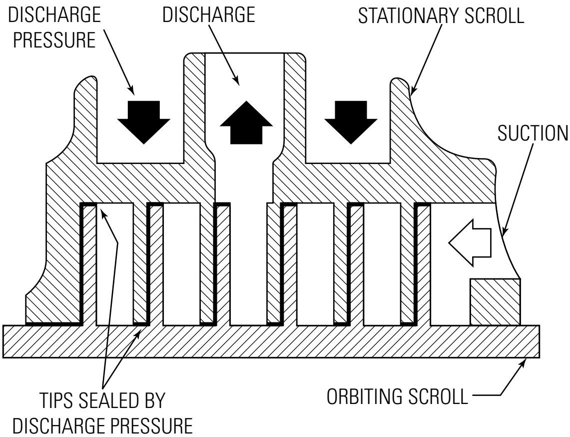


Figure 10-16 Cooling cycle piping diagram. *(Courtesy Bard Mfg. Co.)*

meet the indoor coil load demands. Using a thermostatic expansion valve increases the efficiency of the unit.

Note

A compressor in a system equipped with a thermostatic expansion valve may have difficulty starting. This may be caused by a delay in system pressure equalizing for a short period of time when the compressor is in the off cycle. The solution is to install a start capacitor in the control box.

Desuperheater

Some heat pumps are equipped with a unit that recycles waste heat from the interior of the structure during the cooling cycle. The recycled waste heat is used to produce domestic hot water.

Control Box

The *control box* contains various controls, connections, and wiring important to the operation of the heat pump. The location of a control box on a Lennox reciprocating heat pump is shown in Figure 10-17.

The controls may include contactors, capacitors, relays, circuit boards, transformer, and various accessories. Not all control boxes will contain the same controls, so it is important to consult the heat pump manufacturer's service and repair manuals when repairing or replacing a control box. As shown in Figures 10-18, 10-19, and 10-20, control boxes may even differ among the makes and models of the same manufacturer.

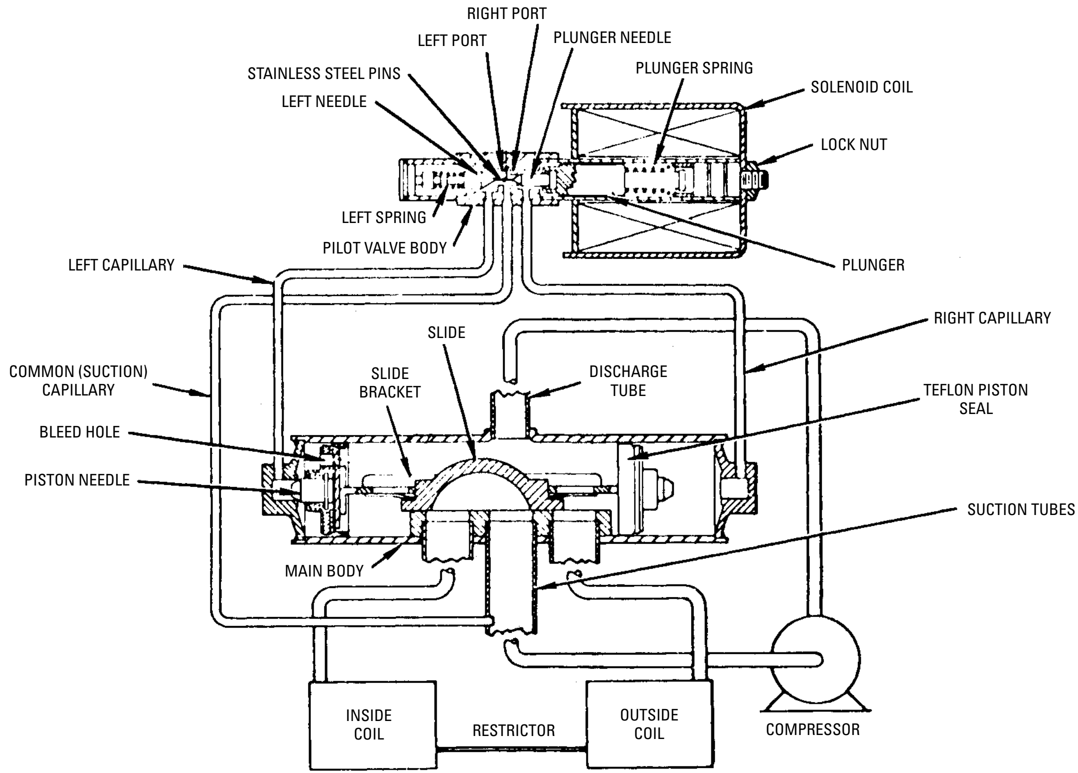


Figure 10-17 Location of control box on a Lennox HP29 reciprocating compressor.
(Courtesy Lennox Industries Inc.)

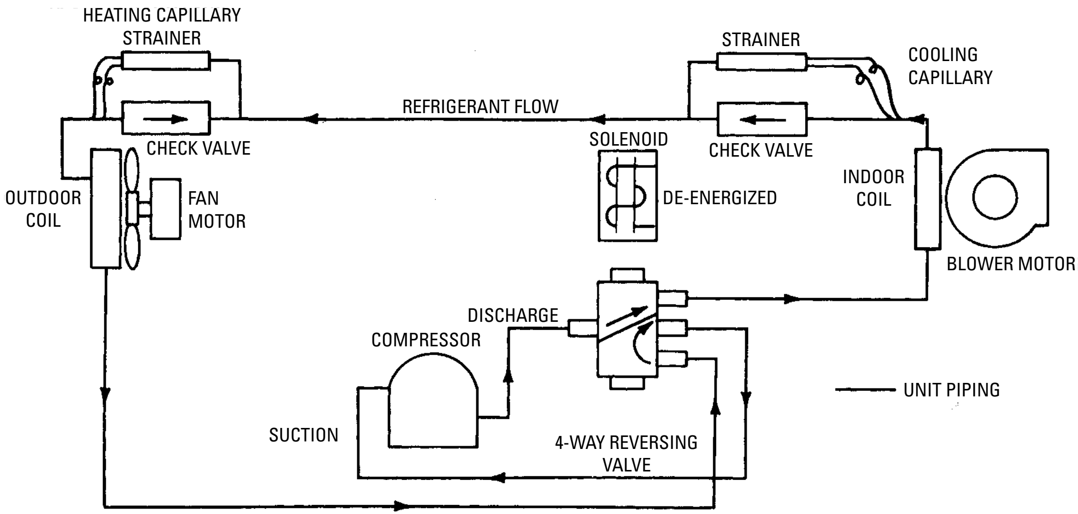


Figure 10-18 Lennox HP29 single-phase unit control box with reciprocating compressor.
(Courtesy Lennox Industries Inc.)

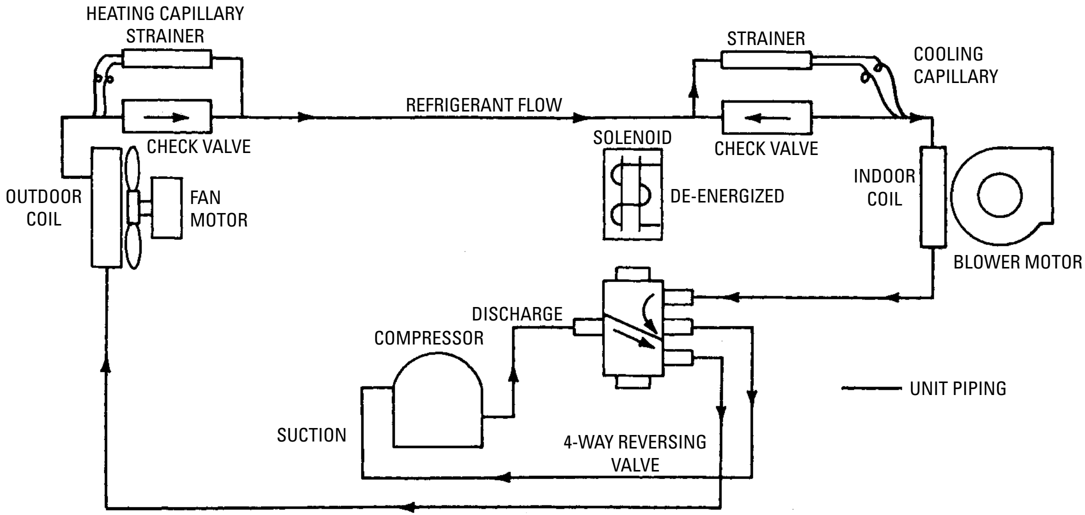


Figure 10-19 Lennox HP29 single-phase unit control box with scroll compressor.
(Courtesy Lennox Industries Inc.)

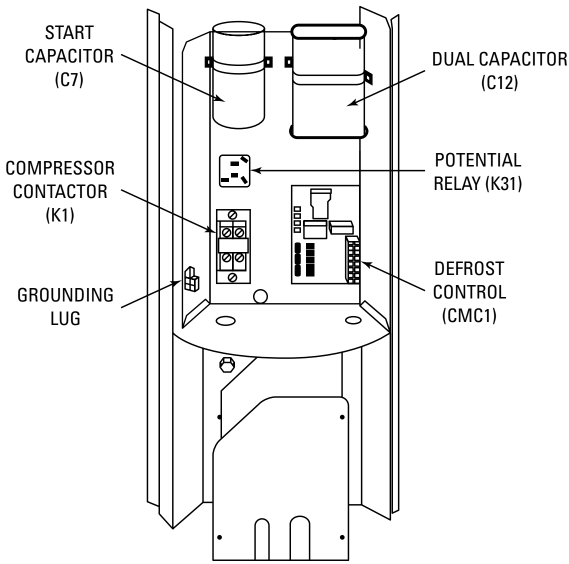


Figure 10-20 Lennox HP29 three-phase unit control box.
(Courtesy Lennox Industries Inc.)

Start, Run, and Dual Capacitors

Every control box will contain capacitors. A capacitor is an electronic device that stores a charge (energy). A *start capacitor* (also sometimes called a *motor start capacitor*) is used to provide the torque required to start the compressor motor. It does this while working in conjunction with a *run capacitor* (also called a *motor run capacitor*) or a *dual capacitor*. A dual capacitor gives a phase shift to single-phase motors in scroll-type or reciprocating-type compressor motors. It is called a dual capacitor because it contains one capacitor for the compressor motor and another for the fan motor.

Compressor Contactor

A *contactor* is an electrically operated switching device in the heat pump control circuit (commonly 24 volts AC circuits). It creates a magnetic field to pull in a set of contacts controlling another device that may or may not receive its electrical power from the same circuit.

Defrost Control

The *defrost control* (or *defrost control board*) is described later in this chapter. See *Heat Pump Defrost System*.

Relays

The *potential relay* controls the starting function of the compressor motor. The *outdoor fan relay* is used in some split-system heat pumps to control the operation of the fan in the outdoor unit.

Fan/Blower Motors

Both the outdoor and indoor units of a split-system heat pump are equipped with a fan. The indoor fan (or *blower* as it is also called) is used to blow the warm air created by the indoor coil (evaporator) through the ductwork into the rooms and spaces of the structure. The most efficient type of indoor blower is a variable-speed one because its operation enables it to compensate for potential airflow restrictions caused by dirty filters or coil or partially blocked air ducts.

Heat Pump Defrost System

A heat pump defrost system consists of a defrost thermostat and a defrost control. The defrost thermostat is located on the liquid line between the expansion/check valve and the distributor. The defrost control board is located in the control box.

Defrost Thermostat

Its function is to signal the defrost control board to start the defrost timing when the defrost thermostat senses a preset low temperature. It terminates the defrost mode when the liquid line warms up to a higher preset temperature.

Defrost Control Board

The defrost control board is located in the control box. The type and location of the various components on a defrost control board will vary among different manufacturers. The two defrost control boards shown in Figure 10-21 include a time-temperature defrost control, defrost relay, time delay, two diagnostic LEDs, a 24-volt terminal strip for field wiring connections, and provisions for pressure switch safety circuit connections. The control provides automatic switching from normal heating operation to defrost mode and back depending on the defrost thermostat settings.

There are two principal types of defrost controls: demand-frost controls and time-temperature defrost controls. The demand-frost controls activate the defrost mode *only* when frost or ice forms on the coil. The time-temperature defrost controls, on the other hand, activate the defrost mode at regular timed intervals for set periods of time whether frost or ice is present on the outdoor coils or not. In both cases, activating the defrost mode causes the reversing valve to divert warm refrigerant fluid to the outdoor coil to thaw the frost or ice forming on the unit coils.

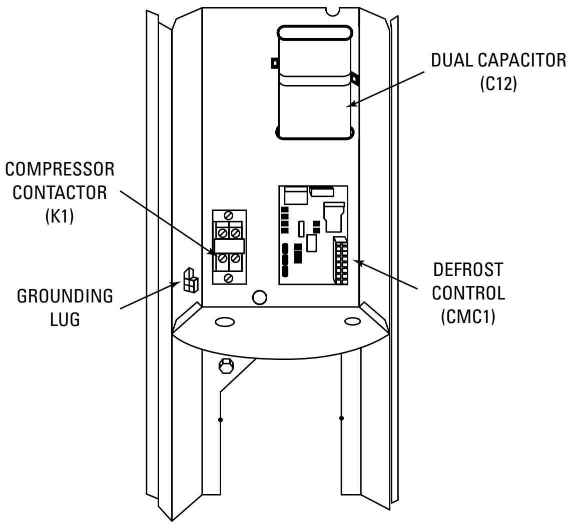


Figure 10-21 Defrost control board component locations. *(Courtesy Lennox Industries Inc.)*

Two LEDs are installed on the defrost board for diagnostic purposes. The LEDs flash a specific sequence according to the condition.

The *time delay* protects the compressor from short-cycling in case the power to the unit is interrupted or a pressure switch opens. The time delay is electrically connected between a thermostat terminal and the compressor contactor.

Other relays, connections, and components forming a part of the defrost control system and located on the defrost control board include the following:

- Defrost relay
- Pressure switch safety circuit connections
- 24-volt terminal strip connections
- Defrost interval timing pins

High-Pressure Switch

An auto-reset high-pressure switch (single pole, single throw) is located on the liquid line. The switch shuts off the compressor if the discharge pressure rises above the factory setting. The switch is normally closed and is permanently adjusted to trip (open) at a factory-preset maximum high-pressure point. The switch resets (closes) when the pressure drops below a factory-preset minimum low-pressure point.

Low-Pressure Switch

Some heat pumps may have a low-charge switch that functions if there is a potentially damaging loss of refrigerant. The switch is an N.C. pressure switch located on the discharge line of the compressor. The switch opens on low-pressure drop in the discharge line to shut off the compressor. The switch opens and closes at preset pressure points.

Other Electric/Electronic Heat Pump Controls and Connections

A *lockout relay* is used on many heat pumps to shut the unit off to protect the compressor from damage if there is a problem in the system. An *anti-restart timer* is required in scroll and rotary compressors to prevent them from running backwards when there is a power failure. Every heat pump system requires a manually operated *disconnect switch* to turn off power and shut down the system when there is a problem or when repairs have to be made.

A *service light thermostat* is a service light switch located on the compressor discharge line and directly connected to the service light in the indoor room thermostat. If the compressor stops running, the service line thermostat senses the change in the discharge line and turns on the service light on the room thermostat. The light is turned off when the compressor is restored to operation and the discharge line returns to normal. Some service light thermostats are connected to terminals on the defrost control board.

Accumulator

Some compressors, such as the piston (reciprocating) types, can be damaged by liquid refrigerant entering the compressor. These compressors are designed to compress the gas formed from the refrigerant. They have a problem compressing the refrigerant liquid. An accumulator is installed in the return line to trap and store the refrigerant liquid before it can enter the compressor. The operation of a scroll compressor is such that an accumulator is not required. It can handle small amounts of liquid refrigerant without damage.

Room Thermostat

The heat pump operation is controlled by a room thermostat. Heat pump thermostats may vary in design among the various manufacturers, but their operation will be essentially the same. Thermostat operation is controlled by the following:

- Temperature selector levers or dial
- Temperature indicator
- Fan switch
- System switch

The *temperature selector levers* (one for cooling and the other for heating) or the *temperature selector dial* are used to manually select the desired temperature setpoints for either heating or cooling.

The *temperature indicator* on the face of the thermostat is used to indicate the actual room temperature. Most will also have an amber (green) light that indicates when the heat pump is operating in the emergency mode.

The *fan switch* will offer up to four settings. The ON or CONT (continuous) setting provides continuous operation of the indoor blower regardless of whether the compressor or an auxiliary heater is operating. This setting is selected when continuous air circulation or filtering is desired. The AUTO or INT (intermittent) setting restricts blower operation only to those times when the thermostat calls for heating or cooling. It is the recommended setting for humidity control.

The *system switch* is used to set the heat pump for heating, cooling, or auto operation. The heating and cooling mode settings are self-explanatory. The AUTO mode provides the heat pump with the ability to automatically switch back and forth between the heating and cooling modes in order to maintain a predetermined comfort setting.

If the heat pump system is designed to provide supplementary heat when there are excessively cold temperatures, the auxiliary heater is controlled by the thermostat through an emergency heat mode. The emergency heat mode locks out heat pump operation while the auxiliary heater is operating.

If a programmable thermostat is used to control the heat pump, then temperature setpoints can be selected (programmed) for different times of the day. For example, with 7-day programming, the heat pump can be programmed for different temperature and humidity settings at different times every day of the week.

Service Valves and Gauge Ports

As shown in Figure 10-22, service valves are installed in the liquid and vapor lines of the heat pump. These valves are used to charge

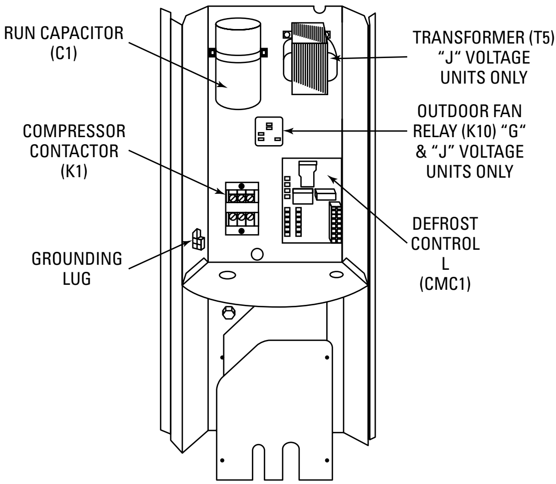


Figure 10-22 Lennox HP29 refrigeration components.
(Courtesy Lennox Industries Inc.)

the system (and check the charge), to test for leaks, and to evacuate the system. Each valve is equipped with a service port containing a factory-installed Schrader valve covered by a protective cap. The service port cap functions as the primary leak seal. Cutaway views of the liquid line and vapor line service valves are illustrated in Figures 10-23 and 10-24.

Gauge Manifold

The gauge manifold is a device equipped with two gauges (see Figure 10-25). One of the gauges measures suction (low) pressure, whereas the other gauge measures head (high) pressure. These gauges indicate how well the compressor is removing the heat collected by the evaporator coil, how well the condenser coil is expelling the heat, and the amount of load placed on the heat pump. An efficient heat pump will have a high suction pressure and a low head pressure.

Filter Dryer

The *filter dryer* (also called *bi-flow filter dryer*) is used to remove dirt, other contaminants, and moisture from the refrigerant before it can damage the compressor and other components in the heating system.

Crankcase Heater

When some heat pumps are shut down during the cold winter months, the liquid refrigerant may enter the compressor crankcase

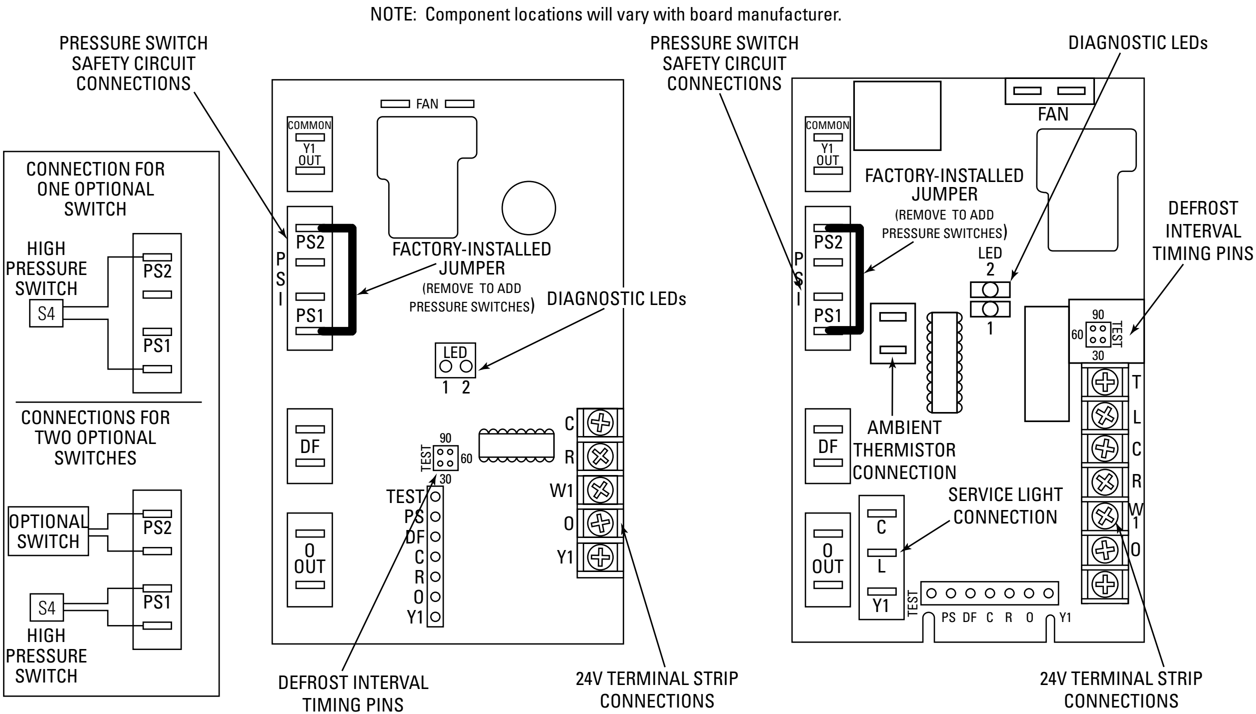


Figure 10-23 Liquid line service valve. *(Courtesy Lennox Industries Inc.)*

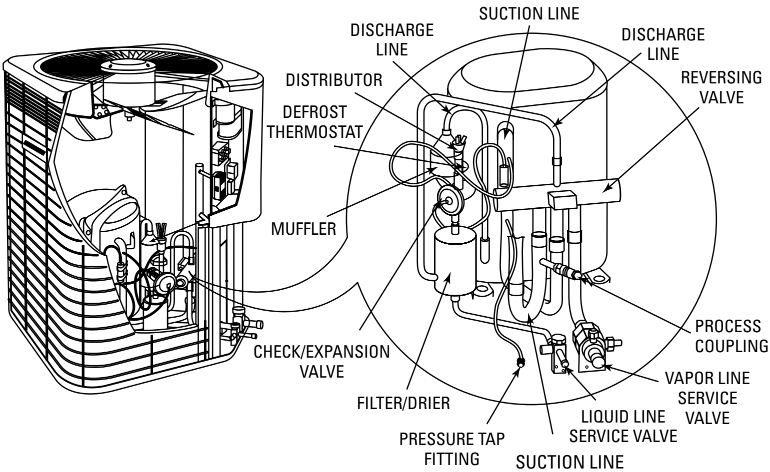


Figure 10-24 Vapor line service valve. *(Courtesy Lennox Industries Inc.)*

and mix with the lubricating oil. When the heat pump is turned on again, the refrigerant in the crankcase evaporates rapidly and forms a foam. This condition dilutes the oil, prevents adequate lubrication, and may shorten the service life of the compressor. A crankcase heater will prevent the refrigerant from liquefying in the lubricating oil. Some crankcase heaters are designed to operate all the time; others only when required. Crankcase heaters are not required on scroll compressors.

Muffler

As shown in Figure 10-13, a muffler is installed in the discharge line to minimize noisy pulsations and vibrations. The muffler greatly reduces the sound inside the house of compressor operation.

Sizing Heat Pumps

The recommended source of information for sizing heat pumps is the latest edition of the Air-Conditioning Contractors of America's *Manual H—Heat Pump Systems: Principles and Applications*. It covers basic principles, equipment, installation, operation, and system design.

The ability of the heat pump to extract heat from the outdoor air decreases as the outdoor temperature drops. At the same time, the heat required to maintain the desired indoor temperature increases. If lines representing the outdoor and indoor conditions

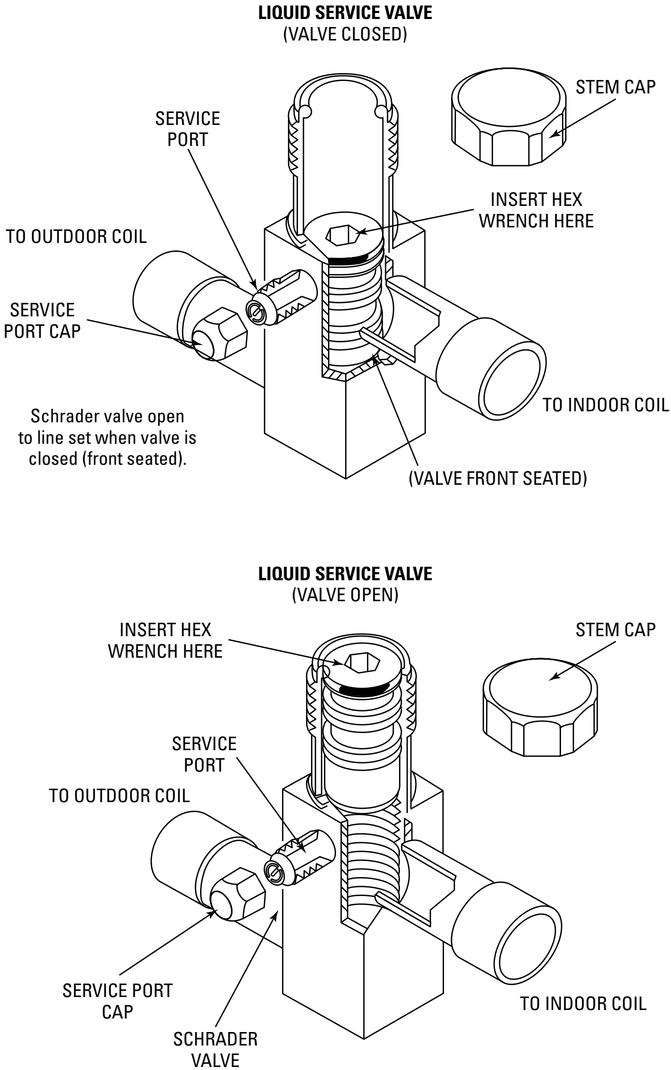


Figure 10-25 Lennox HP26 manifold gauge connections (cooling cycle). *(Courtesy Lennox Industries Inc.)*

were drawn on a graph, the line representing the dropping outdoor temperature would eventually cross the line representing the rising indoor heat requirements. The point at which the two lines on the graph cross is called the *balance point*. The capacity of a heat pump must be sized to match the balance point for the house or building. Most balance points will occur just below and above freezing (Fahrenheit).

Heat Pump Installation Recommendations

All of the installation recommendations included here are provided as a general guide. They do not supersede local, state, or national codes. Always consult local authorities having jurisdiction before installing the heat pump.

Note

Much more detailed installation instructions will be found in the installation manual for the specific heat pump make and model. Always read and carefully follow the manufacturer's installation instructions. Failure to do so could result in voiding the equipment warranty.

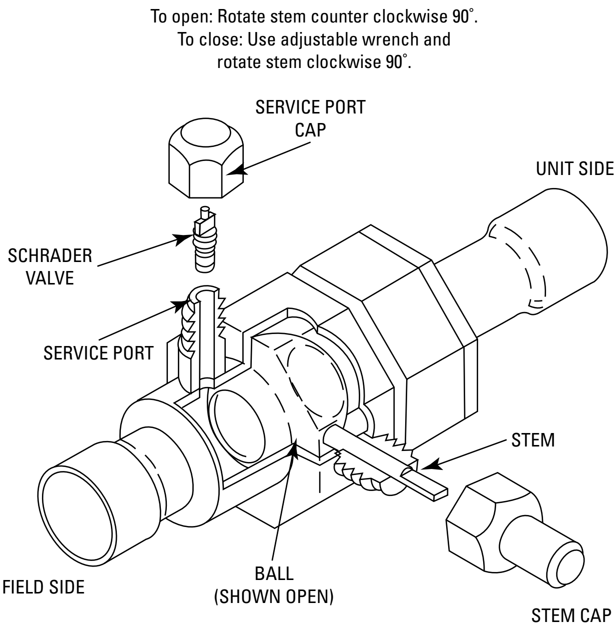
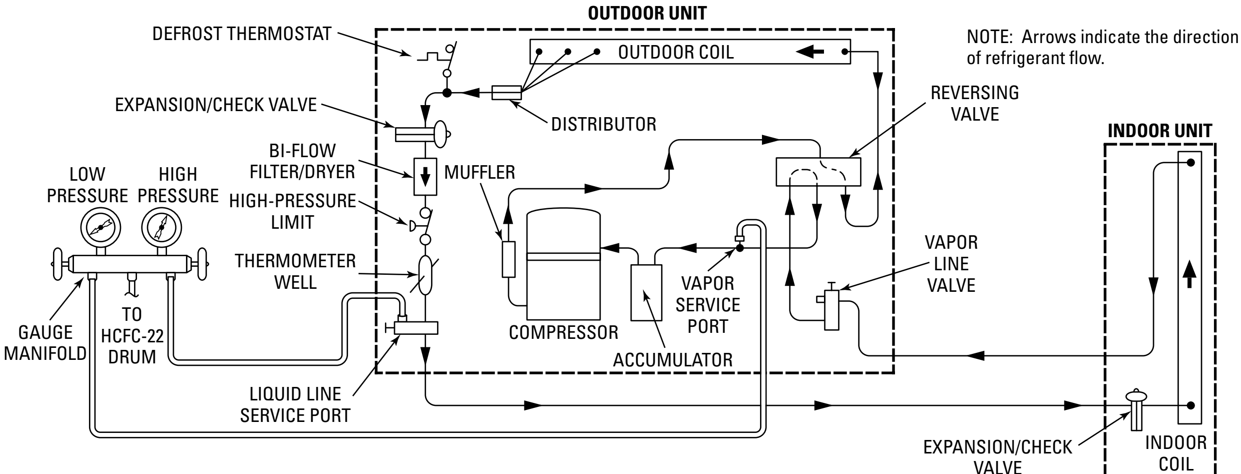


Figure 10-26 Vapor line service valve (valve open)



NOTE: Use gauge ports on vapor line valve and liquid valve for evacuating refrigerant lines and indoor coil . Use vapor gauge port to measure vapor pressure during charging.

Figure 10-27 Manifold gauge connections (cooling cycle)

The following recommendations are offered as a checklist for installing a heat pump:

1. Install unit level or slightly slanted toward drain for proper condensation drainage.
2. Check unit wiring for compliance with wiring diagram and local codes and regulations.
3. Make sure all wiring connections are tight.
4. Ground unit by grounded waterproof conduit or with separate ground wire.
5. Check indoor and outdoor fan/blower for unobstructed and quiet movement.
6. Check condensation drain line for proper slope and drainage.
7. Fasten and seal all ducts and fittings with a suitable duct tape.
8. Check the refrigeration system for leaks after installation.

Note

Heat pump manufacturers require that the outdoor unit be matched with the indoor coils, line sets, and refrigerant control devices. Failure to do so will result in loss of warranty. Check the manufacturer's specifications for the unit being installed.

Recommendations for installing the outdoor unit of the heat pump are as follows:

1. Install the outdoor unit on a concrete pad separate from the house foundation.
2. Do not locate the outdoor unit where its operation will disturb neighbors.
3. Do not locate the outdoor unit under a bedroom window.
4. Shelter the outdoor unit from prevailing cold winter winds.
5. Do not allow bushes or other obstructions to block the airflow to the unit. Provide for free air travel to and from the condenser.
6. Locate the unit far enough from the roof eaves to avoid falling snow and ice.
7. Locate the outdoor unit so that the lengths of copper refrigerant lines connecting to the indoor unit are minimized.

The following are recommendations for checking heat pump operation after installation is completed and the system is running:

1. Check the compressor starting characteristics and capabilities while the system is running.

2. Measure high- and low-side system pressures.
3. Check to make sure the system is operating in accordance with the heat pump manufacturer's specifications.
4. Check the system for correct line and load voltage/amperage.
5. Listen for abnormal noise or unusual odors.
6. Measure outdoor dry-bulb temperature.
7. Measure indoor dry- and wet-bulb temperature.
8. Check for correct refrigerant charge.

Read the heat pump manufacturer's installation manual and add any other recommendations to the preceding list. Not all heat pumps have the same installation requirements.

Heat Pump Operating Instructions

The heat pump manufacturer should provide operating instructions with the installation literature. If no copy is available, contact the manufacturer's local field representative for one.

If no operating instructions are available for the unit, follow those contained in this section. These instructions are suitable for most electric heat pumps used in residential installations.

The first step, of course, is to turn on the power supply at the disconnect switch. This is a very simple but important step that is often overlooked. In remote heat pump installations, both the indoor and outdoor sections may have a disconnect switch or a breaker or fuse in the house box. Both switches must be in the *on* position to start the system.

Move the thermostat setting as high as it will go, and switch the fan selection switch to the *on* setting. This should start the blower. The remainder of the operating instructions will depend on whether heating or cooling is desired.

Heating

For the heating cycle, move the fan selector switch to the *auto* position and slowly *raise* the heating temperature setting on the thermostat. Stop moving the lever as soon as the first-stage (upper) mercury bulb makes contact. The blower, compressor, and condenser fan should start at this point.

Under normal operating conditions, the unit may automatically trip on its high-pressure cutout and stop the compressor and outdoor fan if the outdoor ambient temperature exceeds approximately 80°F. If the outdoor ambient temperature is too low for automatic cutout, block the return air until the unit trips. In a cold climate, it may take 5 minutes or more to trip.

Check the thermostat heat anticipator setting to make sure it matches the current draw of the heating relays (see Chapter 4 of Volume 2, "Thermostats and Humidistats"), and make certain the contactors and heaters are operating correctly.

The defrost timer can be checked in the winter when the outdoor coil is cold enough to activate it. Observe at least one defrost cycle to make sure the unit defrosts properly.

Turn the thermostat off. If the unit is set at the *on* position, only the blower should operate. Turn the thermostat on again and proceed as follows:

1. Adjust discharge air grilles for suitable airflow.
2. Check the system for proper balance and correct if necessary.
3. Check for air leaks in the ductwork and correct if necessary.

Cooling

For the cooling cycle, move the fan selector switch to the *auto* position and *lower* the heating temperature setting on the thermostat to below room temperature. This should start the blower, compressor, and condenser fan. If these components are operating satisfactorily, turn the thermostat off. The unit should stop with the exception of the blower if the thermostat is set at the *on* position.

If a combination heating and cooling thermostat is used, switch it to the *heat* position and check for correct heating operation. Make certain the thermostat heat anticipator is set to match the current draw of the heating relays (see Chapter 4 of Volume 2, "Thermostats and Humidistats").

After waiting approximately 5 minutes, turn the air conditioner on and proceed as follows:

1. Adjust discharge air grilles.
2. Check the system for proper balancing.
3. Check for air leaks in the ductwork.

Heat Pump Service and Maintenance

The heat pump manufacturer will provide the necessary operation and maintenance literature with the unit. This literature contains nontechnical instructions that the average homeowner can understand and follow with little or no difficulty. By following these instructions, the operational life span of the heat pump will be prolonged, and it will operate at maximum efficiency.

Service and Maintenance Checklist

Warning

Turn off the electrical power to the heat pump *at the disconnect switch* before performing any maintenance. The heat pump may have multiple power supplies. Failure to disconnect the electrical power may result in damage to the equipment and a severe shock hazard.

1. Periodically inspect and clean (or replace) the air filters.
2. Inspect and clean the blower wheel, housing, and motor as required.
3. Annually lubricate blower motor on older heat pump models according to the manufacturer's instructions. If the motor lacks lubricating oil, it will eventually burn out. Note: The blower motors in newer heat pumps are sealed and do not require lubrication.
4. Inspect fan motor and fan blades for wear or damage.
5. Inspect blower housing for lint and debris and clean as necessary.
6. Check for excessive frost buildup on the coils. Contact your local serviceperson if an excessive frost buildup is discovered.
7. Periodically clean the coils in the outdoor unit by washing with water hose.
8. Check condensation drain line during cooling season for free-flow condition. Water should flow freely.
9. Check the indoor coil drain pan and the primary and secondary drain lines.
10. Check all refrigerant line connections to make sure they are secure. Tighten loose connections. If the system is low on refrigerant, find and repair the leak before adding any more. Adding refrigerant to a leaking heat pump system will force the equipment to work harder and less efficiently. Continuing to operate a heat pump without refrigerant will eventually overheat the compressor and cause it to fail.
11. Inspect and clean (if required) the auxiliary drain pan (if supplied with the heat pump) and line.
12. Check for damaged wiring and loose connections.
13. Inspect outdoor unit and pad for proper level and adjust if necessary.

14. Monitor heat pump system for correct refrigerant charge.
15. Measure high- and low-side system pressures.
16. Remove dirt, leaves, and debris from inside the outdoor cabinet.
17. Inspect the base pan in the outdoor unit for restricted drain openings and correct as necessary.
18. Inspect the control box for wear and damage and repair as necessary. All control box and electrical parts should be checked for wear or damage.
19. Check condition of control box components, connections, and wiring.
20. Check the refrigeration system for leaks during each service call.

Adjusting Heat Pump Refrigerant Charge

Packaged heat pumps are charged with the refrigerant at the factory under controlled conditions and rarely need adjustment. Split-system heat pumps are charged in the field where there is a greater chance of error. If the performance of a split-system heat pump closely approximates the manufacturer's listed SEER and HSPF ratings, then the system probably has the correct charge. If the performance fails to meet the listed ratings, then there is either too much or too little refrigerant in the system.

Note

Section 608 of the Federal Clean Air Act mandates the requirements for handling HVAC refrigerants, including their reclaiming, recovering, and recycling. All HVAC technicians who handle refrigerants must be certified to do so. City, county, and state governments may also have ordinances governing the handling of refrigerants.

Measure the temperature and pressure readings on the heat pump system and compare the results with those specified by the manufacturer. If they do not match, refrigerant will have to be added or withdrawn.

Note

Refrigerant measurements will not be accurate if the airflow is incorrect. Therefore, the airflow must be measured first, checked against the heat pump manufacturer's specifications, and corrected if necessary before the refrigerant measurements can be made.

Troubleshooting Heat Pumps

Table 10-1 lists the most common problems associated with the operation of a heat pump. For each symptom of a problem, a possible cause and remedy are suggested.

Make certain that the thermostat is set higher than the actual room temperature and the selector switch is on *heat* if heat is needed, or that the thermostat is set lower than the actual room temperature and the switch is on *cool* if air-conditioning is desired. If the thermostat is programmable, be certain the batteries are fresh.

Test for power to the air handler by moving the fan switch from *auto* to *on*. If the blower runs, the air handler is functional. If nothing happens, check the circuit breakers on the air handler cabinet and the breakers or fuses in the main panel. If any breakers are tripped, reset them at once.

Table 10-1 Troubleshooting Heat Pumps

Symptom and Possible Cause	*Possible Remedy*
Noisy operation.	
(a) Loose parts.	(a) Check all setscrews on blower and fan blade. Adjust and tighten all thrust collars.
(b) Loose belts.	(b) Adjust all belts and check drives.
Heat pump will not operate.	
(a) Main power switch off.	(a) Turn switch on. Both disconnect switches must be on in remote system.
(b) Incorrect thermostat setting.	(b) Change to proper setting.
(c) Tripped circuit breaker or blown fuse.	(c) Reset circuit breaker or replace blown fuse.
Insufficient or no heating or cooling.	
(a) Obstructed outdoor coil.	(a) Remove obstruction.
(b) Dirty or plugged air filter.	(b) Clean or change if necessary.
(c) Airflow blocked at supply registers or return grilles.	(c) Remove blockage.
(d) Blower not operating.	(d) Make sure blower door is secure. Close and secure door to restore power to blower.

(continued)

Table 10-1 (*continued*)

Symptom and Possible Cause	*Possible Remedy*
Reversing valve will not shift from heat to cool.	
(a) No voltage to coil.	(a) Repair electrical current.
(b) Defective coil.	(b) Replace coil.
(c) Low refrigerant charge.	(c) Repair leak and recharge system.
(d) Pressure differential too high.	(d) Reset differential.
(e) Pilot valve operating correctly; dirt in one bleeder hole.	(e) Deenergize solenoid, raise head pressure, and reenergize solenoid to break dirt loose. If unsuccessful, remove valve and wash out. Check on air before installing. If no movement, replace reversing valve, add strainer to discharge tube, and mount valve horizontally.
(f) Piston cup leak.	(f) Stop unit. After pressure equalizes, restart with valve solenoid energized. If valve shifts, reattempt with compressor running. If still no shift, replace reversing valve.
(g) Clogged pilot tubes.	(g) Raise head pressure and operate solenoid to free tube of obstruction. If still no shift, replace reversing valve.
(h) Both ports of pilot open; back seat port did not close.	(h) Raise head pressure and operate solenoid to free partially clogged port. If still no shift, replace reversing valve.
Reversing valve starts to shift but does not complete reversal.	
(a) Not enough pressure differential at start of stroke or not enough flow to maintain pressure differential.	(a) Check unit for correct operating pressures and charge. Raise head pressure. If no shift, use valve with smaller ports.
(b) Body damage.	(b) Replace reversing valve.
(c) Both ports of pilot open.	(c) Raise head pressure and operating solenoid. If no shift, replace reversing valve.

(continued)

Table 10-1 (*continued*)

Symptom and Possible Cause	***Possible Remedy***
(d) Valve hung up at mid-stroke; pumping volume of compressor not sufficient to maintain reversal.	(d) Raise head pressure and operate solenoid. If no shift, use a reversing valve with smaller ports.
Reversing valve has apparent leak in heating position.	
(a) Piston needle on end of slide leaking.	(a) Operate reversing valve several times, then recheck. If excessive leak, replace valve.
(b) Pilot needle and piston needle leaking.	(b) Operate reversing valve several times, then recheck. If excessive leak, replace valve.
Reversing valve will not shift from heat to cool.	
(a) Pressure differential too high.	(a) Stop unit. Valve will reverse during equalization period. Recheck system.
(b) Clogged pilot tube.	(b) Raise head pressure. Operate solenoid to free dirt. If still no shift, replace reversing valve.
(c) Dirt in bleeder.	(c) Raise head pressure and operate solenoid. Remove reversing valve and wash it out. Check on air before reinstalling. If no movement, replace valve. Add strainer to discharge tube. Mount valve horizontally.
(d) Piston cup leak.	(d) Stop unit. After pressure equalizes, restart with solenoid deenergized. If valve shifts, reattempt with compressor running. If it still will not reverse while running, replace reversing valve.
(e) Defective pilot.	(e) Replace valve.

Caution

Do not reset the circuit breakers if they trip a second time. Deadly high-voltage conditions exist inside the air handler cabinet and inside the access panel of the condenser. Let a qualified serviceperson open them.

If the air handler runs constantly but cannot satisfy the thermostat setting, it is possible the backup heat is running but the condenser is not. Some condensers have the high-pressure cutout switch externally accessible. Look for a button sticking out of the cabinet in the vicinity of the refrigerant pipes. Press it in. If the machine starts up, the head pressure got too high, possibly from turning on and off too quickly, from too much or too little refrigerant, or from an electrical interruption. As the unit ages, the switch can weaken and pop easily. If the condition repeats itself often, have a service technician check it.

Warning

Because all the controls are internally mounted and high-voltage wiring is exposed, only a qualified and experienced HVAC technician should open panels. High voltages can result in serious injury and even death.

Troubleshooting Heat Pump Compressors

Residential heat pumps use hermetic compressors with the motor, pump, and related components sealed inside a welded housing. A failed hermetic compressor must be replaced. It cannot be repaired on-site. The troubleshooting symptoms in Table 10-2 may be used to identify some of the more common compressor problems.

Caution

Do not continue to operate a heat pump under the following conditions: fan motor not working, low refrigerant charge, or excessive frost/ice buildup. Continuing to run the heat pump under these conditions can burn out the compressor motor.

Table 10-2 Troubleshooting Heat Pump Compressors

Symptom and Possible Cause	*Possible Remedy*
Compressor will not start.	
(a) Loose wires and/or failed components.	(a) Check wiring and components; repair or replace as necessary. If compressor still fails to start, it is locked up and must be replaced.
(b) Tripped circuit breaker or blown fuse.	(b) Reset circuit breaker or replace fuse. If the problem continues and there is a low ohm reading from one or more of the compressor terminals to ground, the compressor is grounded and must be replaced.

(continued)

Table 10-2 *(continued)*

Symptom and Possible Cause	*Possible Remedy*
(c) Defective run capacitor.	(c) Replace run capacitor.
(d) Defective combination (dual) run capacitor.	(d) Replace.
Compressor will not start but fan runs.	
(a) Failed run capacitor.	(a) Replace run capacitor.
(b) Failed start capacitor.	(b) Replace.
Compressor does not draw current but fan runs normally.	
(a) Burned/broken common wire.	(a) Repair.
(b) Open motor overload protector.	(b) Wait for overload to reset. Replace compressor if overload protector fails to reset.
Noisy compressor.	
(a) A hissing noise in a piston (reciprocating) compressor.	(a) Defective valves. Replace compressor.
(b) Sharp-pitched noise after compressor is shut down (piston compressor).	(b) Not a problem. Sound of pressure equalizing in valves.

Chapter 11

Humidifiers and Dehumidifiers

The air around us has a capacity for holding a specific amount of water at given temperatures. For example, 10,000 ft^3 of air at 70°F will hold 10.95 pints of water, no more. This means the air in a home 25 ft by 50 ft with 8-ft ceilings (10,000 ft^3) could hold nearly 11 pints of water when the temperature inside is 70°F. This would represent 100 percent relative humidity conditions. If there were only 2 pints of water in this same home at 70°F, the relative humidity would be $\frac{2}{11}$ or 18 percent.

The amount of water air can hold depends on the temperature of the air. For example, air at 70°F can hold 16 times as much water as air at 0°F. This means that 10,000 ft^3 of air at 0°F will hold $\frac{2}{3}$ pint of water. When that same air is heated to 70°F, it can hold nearly 11 pints of water, or 16 times as much water. Thus, if 0°F air that had a relative humidity of 96 percent were brought into a house through a door, window, or any other crack and warmed to the inside temperature of 70°F, this same air would then have a relative humidity of $\frac{96}{16}$, or 6 percent. This relationship between temperature and relative humidity can be illustrated by the data in Table 11-1.

As you can see, warming the fresh air will reduce the relative humidity in the house until the air becomes extremely dry. In some situations, the air in a house may be even drier than the Sahara Desert. The Sahara has an average relative humidity of 20 percent. The average home in the winter months (that is, the heating season) without humidity control or other means of adding moisture to the air maintains a relative humidity of approximately 12 to 15 percent.

Table 11-1 Relationship Between Temperature and Relative Humidity

Outside Temperature	*Outside Relative Humidity (%)*	*Inside Temperature*	*Inside Relative Humidity (%)*
	0		0
	20		3
20°F	40	70°F	6
	60		8
	80		11

Air that has a low relative humidity will absorb water vapor from any available source. Most important from a personal standpoint is the evaporation of moisture from the membranes of the nose, mouth, and throat. These are our protective zones, and excessive dryness of these membranes will cause discomfort.

Note

> It is difficult to pinpoint the most desirable level of relative humidity, but it is generally agreed that the range between 30 and 50 percent is the best from both health and comfort standpoints. The upper part of this range (40 to 50 percent) is impractical during many very cold days of the winter because of condensation on the windows. Therefore, it is recommended that a relative humidity of between 30 and 40 percent be maintained during the heating season.

Because dry air will pick up moisture from any available source, the furnishings and other contents of the house are also affected by low humidity. Furniture wood shrinks, and the joints may crack. If plaster is used, it may also develop cracks. The wall paint will usually peel, and carpet materials may become dry and brittle.

If the air in the house is excessively dry, there is more evaporation from the skin as moisture from the body is absorbed by the drier air. This evaporation generally makes the individual feel so cool that temperature settings of 70°F (or even higher) are not warm enough for comfort. Moving the temperature setting to a higher point may obtain the desired comfort level, but the higher temperature setting also increases the fuel cost. Each degree that the thermostat setting is raised increases the fuel cost approximately 2 percent for the same period of time. Obviously it is impractical and more costly to obtain comfort in this manner. It is far more economical to devise a means of reducing the rate of evaporation of moisture from the body and thereby eliminate the chilling effect. This can be done by increasing the relative humidity in the home (see *Humidifiers* in this chapter).

Excessive moisture in a home can also be a problem. When there is too much moisture in the indoor air, mold and mildew form on surfaces, the indoor air has an unpleasant odor, and there is generally a feeling of stickiness or dampness. If the condition persists, the excess moisture in the air can damage furniture, wood and metal surfaces, leather shoes, and clothing. It can also cause peeling wallpaper, damp spots on ceilings and walls, and disintegrating plaster. Finally, the allergens produced by mildew and mold are a definite health problem. The solution, then, is to reduce the relative humidity by removing moisture from the air. This can be accomplished by installing a dehumidifier (see *Dehumidifiers* in this chapter).

Terminology

- **Humidity.** The amount of moisture in the air.
- **Relative humidity.** The amount of water vapor in the air compared with the amount it can hold at a given temperature (expressed as a percentage).
- **Humidifier.** A device that adds moisture to the air.
- **Dehumidifier.** A device that removes moisture from the air.
- **Output.** A gallon-per-day measure for moisture put into the air.
- **Humidistat.** A control that automatically regulates humidity comfort levels.
- **Run time.** The amount of time a humidifier runs before refilling is required.

Humidifiers

A *humidifier* is a device used to add moisture to the air (see Figure 11-1). This function is accomplished primarily either by evaporation, by the use of steam, or by breaking water down into fine particles and spraying them into the air.

Figure 11-1 Typical power humidifier. *(Courtesy Amana Refrigeration, Inc.)*

The two types of humidifiers most widely used in residences and small commercial buildings are the bypass humidifier and the power humidifier. These and other types of humidifiers are briefly described in this section. The service, maintenance, and troubleshooting sections of this chapter are primarily concerned with the bypass and power humidifiers.

Spray Humidifiers

A *spray humidifier* (or *air washer*) can be used for either humidification or dehumidification. Essentially this type of humidifier consists of a chamber containing a spray nozzle system, a recirculating water pump, and a collection tank (see Figure 11-2). As the air passes through the chamber, it comes into contact with the water spray from the nozzles, resulting in heat transfer between the air and water. This, in turn, results in *either* humidification (adding moisture) or dehumidification (removing moisture) depending on the relative temperatures of the sprayed water and the air passing through the chamber. Dehumidification occurs when the temperature of the water is lower than the dew point of the air; humidification occurs when it is higher.

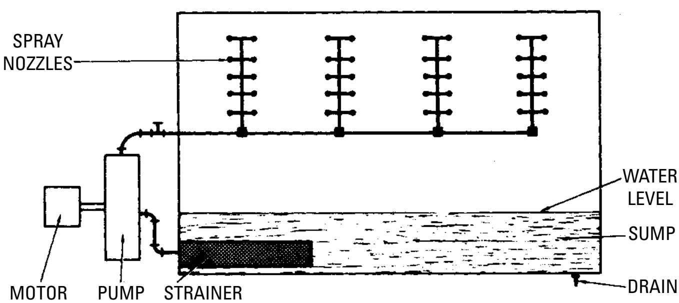


Figure 11-2 Components of a spray humidifier.

In some spray humidifiers, the water is sprayed on a heating coil through which steam or hot water is passed (see Figure 11-3). The heat causes the water to evaporate and thereby increase the moisture content of the air.

An *atomizing humidifier* is a form of spray humidifier that uses compressed air to reduce the water particles to a fine mist (see Figure 11-4). The mist is converted to a vapor, which is absorbed by the drier room air.

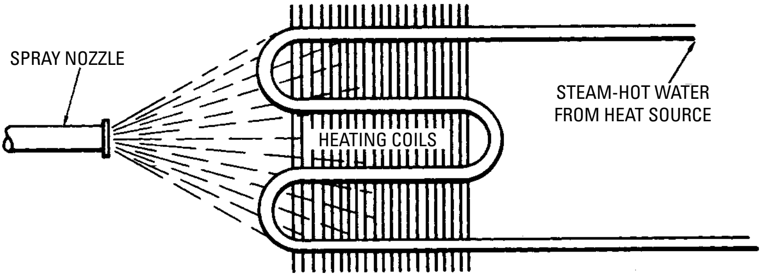


Figure 11-3 Water sprayed on heating coil.

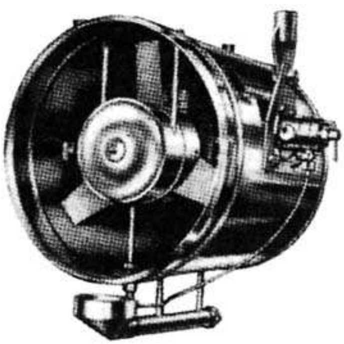


Figure 11-4 Atomizing humidifier.
(Courtesy American Moistening Co.)

The *ultrasonic humidifier* is also a spray-type humidifier. The principal components of an ultrasonic humidifier are a high-frequency power oscillator that drives a piezo transducer, a small bower, a float switch, and a water tank or reservoir. The piezo transducer creates a wave on the surface of the water in the tank. The float switch is used to sense and maintain the proper level of water in the tank. These humidifiers use high-frequency vibrations to break the water droplets down into a fine mist. The mist is blown into the room or rooms by the small blower.

Caution

> The piezo drive module operates with a line voltage as high as 100 volts or more on heat sinks. Do NOT attempt to repair or replace the module unless you are a qualified HVAC technician.

Pan Humidifiers

A *pan humidifier* consists of a water tank (pan), heating coils, a fan, and a fan motor (see Figure 11-5). The heating coils are installed in

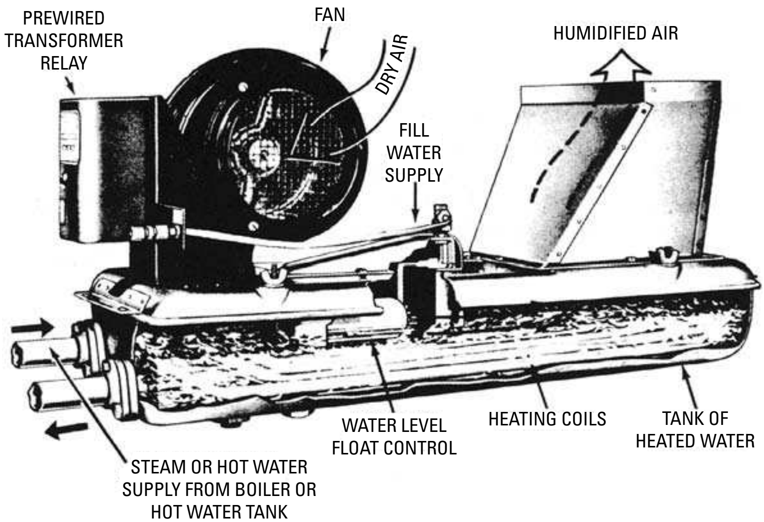


Figure 11-5 Pan humidifier.

the water tank. Heat is supplied to the pan heating coils either by low-pressure steam or forced hot water where a water temperature of 200°F or higher is maintained.

The pan humidifier is completely automatic; the water level in the tank is controlled by means of a float control. When the relative humidity drops below the setting on the humidistat, the fan blows air over the surface of the heated water in the tank. The air picks up moisture as it travels over the surface of the water and is blown into the space to be humidified. When the humidistat is satisfied, the fan is shut off.

Stationary-Pad Humidifiers

A *stationary-pad humidifier* contains a stationary evaporator pad over which warm air from a supply duct is drawn by a motor-operated blower or fan. The air picks up moisture as it passes over the pad. The humidified air is then returned to the room or space.

Steam Humidifiers

A *steam humidifier* (also sometimes called a *vaporizer*) is used with an electric warm-air furnace or an electric heat pump because neither generates warm air at sufficiently high temperatures to evaporate water. These humidifiers are either gas-fired (natural gas or propane) or operated by electricity. They boil the water and send the steam into the room or rooms.

A typical steam humidifier consists of a metal reservoir to hold the water, a heating element submerged in the reservoir, a float valve, and the control wiring. Water is supplied to the reservoir from the domestic water supply. A float valve regulates the amount of water in the reservoir.

Some steam humidifiers are installed in the return duct (or plenum) or the supply duct (or plenum) of a forced warm-air furnace. When line voltage current is passed through the heating element submerged in the reservoir, it produces steam, which releases its moisture into the warm air passing over it. Other steam humidifiers are independent stand-alone units. Some steam humidifiers boil the water and then cool it before it leaves the unit. Instead of steam, a mist of warm water droplets is sent into the room or rooms.

Bypass Humidifiers

A *bypass humidifier* (also sometimes called a *rotary humidifier*, a *wet-pad humidifier*, or a *drum humidifier*) consists basically of an evaporator pad (made of sponge or foam fabric) attached to a rotating device such as a drum, disc, wheel, or belt; a float valve; and a small motor. The evaporator pad is first rotated by the motor through a pan of water where it absorbs moisture. Warm air from the supply plenum passes over the rotating pad, causing the moisture to evaporate and humidify the air. The humidified air then mixes with supply air and is ducted into the rooms of the house. Water is supplied to the humidifier from the domestic water supply and is regulated by a float valve. The float valve controls the level of the water in the reservoir.

The principal components of a bypass humidifier are the following:

1. Motor
2. Water tank or reservoir
3. Rotating disc, wheel, drum, or belt
4. Automatic drain valve
5. Float-operated fill valve
6. Overflow line
7. Fill-water connection
8. Drain connection
9. Metal or plastic cabinet

Some of these components are illustrated by the humidifier in Figures 11-6 and 11-7. This humidifier uses bronze wire-mesh discs that rotate at an angle in the reservoir water. The water-level float is isolated in a separate compartment.

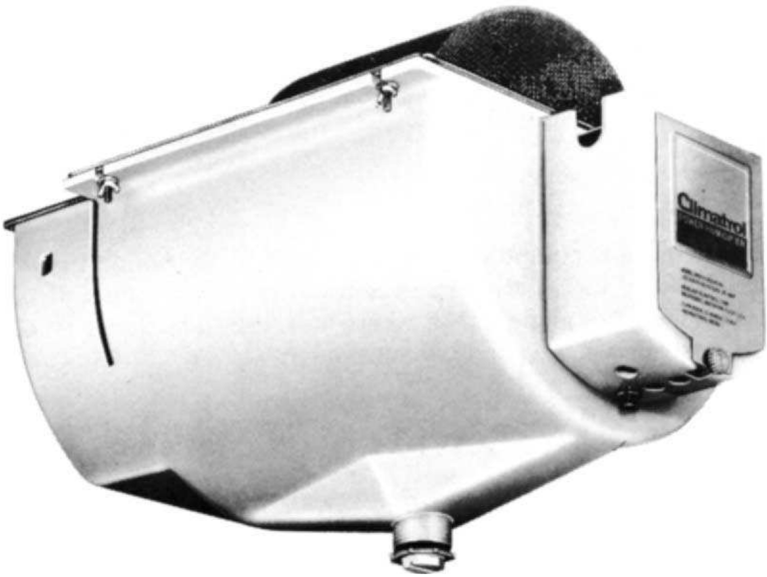


Figure 11-6 Bypass power humidifier. *(Courtesy Mueller Climatrol Corp.)*

A bypass humidifier is commonly located on the furnace supply plenum in a residential heating system where it makes use of the pressure difference between the supply and return air plenums to move the air.

Power Humidifiers

A *power humidifier* is similar in design to a bypass humidifier except that a fan is added to the unit, the cabinet is larger, and there is no duct connection to the return plenum of the furnace. The fan is used to blow the air across the wet drum, pick up the moisture, and then blow it back into the supply plenum.

Automatic Controls

The operation of a humidifier is controlled by a room or furnace-mounted humidistat (see Figure 11-8). The sensing element of the furnace-mounted humidistat should be installed in the return air

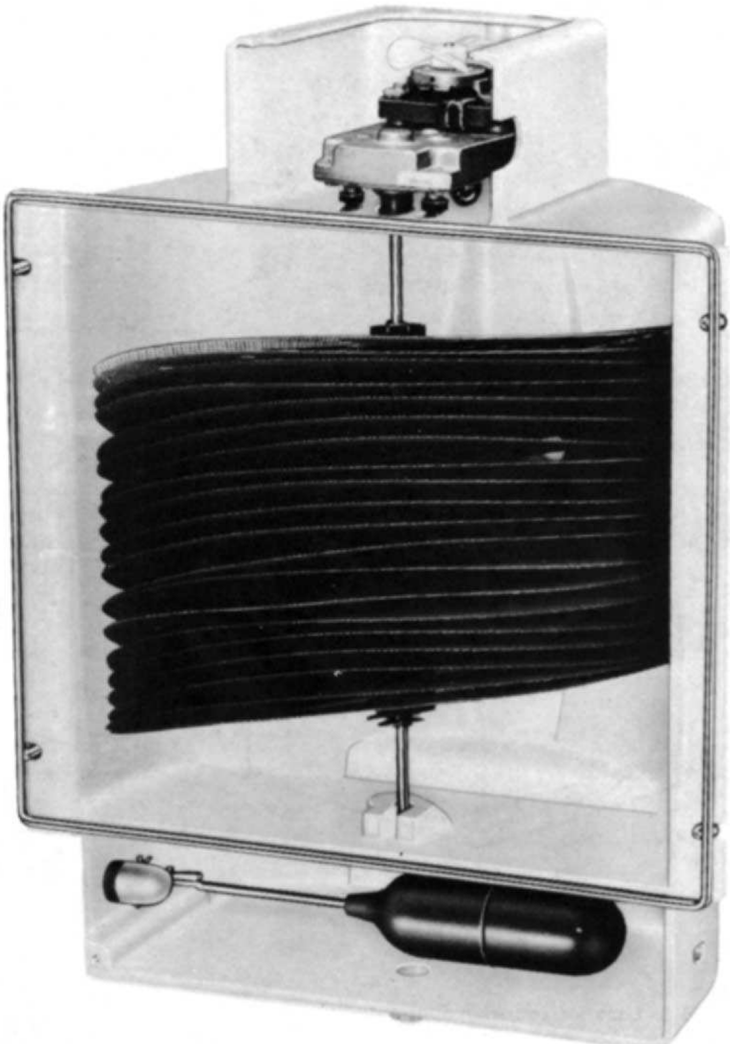


Figure 11-7 Components of a bypass humidifier. *(Courtesy Mueller Climatrol Corp.)*

duct with the open side down (see Figure 11-9). If the humidifier is installed with a plenum adapter, the sensing element of the humidistat should be mounted above the bypass duct. Never use a furnace-mounted humidistat with a horizontal furnace.

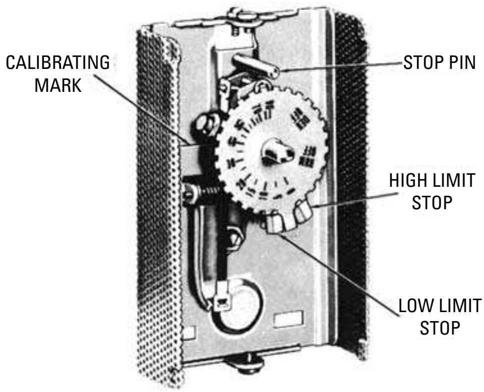


Figure 11-8 Typical humidistat used to control both humidifying and dehumidifying equipment. *(Courtesy Penn Controls, Inc.)*

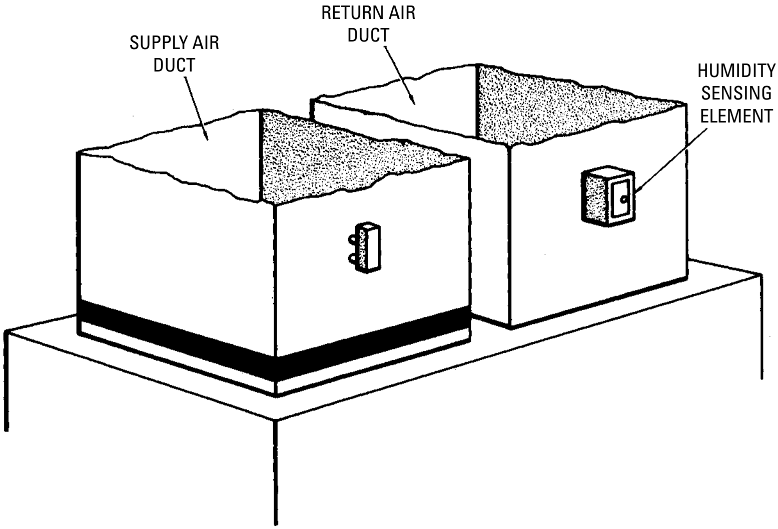


Figure 11-9 Location of furnace-mounted humidistat sensing element.

A room humidistat should be mounted on a wall 4 to 5 ft above the floor in a location that has free air circulation of average temperature and humidity for the entire space to be controlled. Avoid spots near air ducts or supply air grilles.

Modern programmable humidistats have displays that give the exact humidity level plus the temperature in Fahrenheit or Celsius. The humidity level on the humidistat can be manually set.

Depending on the type of installation, either a low-voltage or line voltage humidistat may be used. Wiring diagrams for both types of control circuits are illustrated in Figures 11-10 and 11-11.

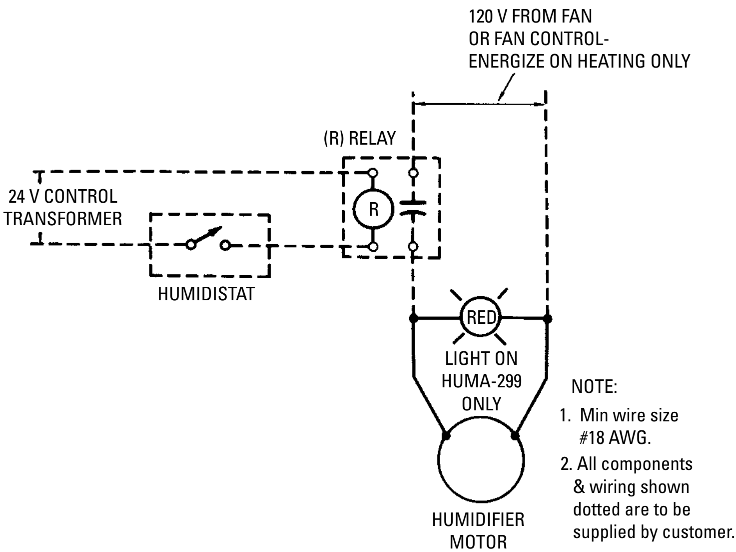


Figure 11-10 Wiring diagram of a low-voltage humidistat.

Installation Instructions

A common location for a bypass humidifier is on the underside of a horizontal warm-air supply duct as close to the furnace as convenient working conditions will permit. The duct should be at least 12 inches wide (see Figure 11-12). As shown in Figure 11-12, a deflector should be installed in the duct to guide the airflow into the humidifier. The deflector should be about 4 to 5 inches wide. It can be cut from sheet metal and screwed to the duct wall with sheet-metal screws.

If the humidifier is to be installed in a furnace plenum that also contains a fan and limit control, care must be taken to keep the sensing element of the fan and limit control a suitable distance from the inlet of the humidifier (see Figure 11-13); otherwise, the return air may be drawn through the humidifier and over the element and cause improper operation of the fan control.

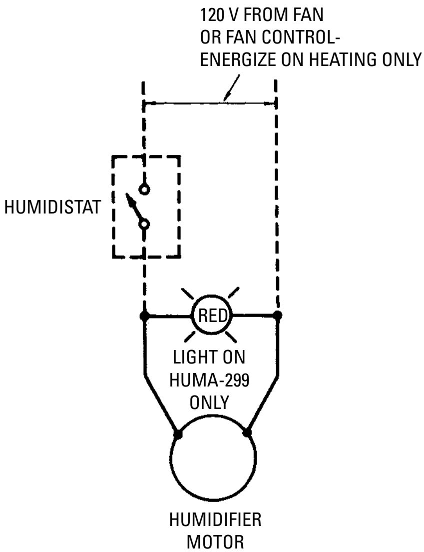


Figure 11-11 Wiring diagram of a line voltage humidistat.

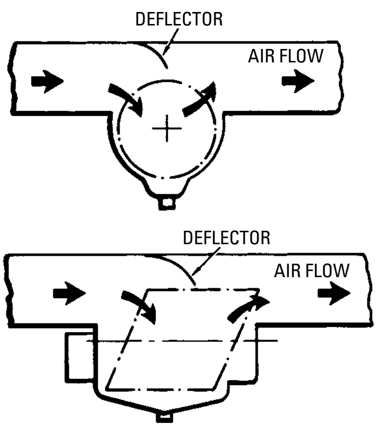


Figure 11-12 Deflector installed to guide airflow.

Humidifiers are also installed on the sides of furnace plenums. The manufacturer usually supplies a plenum adapter kit to mount the humidifier. As shown in Figure 11-14, a typical kit consists of a plenum adapter hood, closing panel adapter collar, and round cold-air collar. A length of flexible or galvanized ductwork is installed between the adapter hood and the cold-air collar (see Figure 11-15).

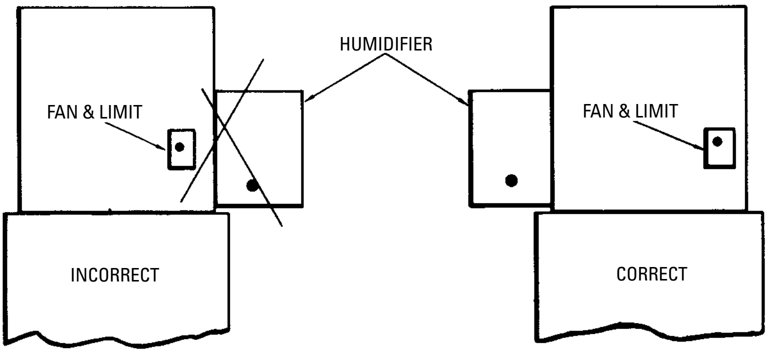


Figure 11-13 Furnace plenum location of humidifier, fan, and limit controls. *(Courtesy Thermo-Products, Inc.)*

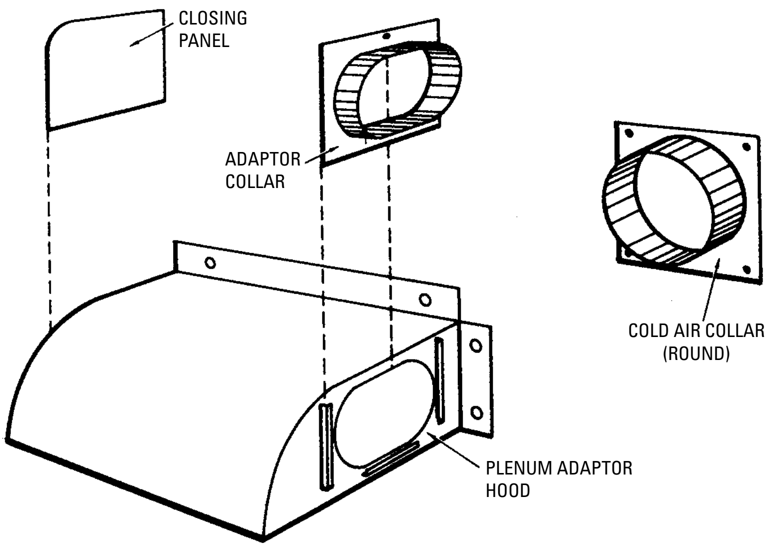


Figure 11-14 Plenum adapter kit. *(Courtesy Trane Co.)*

The most desirable location for a humidifier is the warm-air plenum. Some special installations are illustrated in Figures 11-16, 11-17, and 11-18.

If the adapter is installed on the cold-air return plenum, the distance that the hot air is ducted must be as short as possible. In an air-conditioning system, a damper must be installed to close off the

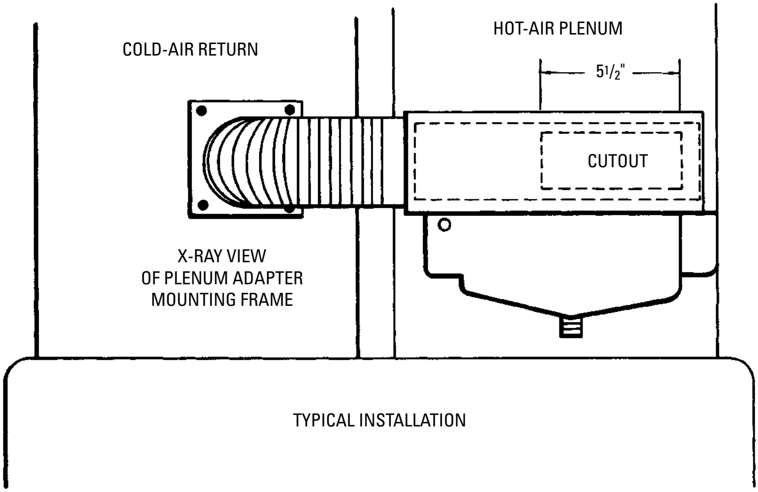


Figure 11-15 Use of flexible ductwork. *(Courtesy Trane Co.)*

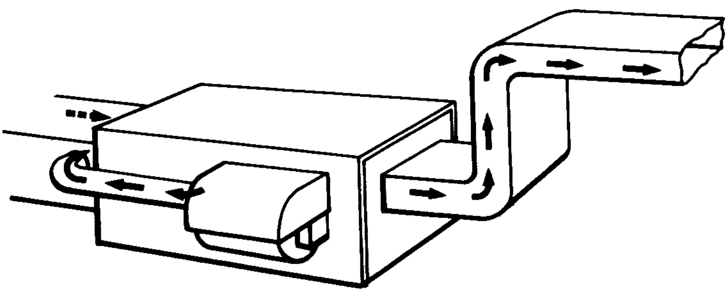


Figure 11-16 Horizontal furnace installation. *(Courtesy Trane Co.)*

cold-air return opening during the cooling season. If the opening is not closed, sufficient air can circulate through the shutdown humidifier to frost the evaporator coil.

The following recommendations should be followed when installing a bypass humidifier:

1. Carefully read the manufacturer's installation instructions and any local codes and regulations that would apply to the installation of a humidifier.

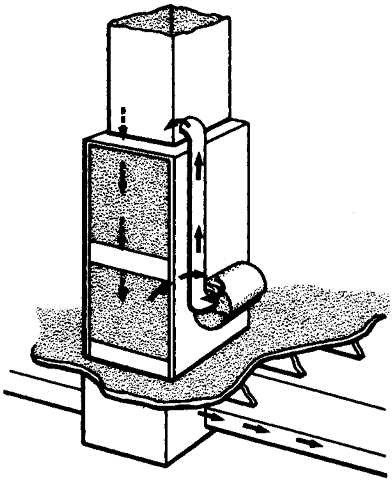


Figure 11-17 Counterflow installation slab mounted. *(Courtesy Trane Co.)*

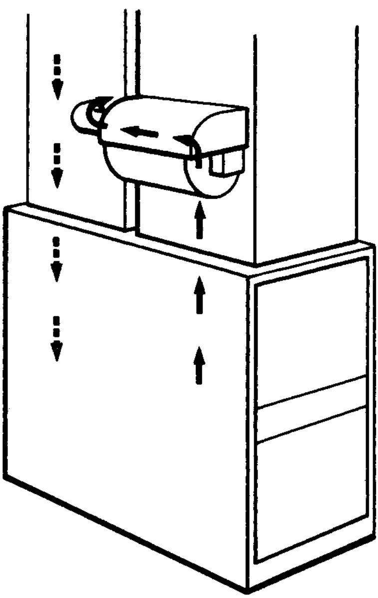


Figure 11-18 Plenum installation. *(Courtesy Trane Co.)*

2. Unpack the humidifier and examine it for any shipping damage. Check the equipment and parts against the inventory list.
3. Place the humidifier base or template against the duct or plenum wall, and mark the position where it will be mounted.

4. Cut out the opening for the humidifier, and mount it according to the manufacturer's instructions.
5. Connect the saddle valve to a convenient water line. *Never* connect to a water line supplying chemically softened water.
6. Install the required drain fittings and connections in the reservoir.
7. Turn on the water supply, and fill the reservoir. The float valve arm should be adjusted to maintain a 2-inch water level in the reservoir.
8. Place the drum or wheel in the reservoir so that the axles are properly seated on the sloped supports. The gears will mesh automatically. Do *not* attempt to rotate the drum by hand because you may damage the gears inside the motor.

Service and Maintenance Suggestions

Many service and maintenance instructions will be model specific. Whenever possible, read and follow the manufacturer's instructions when servicing these units. If none is available, the instructions in this section will provide some guidance.

A humidifier equipped with a reservoir containing standing water should be regularly drained to remove lime and other residue. The first draining of the reservoir is recommended for 2 weeks after the unit has been installed or 2 weeks after the seasonal startup. Subsequent drainings should follow the schedule suggested by the manufacturer. A major problem with any humidifier is the buildup of lime or other mineral deposits in the water reservoir and on the evaporator pad. Manufacturers have attempted to minimize this problem by constructing the reservoir out of an extremely smooth material, such as an acrylic, so that these mineral deposits can be easily flushed loose during maintenance.

Some humidifiers are equipped with an *automatic* flush system to clean the mineral deposits from the unit. The components of a Thermo-Pride automatic flush system are illustrated by the schematic of a humidifier in Figure 11-19. The drum is the rotating pad with the flush wheel attached. As the drum rotates, water in the reservoir pan is scooped up into the flush wheel. The float assembly then permits fresh water to enter the pan to replace that which was scooped out (and which evaporated from the pad). As the flush wheel continues to rotate, the mineral-laden water scooped out is conveyed into the drain cavity of the pan and out the drain hose.

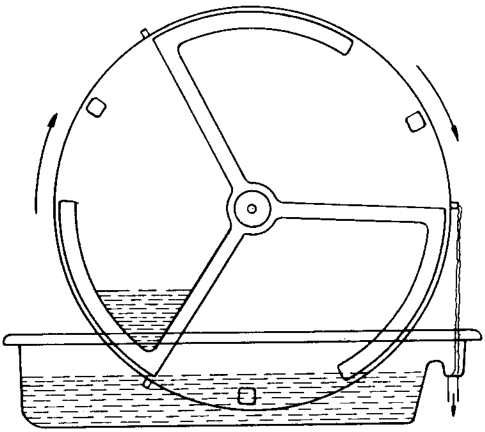


Figure 11-19 Operating principles of an automatic flush system. *(Courtesy Thermo-Products, Inc.)*

The mineral content of the water in the reservoir pan will be maintained at the lowest possible level with the operation of the automatic flush system.

A commonly used method for removing lime and other mineral deposits from the inside surface of the reservoir and the rotating evaporator pad is by cleaning these parts with muriatic acid (*never* with a detergent). Muriatic acid is an extremely efficient cleaning agent for this purpose, but it generates toxic fumes as it works on the deposits. For this reason, it is *absolutely* mandatory that the cleaning take place outdoors.

Note

A safer method of dissolving *recently* formed mineral deposits (although not as effective as muriatic acid or some of the special-purpose chemical cleaners) is by wiping them with a solution of 50 percent water and 50 percent vinegar. This is not effective on older deposits.

Troubleshooting Humidifiers

Table 11-2 lists the most common problems associated with the operation of a humidifier. For each operating problem, a possible cause is suggested and a remedy proposed.

Table 11-2 Troubleshooting Humidifiers

Symptom and Possible Cause	*Possible Remedy*
Humidifier fails to maintain proper humidification.	
(a) Humidistat set too low.	(a) Raise setting.
(b) Humidistat broken.	(b) Repair or replace.
(c) Water valve closed.	(c) Open valve.
(d) Water valve clogged.	(d) Clean valve.
(e) Limed unit.	(e) Clean lime from discs or replace.
Humidifier fails to operate.	
(a) Drum motor not receiving current.	(a) Check wiring to motor.
(b) Inoperative motor due to lack of lubrication.	(b) Lubricate or replace motor.
No water flow.	
(a) Plugged orifice or strainer.	(a) Clean orifice on inlet side of solenoid valve.
(b) No electric power to humidifier.	(b) Reset circuit breaker or replace blown fuse.
(c) Furnace fan not running. (Note: A humidistat will not operate if the furnace fan is not running.)	(c) Check humidistat wiring and correct as necessary.
(d) Solenoid valve not opening.	(d) Check circuit for loose connections. Check continuity through solenoid valve. Make corrections as necessary.
(e) Closed or plugged saddle valve.	(e) Open saddle valve and check for water flow to solenoid valve. Correct as necessary.
Excessive humidification (humidistat installed).	
(a) Continuous water flow.	(a) See *Continuous Water Flow.*
(b) Short in humidistat wiring.	(b) Check wiring and repair as required.
(c) Humidistat not turning off.	(c) Check wiring and repair as required.

(continued)

Table 11-2 *(continued)*

Symptom and Possible Cause	*Possible Remedy*
Excessive humidification (without humidistat)	
(a) Defective humidistat.	(a) Replace humidistat.
(b) Manual air control incorrectly set.	(b) Reset to reduce airflow.
Continuous water flow.	
(a) Worn valve seat.	(a) Replace valve if leaking at seat.
(b) Valve installed incorrectly.	(b) Reinstall correctly (arrow on valve should be pointed in direction of water flow).
(c) Valve plunger stuck in open position.	(c) Clean valve sleeve and plunger assembly.
Excessive water flow.	
(a) Orifice too large.	(a) Replace orifice fitting.
Insufficient or slow water flow.	
(a) Low water pressure.	(a) Install low-pressure orifice.
(b) Partially plugged orifice or strainer.	(b) Disassemble orifice and strainer. Clean thoroughly and reinstall.
Overflowing drain pan.	
(a) Plugged pan outlets or drain hose.	(a) Clean drain pan outlets. Flush drain hose.
(b) Incorrect drain hose slope from humidifier to drain.	(b) Correct slope.
(c) Kink in drain line.	(c) Remove kink.
Excess condensation on windows.	
(a) Humidistat setting too high.	(a) Lower the humidistat setting.

Dehumidifiers

Dehumidification is the name given to the process of removing moisture from the air. The device used for this purpose is called a *dehumidifier* (see Figure 11-20). Dehumidifiers can be classified on the basis of *how* they remove moisture from the air into the following three categories:

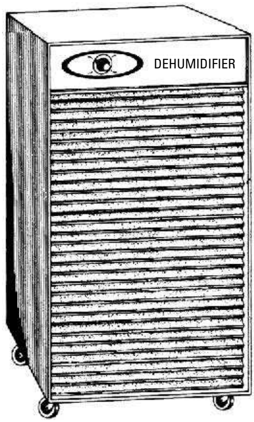


Figure 11-20 Cabinet-model electric dehumidifier.
(Courtesy Westinghouse Electric Corp.)

1. Absorption dehumidifiers
2. Spray dehumidifiers
3. Refrigeration dehumidifiers

Both spray and refrigeration dehumidifiers remove moisture from the air by cooling it. The cooled air condenses and the condensation falls into the dehumidifier tank. Dehumidifiers operating on the refrigeration principle are the type most commonly used in residential heating and cooling systems (see *Refrigeration Dehumidifiers* in this chapter).

Absorption Dehumidifiers

An *absorption dehumidifier* extracts moisture from the air by means of a sorbent material. This type of dehumidifier is very common in commercial and industrial installations but is rarely found in residences except in very large houses.

A sorbent material is one that contains a vast number of microscopic pores. These pores afford great internal surface to which water adheres or is absorbed. Moisture is removed from the air as a result of the low vapor pressure of the sorbent material.

Figure 11-21 illustrates the operating principle of a rotating-bed dehumidifier. The unit consists of a cylinder or drum filled with a dehumidifying or drying agent. In operation, airflow through the drum is directed by baffles, which form three independent airstreams to flow through the adsorbing material. One airstream consists of the wet air to be dehumidified. The second airstream is heated drying air used to dry that part of the dehumidifying material that has become saturated. The third airstream precools the bed to permit an immediate pickup of moisture when that part of the bed returns to the dehydration cycle. In the rotating-bed dehumidifier, the baffle sheets are stationary and the screened bed rotates at a definite speed to permit the proper time of contact in the drying, cooling, and dehumidifying cycles.

The operating principles of a stationary-bed solid-adsorbent dehumidifier are illustrated in Figure 11-22. It has two sets of stationary adsorbing beds arranged so that one set is dehumidifying the air while the other set is drying. With dampers in position as

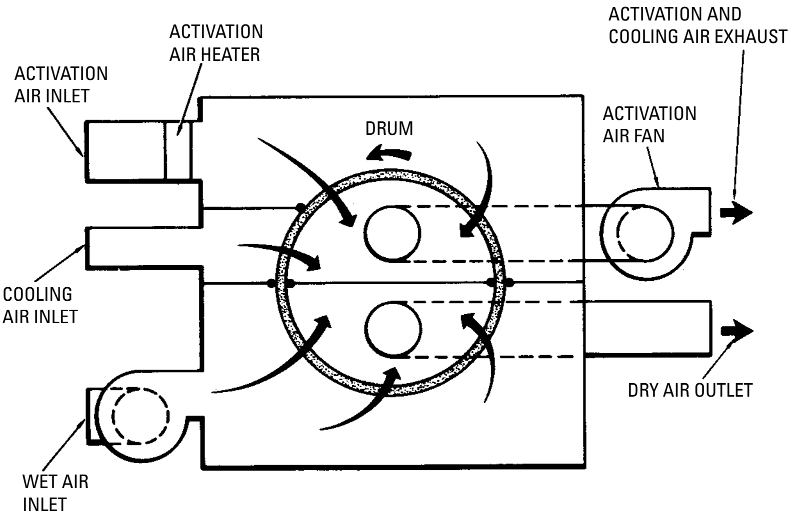


Figure 11-21 Rotating-bed solid-adsorbent dehumidifier.

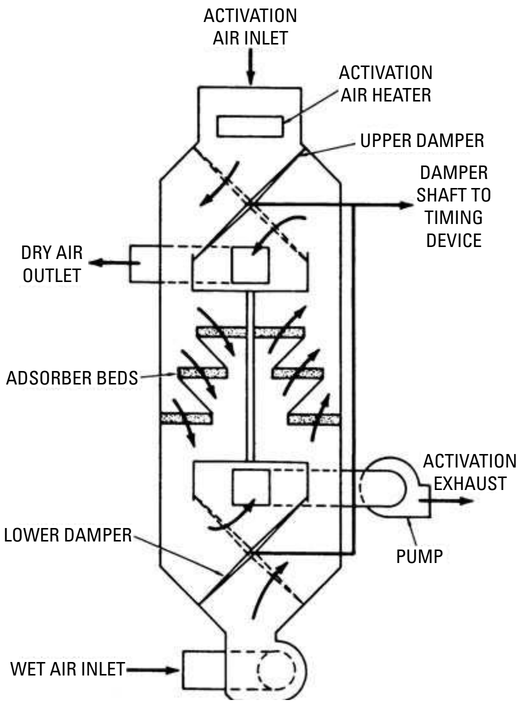


Figure 11-22 Stationary-bed solid-adsorbent dehumidifier.

shown, air to be dried flows through one set of beds and is dehumidified while the drying air is heated and circulated through the other set. After completion of drying, the beds are cooled by shutting off the drying air heaters and allowing unheated air to circulate through them. An automatic timer controller is provided to cause the dampers to rotate to the opposite side when the beds have adsorbed moisture to a degree that begins to impair performance.

The *liquid* adsorbents most frequently used in dehumidifiers are chloride brines or bromides of various inorganic elements, such as lithium chloride and calcium chloride.

A typical liquid-adsorbent dehumidifier is shown in Figure 11-23. It includes an external interchamber having essential parts consisting of a liquid contactor, a solution heater, and a cooling coil, as shown. In operation, the air to be conditioned is brought into contact with an aqueous brine solution having a vapor pressure below that of the entering air. This results in a conversion of latent heat to sensible heat, which raises the solution temperature and consequently the air temperature. The temperature change of the air being processed is determined by the cooling water temperature and the amount of moisture removed in the equipment.

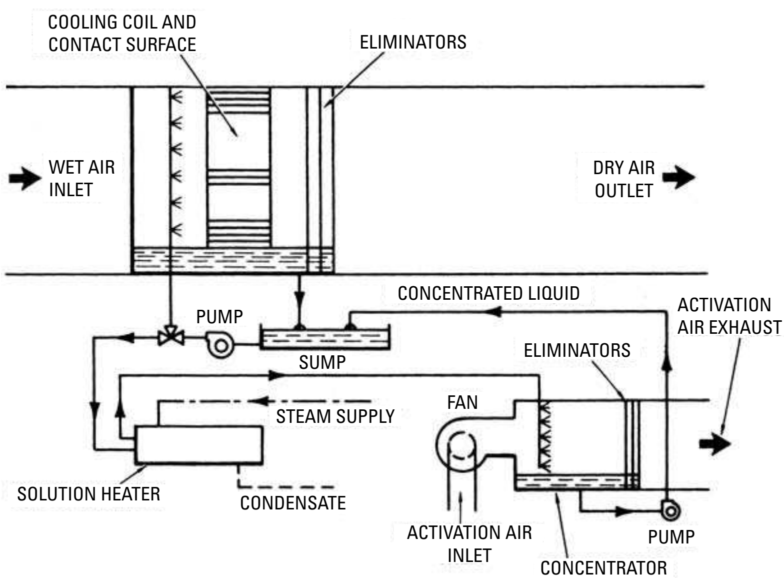


Figure 11-23 Liquid-adsorbent dehumidifier.

Spray Dehumidifiers

Dehumidification can be accomplished by means of an air washer as long as the temperature of the spray is *lower* than the dew point of the air passing through the unit. This is an important fact to remember because condensation will not take place if the temperature of the spray is higher than the dew point. Sensible heat is removed from the air during the time it is in contact with the water spray. Latent heat removal occurs during condensation.

Spray dehumidifiers, or air washers, usually have their own recirculating pumps. These pumps deliver a mixture of water from the washer sump (which has not been cooled) and refrigerated water. The mixture of sump water and refrigerated water is proportioned by a three-way or mixing valve actuated by a dew-point thermostat located in the washer air outlet or by humidity controllers located in the conditioned space.

A spray dehumidifier results in greater odor absorption and cleaner air than is possible with those using a cooling coil. A principal disadvantage of this type of dehumidifier is that it sometimes experiences problems with the water-level control and may flood.

Refrigeration Dehumidifiers

A *refrigeration dehumidifier* removes moisture from the air by passing it over a cooling coil. The cool surfaces of the coil cause the moisture in the air to condense. This moisture then collects on the coils and eventually runs into a collection tray or pan located below the unit, or through a hose into a nearby drain. Portable electrically operated refrigeration dehumidifiers are the type of units most commonly found in residences.

The amount of moisture removed from the air by a refrigeration dehumidifier will depend on the volume of air and its relative humidity. The initial amount of moisture removed will be relatively large in comparison to the amount removed at later stages in the operation of the dehumidifier. This reduction in the amount of moisture removal is *not* an indication that the dehumidifier is not operating properly. This is a normal operating characteristic. As the relative humidity approaches the desired level, the amount of moisture being removed from the air will be considerably less.

Dehumidifying coils depend on the dew point of the air entering and leaving the coil for removal of moisture from the air. To accomplish moisture removal, the dew point of the air entering the coil must be *higher* than the dew point of the air leaving the coil.

Automatic Controls

A refrigeration dehumidifier consists of a motor-driven compressor, a condenser or cooling coil, and a receiver. A refrigerant circulates through the cooling coil of the unit, the refrigerant flow being controlled by a capillary tube circuit.

The room air is drawn over the cooling coil by means of a motor-operated fan or blower. When the moisture-laden air comes in contact with the cool surfaces of the cooling coil, it condenses and runs off the coil into a collection tray or pan, or through a hose into a drain.

Dehumidifier operation is controlled by a humidistat, which starts and stops the unit to maintain a selected humidity level. The humidistat accomplishes this function by switching the compressor and unit fan on and off in response to changes in the moisture content of the air.

Humidistat control settings will generally range from *dry* to *extra dry* to *continuous* to *off*. During the initial period of operation (usually 3 to 4 weeks), the humidistat should be set at *extra dry*. If the moisture content of the air has been noticeably reduced, the humidistat setting can be moved to *dry*. Minor adjustments may be required from time to time.

Never purchase a dehumidifier that does not have a humidistat. Without a humidistat, a dehumidifier will run long after the humidity of the air has dropped to a satisfactory level. Operating such a dehumidifier can prove to be very costly and wasteful of energy.

Dehumidifiers that empty the condensate into a container are equipped with an integral cutoff (float) switch to turn the unit off when the condensate container is full. This action avoids overflow conditions. Most of these dehumidifiers will also have a signal light that indicates when the condensate container needs emptying.

Installation Suggestions

A dehumidifier is most effective in an enclosed area where good air circulation is found. For maximum effectiveness, the unit should be located as close to the center of room, space, or structure as possible.

Operating and Maintenance Suggestions

A dehumidifier generally will not operate very satisfactorily at temperatures below 60°F. The reason for this is obvious. When the ambient temperature is below 60°F, the cooling coil must operate at below-freezing temperatures in order to cause the moisture in the air to condense. Unfortunately, operating at these temperatures also causes ice to form on the coils, and this ice formation may eventually damage the dehumidifier. The ice is removed by running the dehumidifier through a defrost cycle. When a defrost sensor in the dehumidifier detects frost on the coils, it turns off the compressor but allows the fan to continue running. The fan draws the warmer surrounding air across the coils and melts the frost. After the frost has melted, the compressor restarts and the appliance resumes reducing the moisture in the indoor air.

Note

The dehumidifier cannot remove moisture from the air while it is in the defrost cycle.

Fungus will sometimes collect on the cooling coil. This accumulation of fungus can be removed by loosening it with a soft brush and washing away the residue with water.

The principal components of a refrigeration dehumidifier are hermetically sealed at the factory. These components are permanently lubricated and should not require any further servicing. On the other hand, both the condensate collector and the dehumidifier filter can be inspected and cleaned.

As an alternative to manually emptying the condensate container, a unit located in the basement can be connected by a hose to a floor drain, or it can be positioned directly over the drain. In any event, the dehumidifier should be equipped with a cutoff (float) switch to turn off the unit when the condensate container is full.

Troubleshooting Dehumidifiers

Running a dehumidifier will sometimes produce results that are misdiagnosed as problems when, in fact, they are perfectly normal for these appliances. The most frequent complaints include the following:

- The dehumidifier switches on and off several times during the day. The dehumidifier simply is responding to a signal from the humidistat. When the humidity in the surrounding air falls to the setpoint on the humidistat, the dehumidifier shuts off. It turns on again when the humidity rises above the humidistat setpoint.
- The condensate container fills up and must be emptied often. This is normal operation in areas of high humidity, such as Florida and the other Gulf states.

Table 11-3 lists the most common problems associated with the operation of a refrigeration dehumidifier.

Table 11-3 Troubleshooting Dehumidifiers

Symptom and Possible Cause	*Possible Remedy*
Condensation container fills to brim or flows over.	
(a) Overflow prevention control malfunctioning.	(a) Replace cutoff float switch.
(b) Shutoff level too high.	(b) Lower shutoff level.
Dehumidifier runs continuously.	
(a) Humidity too high for unit.	(a) Use dehumidifier with higher capacity.
(b) Defective humidistat.	(b) Replace humidistat.
Rattling noise when dehumidifier is running.	
(a) Dehumidifier not level.	(a) Check level and correct if necessary.
(b) Condensation container not positioned properly.	(b) Check and correct as necessary
Dehumidifier will not start.	
(a) Full condensate container (the red indicator light on the unit should be on).	(a) Empty container and restart dehumidifier.
(b) Faulty wiring.	(b) Check to make sure the dehumidifier is plugged in and then rotate the control. If a click is heard when the control is rotated past its setting (and the unit does not start), there is probably a problem with the wiring. Inspect and repair as necessary.
(c) Defective humidistat.	(c) Check to make sure the dehumidifier is plugged in and then rotate the control. If no click is heard when the control is rotated past its setting (and the unit does not start), the humidistat needs to be repaired (dirty or worn contacts) or replaced.
(d) Faulty compressor or compressor starter relay.	(d) Fan runs but compressor won't start after the internal pressure has equalized. Replace compressor or compressor starter relay.
(e) Low line voltage.	(e) Correct as necessary.

(continued)

Table 11-3 *(continued)*

Symptom and Possible Cause	*Possible Remedy*
Compressor overheats and short-cycles.	
(a) Low line voltage.	(a) Correct as necessary.
(b) Seized fan.	(b) Correct as necessary.
(c) Slow fan rotation.	(c) Correct as necessary.
(d) Excessive dirt buildup on fan, fan shaft, or coils.	(d) Clean.
Excessive ice buildup on coils	
(a) Defective defrost sensor. Unit cannot run defrost cycle.	(a) Replace defrost sensor.
(b) Defective low-temperature shutoff sensor. Dehumidifier continues to run when room temperatures are too cold.	(b) Replace low-temperature shutoff sensor.
Condensate container does not fill.	
(a) Dehumidifier does not run often enough to reduce humidity and fill condensate container.	(a) Set humidistat to drier setting.
(b) Dehumidifier runs constantly but sends little or no condensate to container.	(b) Dirty coils. Clean and restart dehumidifier or defective refrigeration system. Should be repaired only by a qualified and experienced technician.
No air blows out of front of dehumidifier.	
(a) Defective fan motor.	(a) Replace fan motor.
(b) Seized fan or broken fan blade.	(b) Replace fan.

Chapter 12

Air Cleaners and Filters

All indoor air contains a certain amount of microscopic airborne dust and dirt particles. Cooking and tobacco smoke also contribute to the pollution of the indoor air, and pollen is a factor during some months of the year.

Excessive air pollution stains furniture and fabrics and causes a dust film to form on glass surfaces such as windows or mirrors. It can also be a health problem, especially to those with dust or pollen allergies.

A number of devices are used to remove dust, dirt, smoke, pollen, and other contaminants from the indoor air. They are not all equally effective. For example, an ordinary air filter in a furnace removes only approximately 10 percent of all airborne contaminants. An electronic air cleaner, on the other hand, can remove as much as nine times that amount.

The air-cleaning devices described in this chapter are: (1) electronic air cleaners, (2) air washers, and (3) conventional air filters.

Electronic Air Cleaners

Electronic air cleaners are devices designed to remove airborne particles from the air electrically. The best electronic air cleaners remove 70 to 90 percent of all air contaminants. These standards are met in testing methods devised by the National Bureau of Standards and the Air-Conditioning and Refrigeration Institute. Claims by manufacturers for higher rates of airborne particle removal should be attributed to enthusiasm for their product. In any event, an electronic air cleaner is vastly more effective than the conventional filter used in a warm-air furnace. They are available as permanently mounted units for use in central heating and/or cooling systems or as independent cabinet units.

Permanently mounted electronic air cleaners are installed at the furnace, air handler, or air-conditioning unit or in wall or ceiling return air grilles. Some typical installations are shown in Figure 12-1.

An electronic air cleaner installed at the furnace, air handler, or air-conditioning unit is either mounted against the surface of the unit or a short distance from it on the return air duct. These electronic air cleaners are sometimes referred to as *multiposition* models because they can be installed in a number of locations with equal

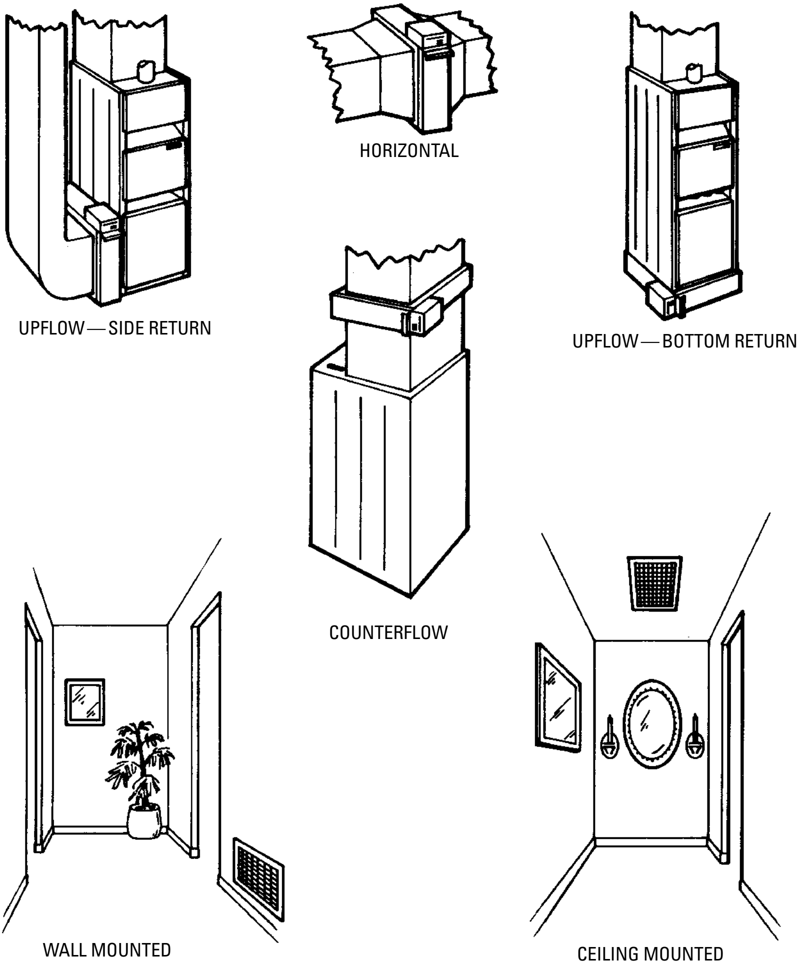


Figure 12-1 Some typical electronic air cleaner installations.
(Courtesy Mueller Climatrol Corp.)

effectiveness. Some typical examples of multiposition electronic air cleaners are shown in Figures 12-2, 12-3, and 12-4.

A design feature of some *return grille* electronic air cleaners is a hinged cell carrier, which swings out to allow the cells to be removed (see Figure 12-5). Return grille electronic air cleaners can be installed in the wall or ceiling openings of return air ducts, but

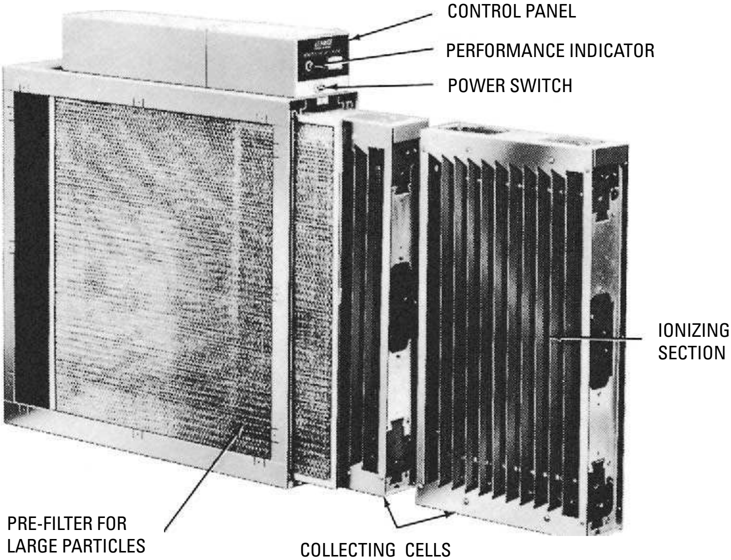


Figure 12-2 Multiposition electronic air cleaner.
(Courtesy Lennox Air Conditioning and Heating)

not in a floor return. These units are also referred to as *wall* (or *ceiling*) *electronic air cleaners* or as *through-the-wall electronic air cleaners*. Typical installations are shown in Figures 12-6, 12-7, and 12-8.

The independent cabinet units (see Figures 12-9 and 12-10) are designed for use in installations where a permanently mounted unit is impractical or where *selective* air cleaning is desired. These units can be installed anywhere in the structure.

Based on their operating principle, electronic air cleaners can be divided into the following two principal types:

1. Charged-media air cleaners
2. Two-stage air cleaners

Charged-Media Air Cleaners

The basic working components of a *charged-media electronic air cleaner* are an electrically charged grid operating in conjunction with a media pad or mat. Media pads are commonly made of fiberglass, cellulose, or a similar material.

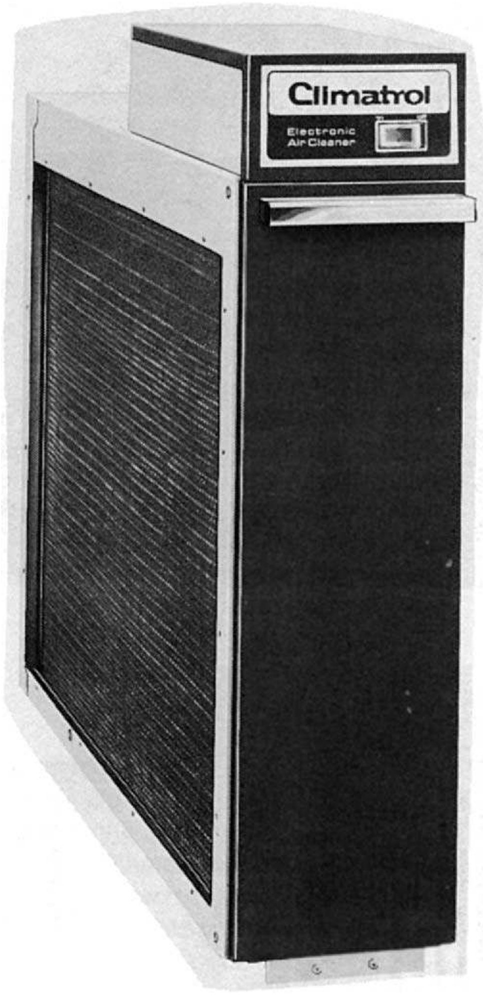


Figure 12-3 Climatrol multiposition electronic air cleaner. *(Courtesy Mueller Climatrol Corp.)*

The charged-media air cleaner operates on the electrostatic principle. When voltage is applied to the grid, an intense electrostatic field is created. Dust particles passing through this field are polarized and caught by the media pads in much the same way that metal filings adhere to a magnet. When these media pads are filled, they must be removed and replaced with clean ones.

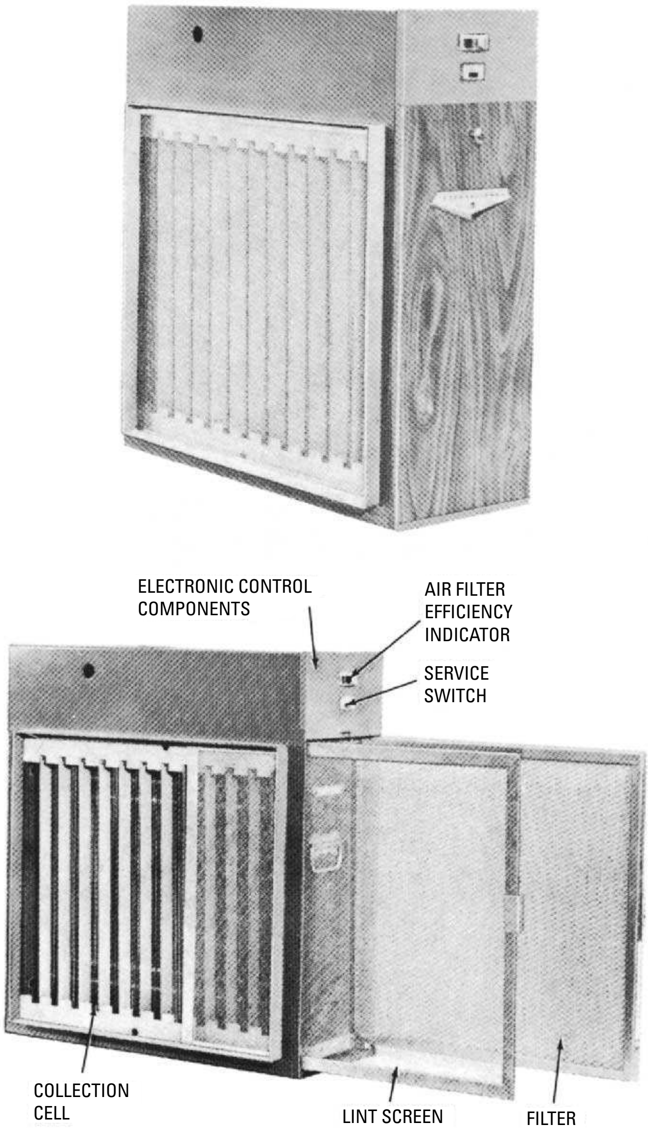


Figure 12-4 Utica International multiposition electronic air cleaner.
(Courtesy International Heating and Air Conditioning)

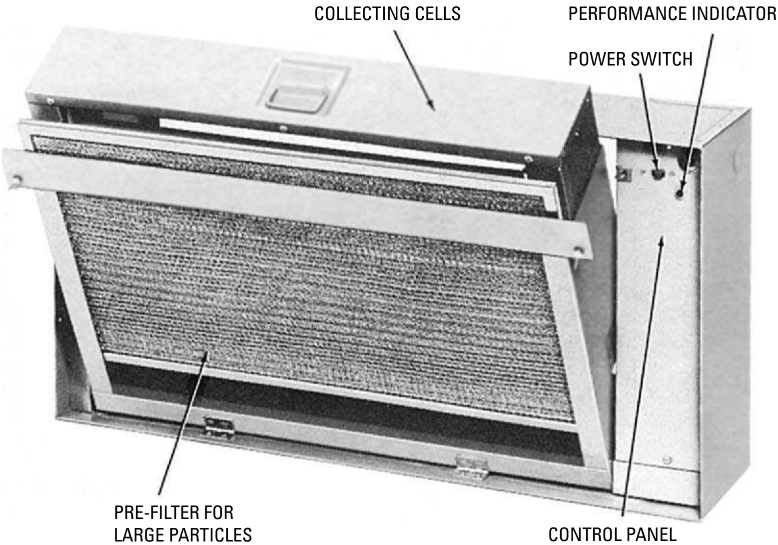


Figure 12-5 Wall-mounted electronic air cleaner. *(Courtesy Trane Co.)*

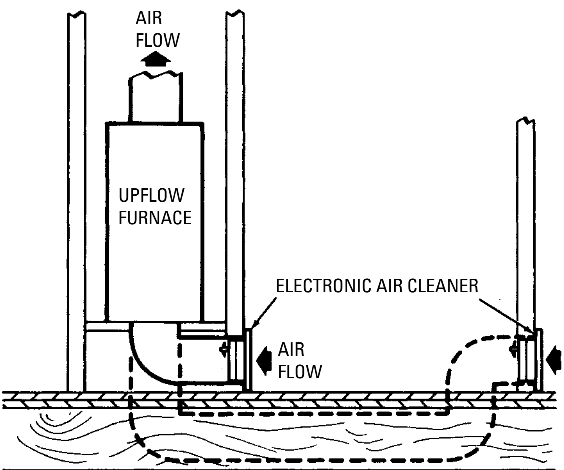


Figure 12-6 Typical application on a platform-mounted upflow furnace. *(Courtesy Trane Co.)*

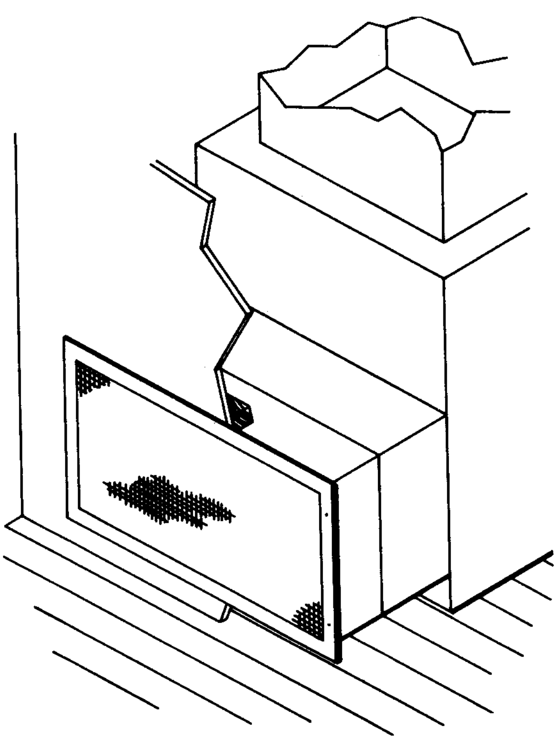


Figure 12-7 Typical installation on an upflow (highboy) furnace. *(Courtesy Trane Co.)*

Two-Stage Air Cleaners

The *two-stage* (or *ionizing*) *electronic air cleaner* also operates on the electrostatic principle, but the airborne particles pass through *two* electrical fields rather than the single field used in charged-media air cleaners. The effectiveness of this type of air cleaner is indicated in test results from the National Bureau of Standards (see Figure 12-11).

Air entering a two-stage air cleaner must first pass through a permanent screen or prefilter, which catches the larger airborne particles. After passing through the prefilter, the air enters the so-called ionizer, or first stage, where the airborne particles receive an intense positive electrical charge. The positively charged airborne particles subsequently enter the collection, or second stage, which consists of a series of collector plates. These collector plates are metal

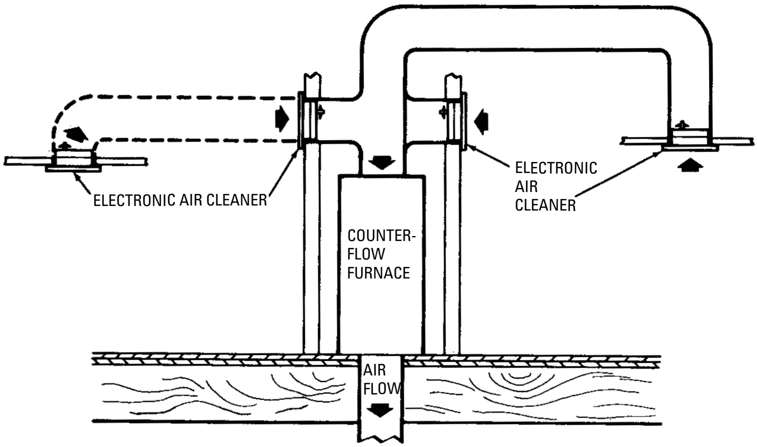


Figure 12-8 Typical application on a high-capacity counterflow (downflow) furnace. *(Courtesy Trane Co.)*

plates or screens alternately charged with positive and negative high voltages. Because the airborne dust and dirt particles received a positive charge when they passed through the first stage of the electronic air cleaner, they are repelled by the *positively* charged plates in the second stage and propelled against the negatively charged collector plates where they adhere until washed away. The airborne particles are removed from the negative collector plates by periodic vacuuming or washing. Some electronic air cleaners are equipped with washing systems that flush the particles off the plates.

The first stage (ionizing section) and second stage (collector section) are referred to collectively as the *electronic cell*, or the *electronic air-cleaning cell.*

Automatic Controls

A built-in electronic air cleaner can be connected electrically to the system blower motor or directly through a disconnect switch to the 120-volt line voltage power source. If the unit is connected to the system blower motor, the electronic cell will energize each time the blower motor operates.

Because the electronic air cleaner can be wired to operate either automatically or continuously in conjunction with fan operation, there is no need for a special wall-mounted air cleaner control. Thus, the fan control on a room thermostat, or combination thermostat

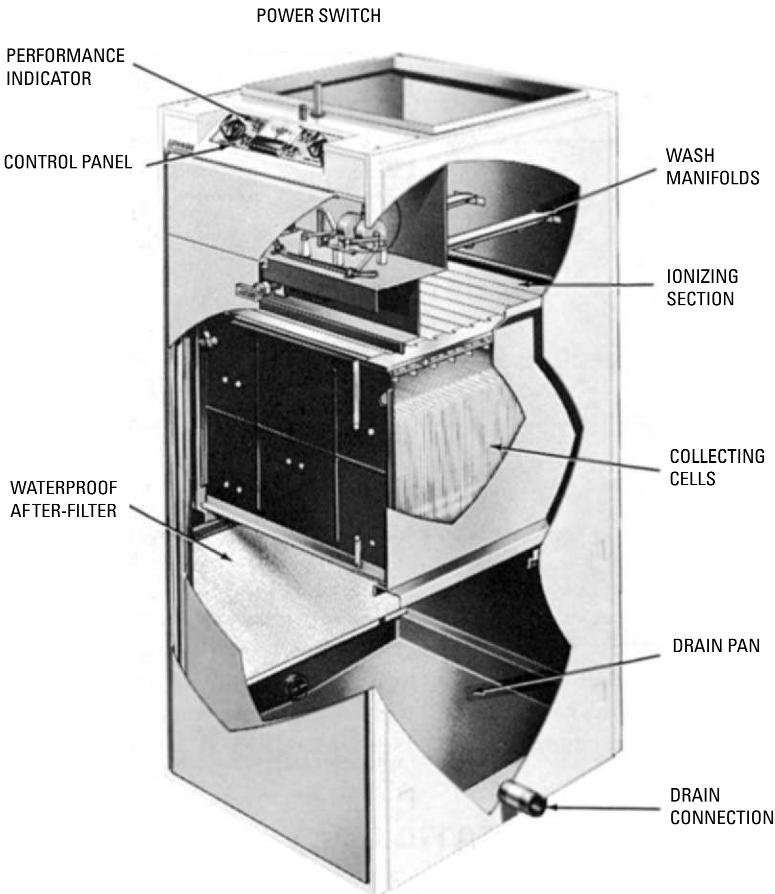


Figure 12-9 Cabinet-model electronic air cleaner.
(Courtesy Lennox Air Conditioning and Heating)

and humidistat, is used to control both the system fan and the electronic air cleaner. A typical unit combining all heating and/or cooling system controls under a single cover is shown in Figure 12-12. When the fan control switch is set on *auto*, the air is cleaned automatically whenever the heating and/or cooling system is operating. Continuous air cleaning (when extra air cleaning is required) is obtained by setting the fan control switch at *on*.

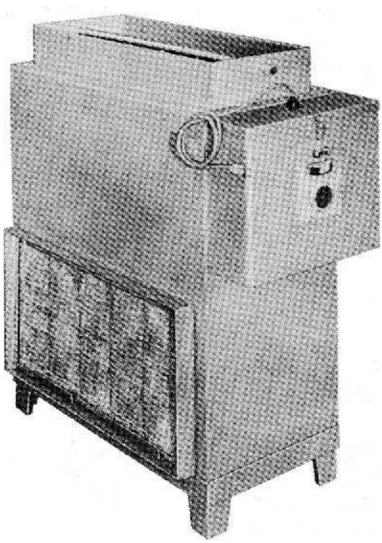


Figure 12-10 Cabinet-model electronic air cleaner with built-in automatic water-wash system.

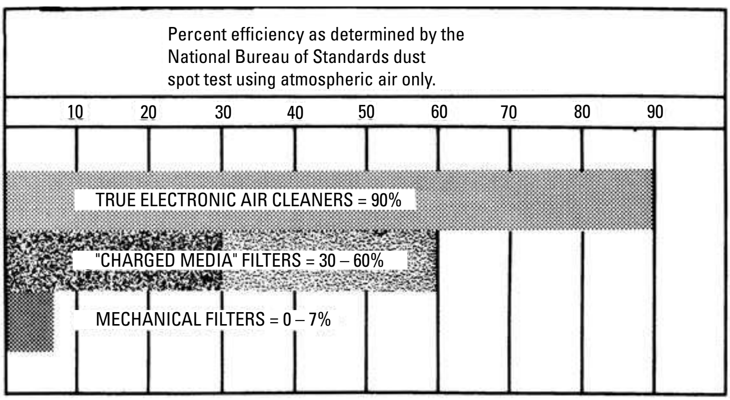


Figure 12-11 National Bureau of Standards test results.

Clogged-Filter Indicator

The *clogged-filter indicator* shown in Figures 12-13 and 12-14 is used with Trane electronic air cleaners to sense pressure conditions in the blower chamber between the unit and the blower. An increase in pressure indicates a clogged filter, and this condition will be indicated by the light on the room thermostat control (see Figure 12-12) or when the clogged-filter indicator on the furnace shows red.

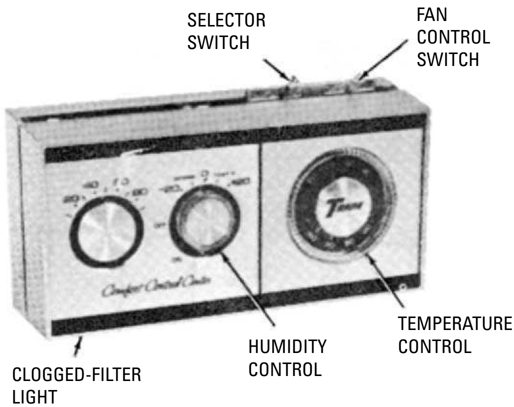


Figure 12-12 Combination thermostat and humidistat used to control electronic air cleaner. *(Courtesy Trane Co.)*

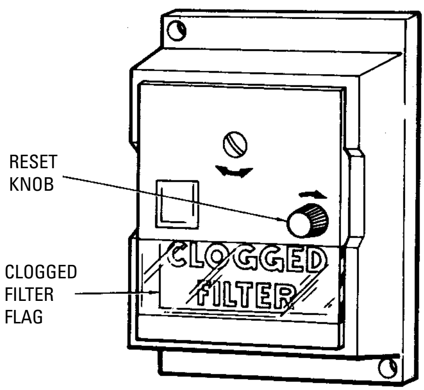


Figure 12-13 Furnace-mounted clogged-filter indicator. *(Courtesy Trane Co.)*

The clogged-filter indicator should be located on a rigid sheet-metal mounting surface to prevent bumps or other vibrations from tripping the indicator. It should also be located where it can properly sense the pressure conditions.

Performance Lights

Most electronic air cleaners are equipped with performance lights to indicate how the unit is operating. How these lights will be used will depend on the individual manufacturer. Read the manufacturer's

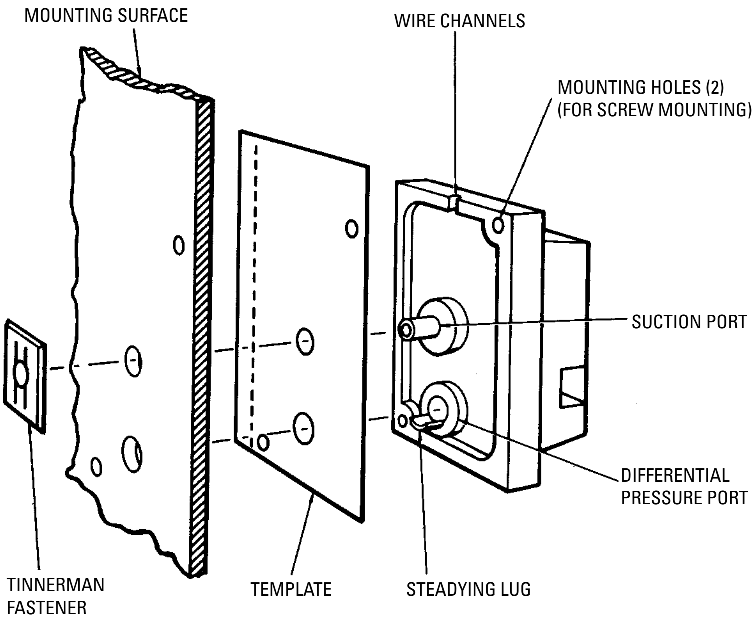


Figure 12-14 Clogged-filter indicator details. *(Courtesy Trane Co.)*

operating instructions concerning the use of these lights. As the following paragraphs make clear, they are not always used in the same way.

The built-in performance indicator light on the Trane electronic air cleaner shown in Figure 12-15 operates in conjunction with the on-off switch. If the electronic air cleaner is operating correctly, the performance indicator light will be on whenever the system fan is running and the on-off switch is in the *on* position.

The performance indicator light on the Lennox electronic air cleaner shown in Figure 12-16 glows red when the unit is operating correctly. This light also operates in conjunction with the on-off switch, which must be *on*. An optional performance light is available with a Lennox electronic air cleaner for installation in the living spaces (see Figure 12-17). It remains off when the unit is operating correctly.

Thermo-Pride electronic air cleaners use both an amber-colored operating light and a red performance light with their units. The

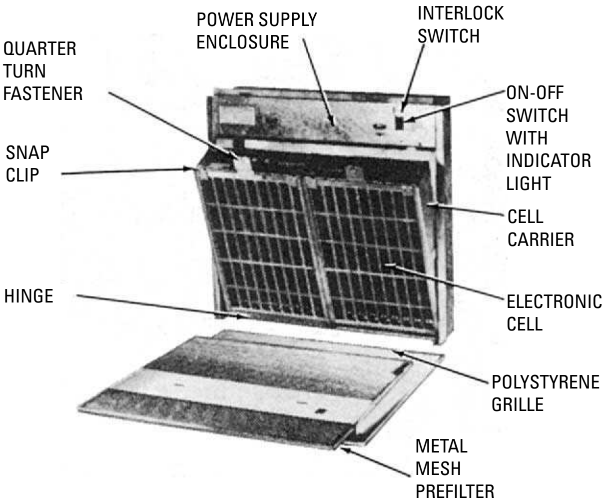


Figure 12-15 Trane multiposition electronic air cleaner. *(Courtesy Trane Co.)*

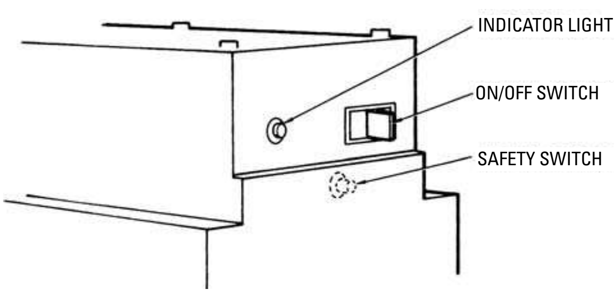


Figure 12-16 Lennox performance indicator light.
(Courtesy Lennox Air Conditioning and Heating)

operating light indicates that line voltage is on. The red performance light indicates that the electronic cell is operating properly. Both lights must be on during normal operation.

Sail Switch

A *sail switch* (see Figure 12-18) is designed to complete circuit power to auxiliary equipment in a forced warm-air system when the duct air velocity is increased. Consequently, it provides on-off

Figure 12-17 Optional performance light. *(Courtesy Lennox Air Conditioning and Heating)*

control of electronic air cleaners, humidifiers, odor-control systems, and other equipment that is energized when the fan is operating.

In operation, the air movement pushing against the sail actuates the switching device, which then energizes the power supply. Using a sail switch allows the auxiliary equipment to be wired independently of the system blower motor.

The manufacturer's installation instructions should be carefully read and followed because the sail is installed at the site. The switch mechanism or sail switch body is mounted on the back of the electronic air cleaner usually before it is installed in the return air duct opening (see Figure 12-18). The sail is mounted on the switch body after installation of the air cleaner to prevent damage of the sail. A typical wiring diagram is shown in Figure 12-19.

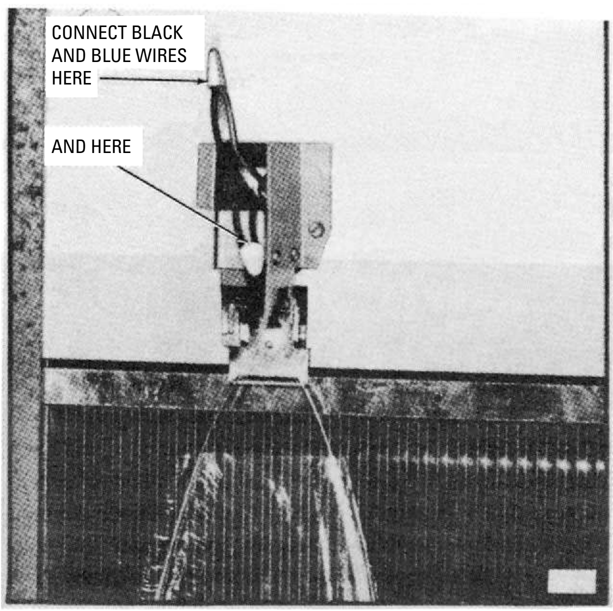


Figure 12-18 Sail switch mounted on back of electronic air cleaner. *(Courtesy Trane Co.)*

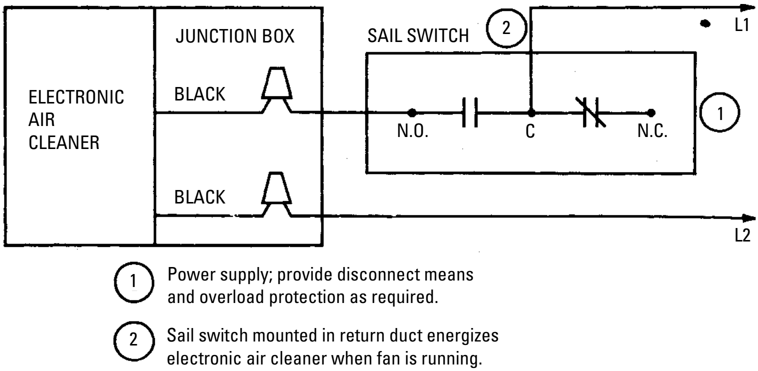


Figure 12-19 Wiring diagram of an electronic air cleaner controlled by a sail switch. *(Courtesy Honeywell Tradeline Controls)*

In-Place Water-Wash Controls

Some electronic air cleaners are equipped with a water-wash system for in-place cleaning of the electronic cells. Operation of the water-wash system is governed by a control unit that includes a sequencing timer, water valve, detergent aspirator and valve, and a fan interlock switch to control the system fan during the wash cycle (see Figure 12-20). The timer controls the internal water and detergent valves

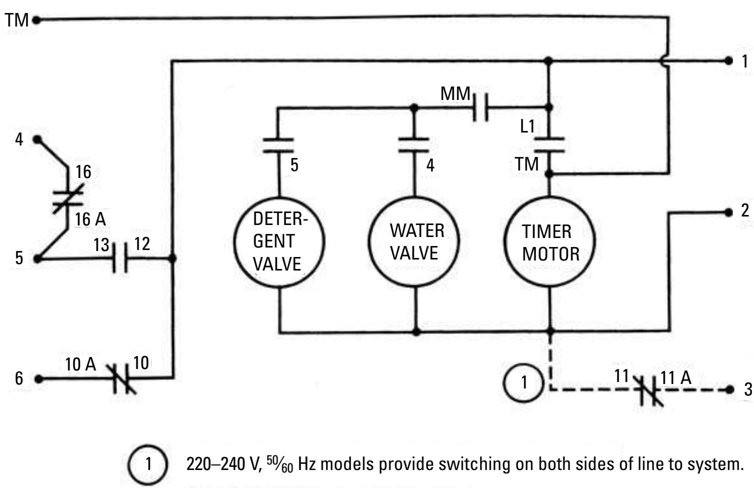
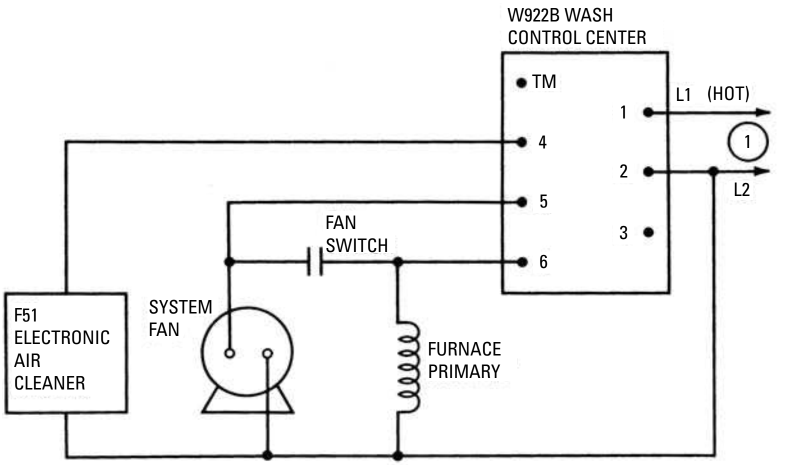
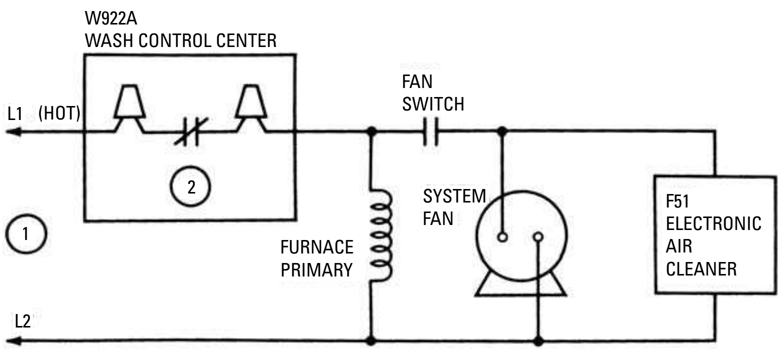


Figure 12-20 Water-wash control wiring diagram.
(Courtesy Honeywell Tradeline Controls)



1 120 V, 60 Hz power supply. Provide disconnect means and overload protection as required.

Figure 12-21 Typical hookup of wash control and electronic air cleaner for in-place washing of the electronic cell. *(Courtesy Honeywell Tradeline Controls)*



1 120 V, 60 Hz power supply. Provide disconnect means and overload protection as required.

2 The normally closed contacts open when cover is opened.

Figure 12-22 Typical hookup of wash control and electronic air cleaner for automatic wash and rinse of electronic cells.
(Courtesy Honeywell Tradeline Controls)

to provide automatic wash and rinse of the electronic cells. Typical hookups for a Honeywell W922 wash control are shown in Figures 12-21 and 12-22.

Cabinet-Model Control Panels

The cabinet-model electronic air cleaner shown in Figure 12-9 is equipped with a control panel that contains a meter, operating controls, and water-wash controls.

The meter is used to check the performance of the electronic air cleaner (see Figure 12-23). The meter is divided into three sections. If the unit is operating properly, the indicator needle will be steady and remain in the center section (the normal operating range on the meter). Fluctuations of the needle outside the normal operating range indicate that the unit is not operating properly. The specific problem is determined by the position of the needle.

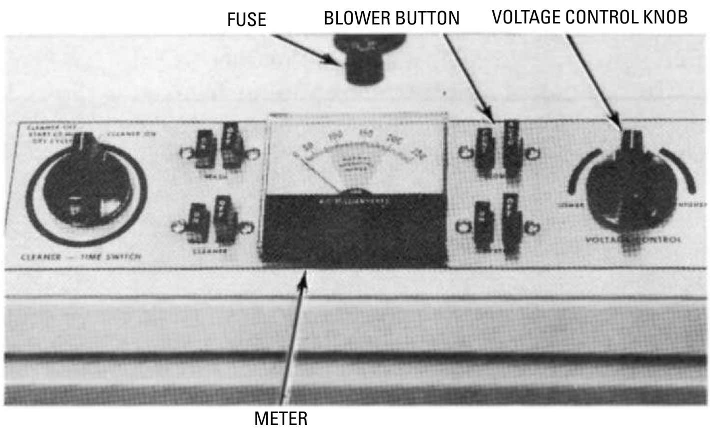


Figure 12-23 Cabinet-model control panel.
(Courtesy Lennox Air Conditioning and Heating)

The system/blower controls are located to the right of the meter; the washer/cleaner controls to the left. The voltage-control knob operates in conjunction with the meter and is used to adjust the unit for line voltage variations. The basic procedure for operating the electronic air cleaner shown in Figure 12-9 is as follows:

1. Turn cleaner time switch to *on* position.
2. Push the *off* wash button.

3. Push the *on* cleaner button.
4. Push the *cont* blower button for continuous operation or the *auto* blower button for intermittent operation.
5. Push the *on* system button.
6. Adjust the voltage-control knob so that the needle remains in the normal operating range section on the meter.

Installation Instructions

When installing a built-in electronic air cleaner, make certain there is enough clearance to allow easy access to the filters and collector cells. These components must be cleaned periodically and should not be obstructed. Most manufacturers recommend at least 30 inches of clearance for servicing.

Pay particular attention to the airflow arrow printed on the side of the electronic cell. This arrow is used to indicate the correct direction of the airflow through the unit. If the electronic cell is installed so that the airflow arrow is facing the wrong direction, excessive arcing will occur and the unit will not operate efficiently.

The conventional air filter should be removed after the electronic air cleaner has been installed in order to help reduce pressure drop through the furnace.

Air volume adjustment is another factor that must be taken into consideration when installing one of these units. These adjustments should be made in accordance with the manufacturer's instructions. They will involve determining the required temperature rise through the heat exchanger, making the necessary fan speed adjustments, and calibrating the filter flag setting (when used).

Some existing installations may require transitions or duct turns. If the ductwork makes an abrupt turn at the air cleaner, turning vanes should be installed in the duct to help provide an equal distribution of air across the entire surface of the filters. Do not install an atomizing humidifier upstream from an electronic air cleaner.

Electrical Wiring

Read and carefully follow the manufacturer's installation instructions before attempting to make any wiring connections. All wiring should be done in accordance with local codes and regulations. *Always* disconnect the power source before beginning any work in order to prevent electric shock or damage to the equipment.

Electronic air cleaners operate on regular 120-volt current and use less electricity than a 60-watt light bulb. Typical wiring connections for a Trane Model EAP-12A Electrostatic Air Cleaner are shown in Figure 12-24. A ground wire for this unit is required. No

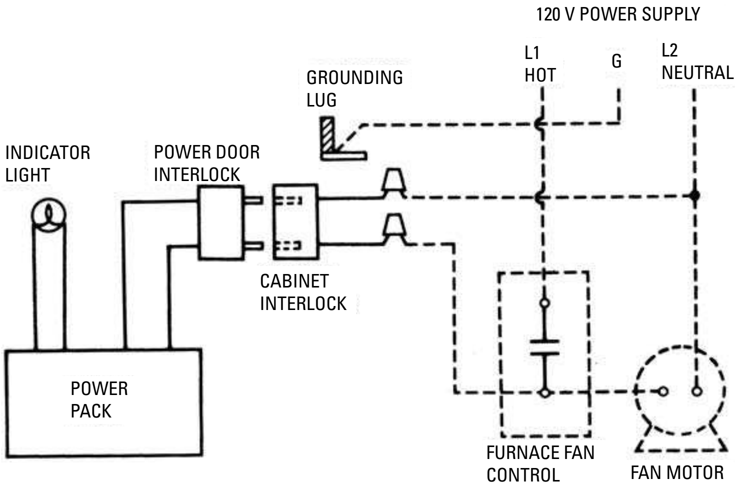


Figure 12-24 Wiring diagram for Trane Model EAP-12A electronic air cleaner. *(Courtesy Trane Co.)*

ground wire is required for the return grille electronic air cleaner shown in Figure 12-25. Other than installing the ground wire (where required), wiring an electronic air cleaner generally consists of simply hooking the unit up to the power source.

When making external circuit connections to the line voltage lead wires of an electronic air cleaner, only connectors listed by Underwriters Laboratories should be used.

An electronic air cleaner can be connected electrically to the system blower motor or directly through a disconnect switch to the 120-volt power source. If the unit is connected to the system blower motor, the electronic cell will energize each time the blower operates.

As shown in Figure 12-25, resistors are installed in the circuit to bleed off the electrical charges that the collector plates, acting as capacitors, are capable of storing. As a result, the serviceperson and homeowner are protected against shock. On a unit that does *not* include bleed-off resistors in its circuit, the cell must be grounded out before it is touched.

Maintenance Instructions

The function of the filter in an electronic air cleaner is to eliminate the need for frequent cleaning of the electronic cell. Particles build up on the collecting plates until they reach a size large enough to be affected by the air velocity. When this point is reached, the particles are blown off the plates onto the after filter.

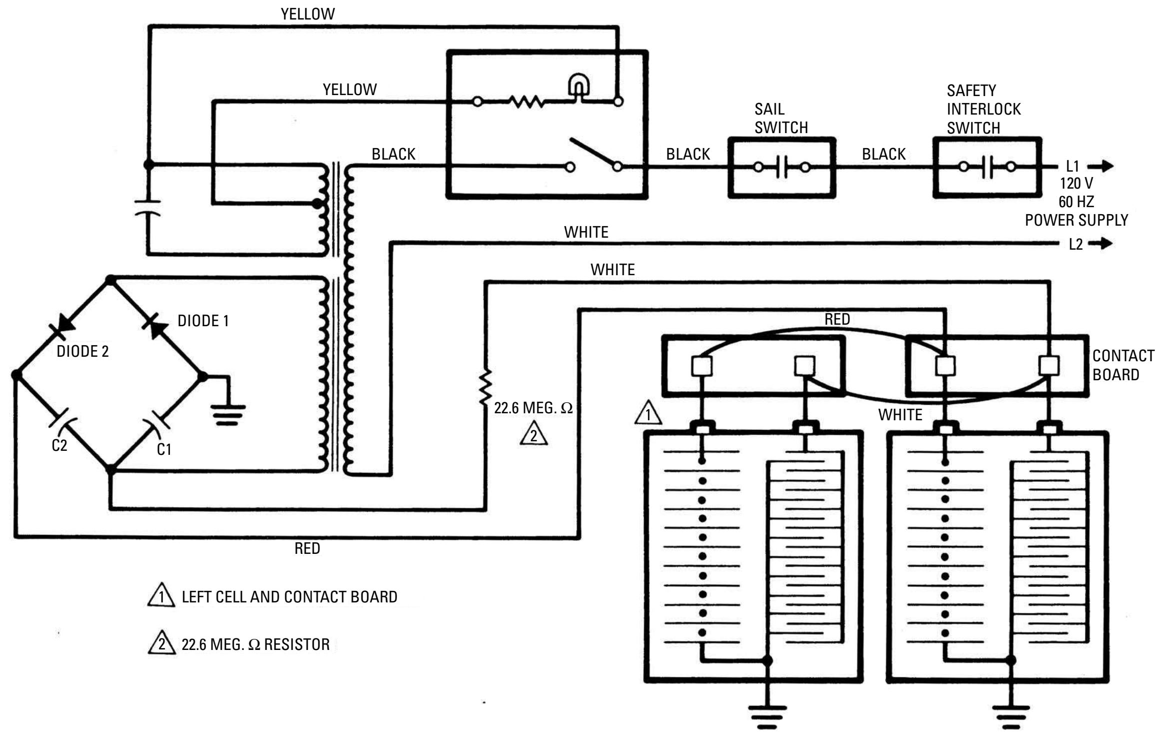


Figure 12-25 Wiring diagram for Trane return grille electronic air cleaner. *(Courtesy Trane Co.)*

The prefilter (lint filter) and the after filter (so named because it follows the collecting plates in the unit) should be cleaned every 4 to 6 weeks. The required frequency of cell washing varies from one installation to the next and will depend largely on the level of air pollution each unit is expected to handle. In any event, the normal period will range from 1 to 6 months. Homes with large families, heavy and frequent cooking and laundering, and several tobacco smokers usually require monthly cleaning of the cell.

An automatic dishwasher can be used to wash an electronic cell without any fear of damaging the cell itself. Place the cells on the lower rack of the dishwasher with the airflow arrows facing up. If the cells are too large for the dishwasher, they will have to be washed by hand.

The procedure for manually cleaning the filters is as follows:

1. Turn off the current to the unit. Wait a few minutes to allow the grids to lose their static charge.
2. Note direction in which airflow arrows are pointing on the cell.
3. Remove the cell and both filters.
4. Soak cell and filters in a tub of water and electric dishwater detergent for about 30 minutes.
5. Rinse both sides of cell and filters with clear, clean water until all traces of dirt and detergent have been removed.
6. Shake excess water from cell and filters.
7. Replace cell and filters in the same order as before.

Caution

Do not turn the power back on if the reinstalled filters are not completely dry. Moisture can short out the grids and damage the power pack. Keep the power switch off and allow air to flow through the grids for 2 or 3 days until any remaining moisture is gone.

This last step is very important. If the cell and filters are not replaced so that the air flows in the direction of the arrow, the unit will not function properly.

Excess arcing or flickering of the red performance light immediately after washing the cell and filters is normal and is caused by water droplets on the surface. If these conditions continue, check to make certain the cell and filters were replaced in the correct order. If there is no problem with the direction of airflow, the unit is shorting (see *Electrical Wiring* and *Troubleshooting Electronic Air Cleaners* in this chapter).

Replacing Tungsten Ionizing Wires

From time to time, the tungsten ionizing wires in the charging section of the electronic cell may break or become damaged. A broken or damaged wire generally causes a short to ground, which may or may not be accompanied by visible arcing or sparking. All parts of these broken or damaged wires should be removed from the unit immediately to prevent further shorting of the circuit. The unit will be able to operate on a *temporary basis* with one wire missing, but a new wire should be installed as soon as possible.

Some electronic air cleaners require the disassembly of the electronic cell in order to replace a broken or damaged ionizing wire. The procedure is as follows:

1. Place the cell on a flat surface and remove the screws from the terminal end of the cell (see Figure 12-26). Pull off the terminal end.
2. Remove the screws from the rear end and then pull off the end and the two sides.
3. Remove the top screen and carefully lift off the ionizer section. Turn the ionizer section upside down as shown in Figure 12-27.
4. Remove all parts of the broken or damaged wire.
5. Compress both tension members and string the new ionizing wire.
6. *Slowly and carefully* release the compression force first on one tension member and then on the other (sudden release may snap the wire).
7. Reassemble the cell.

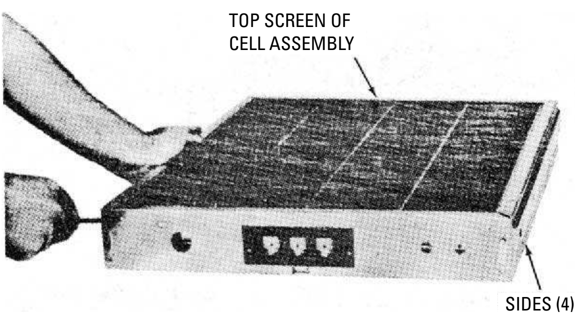


Figure 12-26 Cell placed on a flat surface. *(Courtesy Trane Co.)*

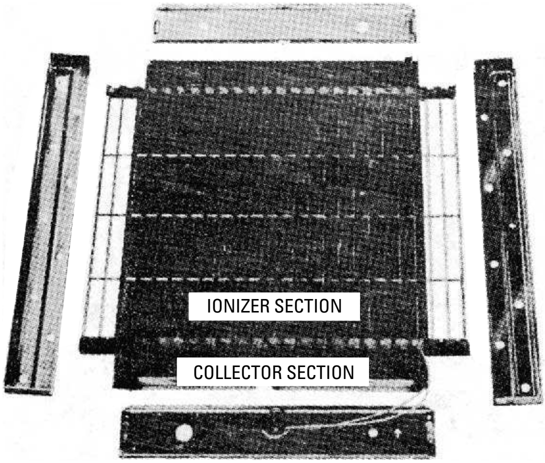


Figure 12-27 Ionizer section turned upside down. *(Courtesy Trane Co.)*

The complete disassembly of the cell in order to replace an ionizing wire is not necessary on all electronic air cleaners. On the return grille electronic air cleaner, shown in Figure 12-15, the replacement wires are cut to length and installed as follows:

1. Remove all parts of the broken or damaged ionizing wire.
2. Hook one eyelet of the ionizing wire over the spring connector at one end of the cell (see Figure 12-28).
3. Hold the opposite eyelet of the ionizing wire with needle-nose pliers and stretch the wire the length of the cell.
4. Depress the opposite spring connector and hook the eyelet over it.

Troubleshooting Electronic Air Cleaners

Most electronic air cleaners are equipped with a performance indicator light, which is usually mounted in the control panel with the other controls. If the *unit* performance indicator light is off and the unit switch is on when the furnace is running, the air cleaner power pack may be burned out or disconnected from its power source, or the pressure switch used to sense airflow and charge the grids is defective. Each of these problems requires opening up the power pack and exposing dangerous high voltages. These repairs should be done only by a qualified electrician or HVAC technician.

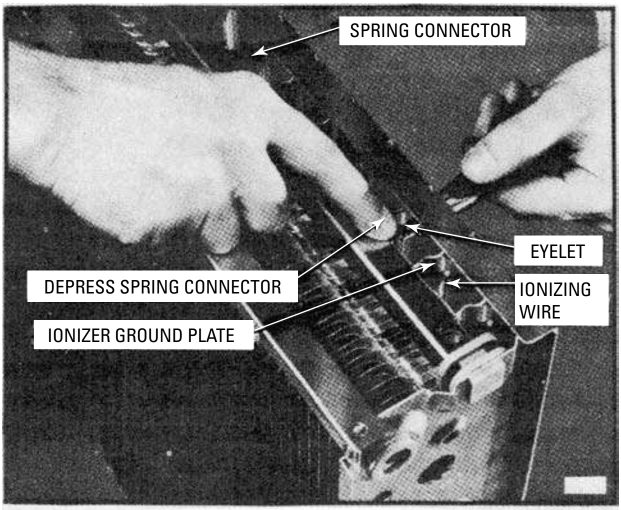


Figure 12-28 Installation of new ionizing wires. *(Courtesy Trane Co.)*

A flickering performance indicator light is not necessarily an indication that the air cleaner is malfunctioning. It is not unusual for the light to flicker when the unit needs cleaning. Another indication that grid cleaning is required is loud snapping sounds caused by electrical shorts when dirt or other debris becomes stuck on the wire grid.

Table 12-1 lists the most common problems associated with operating an electronic air cleaner. For each operating problem, a possible cause and its remedy have been suggested.

Table 12-1 Troubleshooting Electronic Air Cleaners

Symptom and Possible Cause	*Possible Remedy*
Air cleaner will not operate.	
(a) Unit power switch off.	(a) Turn switch on.
(b) System fuse blown.	(b) Check and replace with same-size fuse.
(c) Blower unit or furnace power (disconnect) switch off.	(c) Turn switch on.
(d) Unit rectifier malfunctioning.	(d) Replace rectifier.
(e) Unit transformer malfunctioning.	(e) Replace transformer.

Table 12-1 *(continued)*

Symptom and Possible Cause	*Possible Remedy*
Unit performance indicator light flickers.	
(a) Dirty electronic cells.	(a) Remove and clean cells.
(b) Air flowing through cell in wrong direction.	(b) Rearrange components in proper order (airflow in direction of arrow on cell).
Excess arcing.	
(a) Broken ionizing wires.	(a) Replace wires.
(b) Bent collecting plates.	(b) Repair or replace plates.
(c) Foreign object wedged between plates or ionizers.	(c) Inspect and remove.

Air Washers

Air washers operate by first passing the air through fine sprays of water and then past baffle plates, on the wetted surface of which is deposited whatever dust and dirt were not caught by the sprays.

An air washer functions as a filter, humidifier, and dehumidifier. Using it to regulate the moisture in the air decreases its efficiency as a filter for removing airborne dust and dirt particles.

Air washers are classified as either two-unit or three-unit types. The two-unit air washer consists simply of sprays and eliminators as shown in Figure 12-29. A three-unit air washer includes a filter located between the sprays and eliminators (see Figure 12-30). Excluding the air filter, the basic components of a typical air washer are the following:

1. Cabinet
2. Spray nozzles
3. Eliminators or baffles
4. Sump
5. Pump
6. Blower

The major advantage of using an air washer instead of a conventional air filter or an electronic air cleaner is that it does not become clogged with dust and dirt and is therefore not subject to loss of

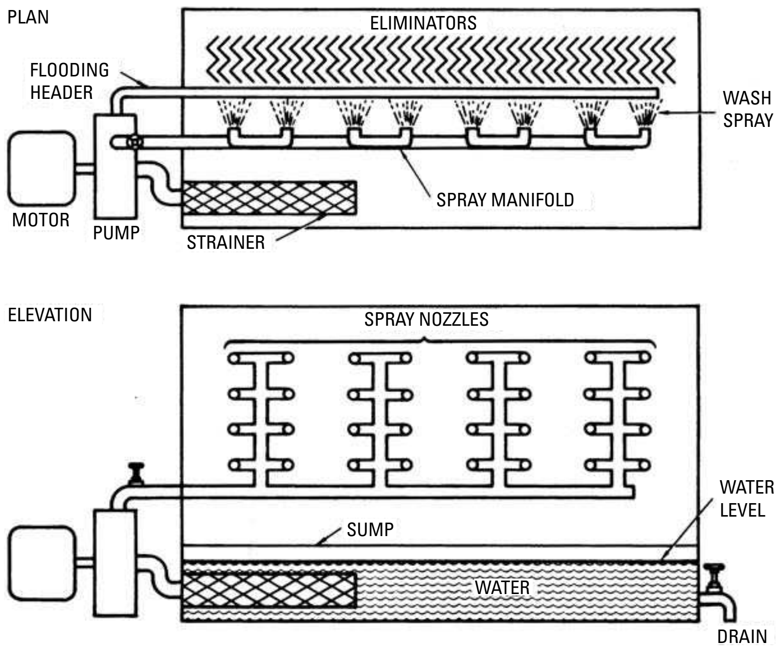


Figure 12-29 Elevation and plan of a two-unit (sprayer and eliminator) washer.

efficiency; however, air washers are no longer used in air-cleaning installations because of the following disadvantages:

1. Equipment bulk.
2. Higher operating expense.
3. Inefficiency in removing fine particles.
4. Tendency to add moisture to the air when the water is not cool.

Air Filters

Conventional air filters are commonly used in forced warm-air furnaces to trap and remove airborne particles and other contaminants from the air (see Figure 12-31). These filters are generally placed in the return air duct at a point just before the air supply enters the furnace or in the outdoor air intake ducts. In air conditioners, filters are properly placed ahead of heating or cooling coils and other air-conditioning equipment in the system to protect them from dust and dirt. Air filters are *not* used in gravity warm-air furnaces because they

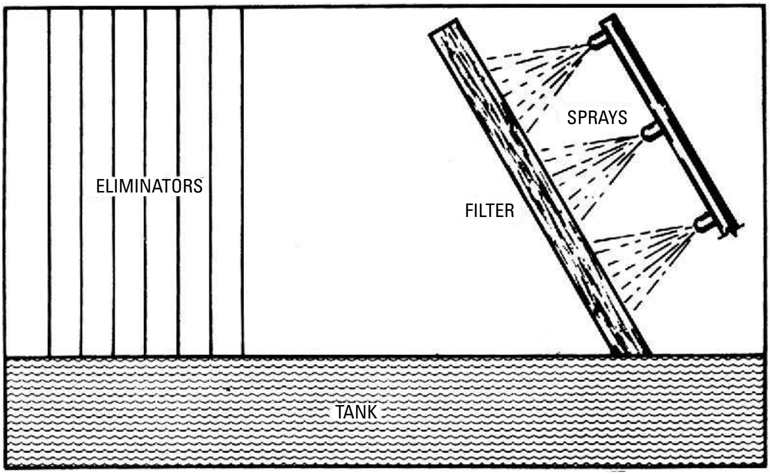


Figure 12-30 Three-unit air washer consisting of sprays, filter, and eliminator plates.

obstruct the flow of air. Conventional air filters will effectively clean the air that is being circulated through the structure, but they will not prevent dirt from leaking into the house. On the average, a conventional air filter installed in the furnace can be expected to remove approximately 10 percent of all airborne particles from the air.

Filters should be inspected *at least* twice a year. Throwaway filters must be replaced with new ones, and washable filters should be

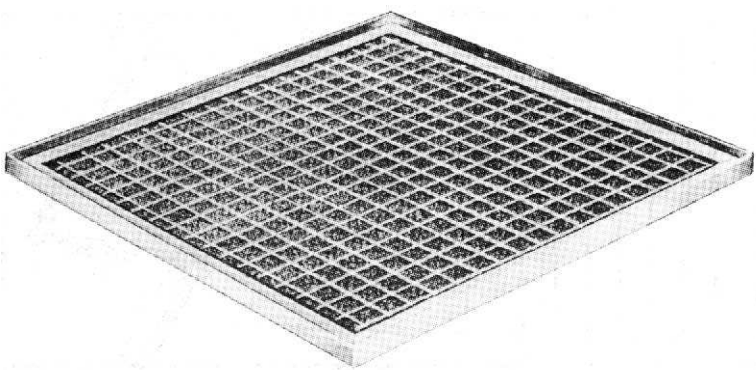


Figure 12-31 Conventional permanent washable air filter.
(Courtesy Dornback Furnace & Foundry Co.)

cleaned when they become loaded with foreign matter. If this action is not taken, the efficiency of the furnace or air conditioner will be greatly reduced. As the dirt builds up on the filter, it increases the resistance of the passage of the air.

In a new house, the first set of filters may become clogged after a short time due to the presence of dust and dirt in the air created by the building operation. Check the filters after the first month of operation.

In an older house in which a winter air-conditioning system has been installed, the dust and dirt that accompanies the dismantling of the old heating system may also clog the first set of filters in a short time. The new filters should also be checked after about a month of furnace operation.

If new rugs or carpets have been installed in the house, considerable lint will be given off at first. Under such conditions, replacement or cleaning of the filters will be necessary.

Dry Air Filters

A *dry air filter* consists of a dry filtering medium such as cloth, porous paper, pads of loosely held cellulose fiber, wool felt, or some similar material held together in a lightweight metal or wire frame.

Both washable and disposable (throwaway) dry air filters are used in forced warm-air furnaces. Disposable filters are constructed of inexpensive materials and are designed to be discarded after one use. The frame is frequently a combination of cardboard and wire. Washable filters usually have metal frames. Various cleaning methods have been recommended, such as air jet, water jet, steam jet, or washing in kerosene and dipping in oil. The latter method may serve both to clean the filter and to add the necessary adhesive.

Viscous Air Filters

A *viscous air filter* (or *viscous-impingement air filter*) contains a filtering material consisting of coarse fibers coated with a sticky substance. This sticky substance catches the dust and dirt as the air passes through the mat. Viscous air filters can be reconditioned by washing them and recoating their surface with fresh liquid.

An oil or grease, sometimes referred to as the *adhesive* or *saturant*, is used as the viscous substance in these filters. The arrangement of the filter mat is such that the airstream is broken up into many small airstreams, and these are caused to abruptly change direction a number of times in order to throw the dust and dirt particles by centrifugal force against the adhesive.

The method used for cleaning a viscous filter will depend on the filter and the dust and dirt particles trapped by it. Most dry dust and dirt particles, as well as lint, can often be removed by rapping the filter frame.

Filter Installation and Maintenance

Access to filters must be provided through a service panel in the furnace. Inspection and replacement of the filter by the user must be made possible without the use of special tools. When a new furnace is installed, care must be taken to provide sufficient clearance to the filter service panel. The furnace manufacturer will usually specify the minimum clearance in the installation instructions. An additional set of filter instructions should be attached to the filter service panel.

Always replace a disposable filter with one having the *same* dimensional size. The filter dimensions are printed on the filter frame. Always replace a filter with one of the same size.

The mat-type filter is commonly used in a gas-fired downflow furnace. It consists of a removable metal cage located in the blower cabinet of the furnace. The metal cage contains the filter material, which is either cut to size and prepackaged or available in rolls for measuring and cutting on-site. When installing a mat-type filter, make sure the side that collects the dust and other airborne contaminants (that is, the oily side) is facing upward into the cold-air duct.

Box-type filters are commonly installed in the top of the blower or in a slot in the cold-air return. Some of these filters have an arrow on the top of the frame. The arrow points to the direction of the airflow and the filter should always be installed with the arrow facing the blower. Most box-type filters have one side that is covered with wire mesh. The wire mesh should face the blower (see Figure 12-31).

Appendix A

Professional and Trade Associations

Many professional and trade associations have been formed to develop and provide research materials, services, and support for those working in the heating, ventilating, and air conditioning trades. The materials, services, and support include:

1. Formulating and establishing specifications and professional standards.
2. Certifying that equipment and materials meet or exceed minimum standards.
3. Certifying that technicians have met education and training standards.
4. Conducting product research.
5. Promoting interest in the product.
6. Providing education and training.
7. Publishing books, newsletters, articles, and technical papers.
8. Conducting seminars and workshops.

A great deal of useful information can be obtained by contacting these associations. With that in mind the names and addresses of the principal organizations have been included in this Appendix. They are listed in alphabetical order.

Air-Conditioning and Refrigeration Wholesalers International (ARWI)

(*See* Heating, Air Conditioning & Refrigeration Distributors International)

Air-Conditioning and Refrigeration Institute (ARI)

4100 North Fairfax Drive, Suite 200

Arlington, Virginia

Phone: (703) 524-8800

Fax: (703) 528-3816

Email: ari@ari.org

Web site: www.ari.org

A national trade association of manufacturers of central air conditioning, warm-air heating, and commercial and industrial refrigeration equipment, ARI publishes ARI standards and guidelines, which can be downloaded free from its web site. ARI is an approved certifying organization for the EPA Technician Certification Exam. ARI also provides a study manual for those taking the EPA Technician Certification Exam. ARI developed the Curriculum Guide in collaboration with HVACR instructors, manufacturing training experts, and other industry professionals for use in all school programs that educate and train students to become competent, entry-level HVACR technicians.

Air Conditioning Contractors of America (ACCA)

2800 Shirlington Road

Suite 300

Arlington, Virginia 22206

Phone: (703) 575-4477

Fax: (703) 575-4449

Email: info@acca.org

Web site: www.acca.org

A national trade association of heating, air conditioning, and refrigeration systems contractors, ACCA (until 1978, the National Environmental Systems Contractors Association) publishes a variety of different manuals useful for those working in the HVAC trades, including residential and commercial equipment load calculations, residential duct system design, and system installation. ACCA also publishes training and certification manuals. The ACCA publications can be purchased by both members and nonmembers. Check the web site for a list of the ACCA publications, because it is very extensive.

Air Diffusion Council (ADC)

1000 E. Woodfield Road

Suite 102

Schaumburg, Illinois 60173

Phone: (847) 706-6750

Fax: (847) 706-6751

Email: info@flexibleduct.org

Web site: www.flexibleduct.org

The Air Diffusion Council (ADC) was formed to promote the interests of the manufacturers of flexible air ducts and related air distribution equipment. The ADC supports the maintenance and development of uniform industry standards for the installation, use, and performance of flexible duct products. It encourages the use of those standards by various code writing groups, government agencies, architects, engineers, and heating and air conditioning contractors.

Air Filter Institute

(*See* Air-Conditioning and Refrigeration Institute)

Air Movement and Control Association International, Inc. (AMCA)

30 West University Drive
Arlington Heights, Illinois 60004
Phone: (847) 394-0150
Fax: (847) 253-0088
Email: amca@amca.org
Web site: www.amca.org

The Air Movement and Control Association International, Inc. (AMCA) is a trade association of the manufacturers, wholesalers, and retailers of air movement and control equipment (fans, louvers, dampers, and related air systems equipment). The AMCA Certified Ratings Programs are an important function of the association. Their purpose is to give the buyer, specification writer, and user of air movement and control equipment assurance that published ratings are reliable and accurate. The AMCA publishes current test standards for fans, louvers, dampers, and shutters. It also issues a variety of AMCA certified rating seals for different types of air movement and control equipment. It publishes a newsletter various technical specifications for members and those who work with air movement and control systems.

American Boiler Manufacturers Association (ABMA)

4001 North 9th Street
Suite 226
Arlington, Virginia 22203
Phone: (703) 522-7350
Fax: (703) 522-2665

Email: randy@abma.com

Web Site: www.abma.com

The American Boiler Manufacturers Association (ABMA) is a national association representing the manufacturers of commercial, industrial, and utility steam generating and fuel burning equipment, as well as suppliers to the industry. The primary goal of ABMA is topromote the common business interests of the boiler manufacturing industry and to promote the safe, environmentally friendly use of the products and services of its members. Publishes technical guides and manuals.

American Gas Association (AGA)

151400 North Capitol Street, N.W.

Washington, DC 20001

Phone: (202) 824-7000

Fax: (202) 824-7115

Email: Fax: krogers@aga.org

Web site: www.aga.org

The AGA develops residential gas operating and performance standards for distributors and transporters of natural, manufactured, and mixed gas.

American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE)

1791 Tullie Circle NE

Atlanta, GA 30329

Phone: (800) 527-4723 (toll free)

Phone: (404) 636-8400

Fax: (404) 321-5478

Email: ashrae@ashrae.org

Web site: www.ashrae.org

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) is an international professional association concerned with the advancement of the science and technology of heating, ventilation, air conditioning, and refrigeration through research, standards writing, continuing education, and publications. Membership in ASHRAE is open to any person associated with heating, ventilation, air conditioning, or refrigeration. There are several different types of membership depending on the individual's background and experience in the different HVAC and refrigeration fields. An important benefit of belonging to ASHRAE is access to numerous technical publications.

American Society of Mechanical Engineers (ASME)

Three Park Avenue

New York, New York 10016

Phone: (800) 843-2763 or (973) 882-1167

Fax: (973) 882-1717

Email: infocentral@asme.org

Web site: www.asme.org

A nonprofit technical and education association, ASME develops safety codes and standards and has an extensive list of technical publications covering pressure vessels, piping, and boilers. ASME offers educational and training services and conducts technology seminars and on-site training programs.

Better Heating-Cooling Council

(*See* Hydronics Institute)

Fireplace Institute

(Merged with Wood Energy Institute in 1980 to form the Wood Heating Alliance. *See* Wood Heating Alliance) Gas Appliance Manufacturers Association (GAMA)

2701 Wilson Boulevard, Suite 600

Arlington, Virginia 22201

Phone: (703) 525-7060

Fax: (703) 525-6790

Email: information@gamanet.org.

Web Site: www.gamanet.org

GAMA is a national trade association of manufacturers of gas-fired appliances, and certain types of oil-fired and electrical appliances, used in residential, commercial, and industrial applications. An important service provided by GAMA to its members is a testing and certification program. GAMA will test the rated efficiency and capacity of a manufacturer's product and, if it passes the testing criteria, certify it. The manufacturer can then market the product with the appropriate certification label. Program participants and their products are listed in the ratings directories.

Heating and Piping Contractors National Association

(*See* Mechanical Contractors Association of America)

Heating, Airconditioning & Refrigeration Distributors International (HARDI)

1389 Dublin Road

Columbus, Ohio 43215

Phone: (888) 253-2128 (toll free)

Phone: (614) 488-1835

Fax: (614) 488-0482

Email: HARDImail@HARDInet.org

Web site: www.hardinet.org

Heating, Airconditioning & Refrigeration Distributors International (HARDI) is national trade association of wholesalers and distributors of air conditioning and refrigeration equipment. It was formed by merging the Northamerican Heating, Refrigeration & Airconditioning Wholesalers (NHRAW) and the Air-conditioning & Refrigeration Wholesalers International (ARWI). Among products and services provided to its members are self-study training materials, statistical studies, as well as training and reference materials. See Appendix B (Education, Training, and Certification) for a description of the HARDI Home Study Institute. The HARDI publications are available to both members and nonmembers.

Home Ventilating Institute (HVI)

30 West University Drive

Arlington Heights, Illinois 60004

Phone: (847) 394-0150

Fax: (847) 253-0088

Email: hvi@hvi.org

Web site: www.hvi.org

The Home Ventilating Institute (HVI) is a nonprofit trade association representing national and international manufacturers of residential ventilation products. HVI is primarily concerned with developing performance standards for residential ventilating equipment. It has created a number of certified ratings programs that provide a fair and credible method of comparing ventilation performance of similar products. HVI publishes a number of interesting and informative articles on ventilation that can be downloaded from its Web site.

The Hydronics Foundation, Inc. (THFI)

The Hydronics Foundation, Inc. (THFI) was chartered in 1997 as a nonprofit organization to disseminate knowledge about hydronic equipment and technology. Manufacturers of HVAC equipment also contribute material from installation manuals, specification sheets, and product reviews.

119 East King Street
P.O. Box 1671
Johnson City, TN 37606
Phone: (800) 929-8548
Fax: (800) 929-9506
Email: jdhowell@jdhowell.com
Web site: www.hydronics.com or www.hydronics.org

Hydronic Heating Association (HHA)

P.O. Box 388
Dedham, MA 02026
Phone: (781) 320-9910
Fax: (781) 320-9906
Email: info@comfortableheat.net
Web site: www.comfortableheat.net

The Hydronic Heating Association is an organization of independent contractors, wholesalers, and manufacturers established to promote the latest hydronic technology, set uniform industrial standards, educate HVAC contractors, and inform the public of the benefits of having a quality hot-water system installed. Their Web site contains useful articles and essays on hydronic equipment and systems. It also offers many useful links to manufacturers of hydronic system products.

The Hydronics Institute Division of GAMA

P.O. Box 218

Berkley Heights, New Jersey 07922

Phone: (908) 464-8200

Fax: (908) 464-7818

Email: information@gamanet.org

Web site: www.gamanet.org

The Hydronics Institute was originally formed by a merger of the Better Heating-Cooling Council and the Institute of Boiler and Radiator Manufacturers. It represents manufacturers, suppliers, and installers of hot-water and steam heating and cooling equipment. It is now a division of the Gas Appliance Manufacturers Association. The Hydronics Institute represents and promotes the interests of the manufacturers of hydronic heating equipment. It also provides training materials for hydronic heating courses in schools and technical publications for technicians in the field.

Institute of Boiler and Radiator Manufacturers

(*See* Hydronics Institute)

Mechanical Contractors Association of America, Inc. (MCAA)

1385 Piccard Drive

Rockville, MD 20850

Phone: 301-869-5800

Fax: 301-990-9690

Web site: www.mcaa.org

The Mechanical Contractors Association of America, Inc. (MCAA) is a national trade association for contractors of piping and related equipment used in heating, cooling, refrigeration, ventilating, and air conditioning.

National Association of Plumbing Heating Cooling Contractors (PHCC)

180 S. Washington Street

P.O. Box 6808

Falls Church, VA 22040

Phone: (800) 533-7694 (toll free) or (703) 237-8100
Fax: (703) 237-7442
Email: naphcc@naphcc.org
Web site: www.phccweb.org

The National Association of Plumbing Heating Cooling Contractors (PHCC) is a trade association of local plumbing, heating, and cooling contractors. There are 12 regional chapters.

National Environmental Systems Contractors Association
(*See* Air Conditioning Contractors of America)

National Warm Air Heating and Air Conditioning Association
(*See* Air Conditioning Contractors of America)

North American Heating Refrigerating Air conditioning Wholesalers (NHRAW)
(*See* Heating, Airconditioning & Refrigeration Distributors International)

Radiant Panel Association (RPA)

P.O. Box 717
1399 South Garfield Avenue
Loveland, CO 80537
Phone: (800) 660-7187 (toll free) or (970) 613-0100
Fax: (970) 613-0098
Email: info@rpa-info.com
Web site: www.radiantpanelassociation.org

The Radiant Panel Association provides downloadable technical papers and notes on a variety of different topics concerning radiant panel heating and cooling systems. Links to several manufacturers of radiant heating equipment are also available at their Web site.

Refrigeration and Air Conditioning Contractors Association
(*See* Air Conditioning Contractors of America)

Refrigeration Service Engineers Society (RSES)

1666 Rand Road

Des Plaines, Illinois 60016

Phone: (800) 297-5660 (toll free) or (847) 297-6464

Email: general@rses.org.

Web site: www.rses.org

The Refrigeration Services Engineers Society (RSES) is an international association of refrigeration, air conditioning, and heating equipment installers, service persons, and sales persons. The Society conducts educational meetings, seminars, workshops, technical qualification and examination programs, instructor-led and self-study training courses. It offers a variety of certification program for technicians.

Sheet Metal and Air Conditioning Contractors National Association (SMACNA)

4201 Lafayette Center Dr.

Chantilly, Virginia 20151

Phone: (703) 803-2980

Fax: (703) 803-3732

Email: info@smacna.org

Web site: www.smacna.org

The SMACNA is an international trade association of union contractors who install ventilating, warm-air heating, and air-handling equipment and systems. SMACNA publishes technical papers, answers technical question, and provides distance learning courses for its members. American National Standards Institute has accredited SMACNA as a standards-setting organization matter.

Steam Heating Equipment Manufacturers Association

(*defunct*)

Steel Boiler Institute

(*defunct*)

Underwriters Laboratories, Inc. (UL)

Northbrook Division

Corporate Headquarters

333 Pfingsten Road

Northbrook, Illinois 60062
Phone: (847) 272-8800
Fax: (847) 272-8129
Email: northbrook@us.ul.com
Web site: www.ul.com

The Underwriters Laboratories is an independent, nonprofit product safety testing and certification organization. It promotes safety standards for equipment through independent testing.

Wood Energy Institute

(Merged with Fireplace Institute in 1980 to form Wood Heating Alliance.)

Other National and International Professional and Trade Associations

The following associations also provide support, services, technical publications, and/or training to its members who are involved in the manufacture, sale, or installation and repair of heating, ventilating, and air conditioning systems and equipment. Because space is limited, only their names are listed. Contact information can be obtained by accessing the Internet and entering the association name or by visiting the reference room of your local library and using the *Encyclopedia of Associations*.

Air Distribution Institute (ADI)

American National Standards Institute (ANSI)

American Society for Testing and Materials (ASTM)

Australian Home Heating Association (AHHA)

Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH)

Heating Alternatives, Inc

Heating, Refrigeration and Air Conditioning Contractors of Canada (HRAC)

Heating, Refrigeration and Air Conditioning Institute of Canada (HRAE)

Institute of Heating & Air Conditioning, Inc (IHACI).

Insulation Contractors of America (ICA)

International Energy Association (IEA)—Solar Heating and Cooling Programme

National LP-Gas Association (NLPGA)
National Oil Fuel Institute
National Oilheat Research Alliance
Plumbing-Heating-Cooling Contractors—National Association (PHCC)
Plumbing-Heating-Cooling Information Bureau (PHCIB)
Wood Heating Alliance (WHA)

Appendix B

Manufacturers

Adams Manufacturing Company
9790 Midwest Avenue
Cleveland, OH 44125
(216) 587-6801
(216) 587-6807 (Fax)
www.gamanet.org

Amana Refrigeration, Inc.
1810 Wilson Parkway
Fayetteville, TN 37334
(800) 843-0304
(931) 433-6101
(931) 433-1312
www.amana.com

American Standard Companies Inc.
One Centennial Ave.
Piscataway, NJ 08855
(732) 980-6000
(732) 980-3340 (Fax)
www.americanstandard.com

A.O. Smith Water Products Company
600 E. John Carpenter Freeway #200
Irving, TX 75062-3990
(972) 719-5900
(972) 719-5960 (Fax)
www.hotwater.com

Bacharach Inc.
621 Hunt Valley
New Kensington, PA 15068
(724) 334-5000

(724) 334-5001 (Fax)
www.bacharach-inc.com

Bard Manufacturing Co
P.O. Box 607
Bryan, OH 43506
(419) 636-1194
(419) 636-2640 (Fax)
www.bardhvac.com

R.W. Beckett Corporation
P.O. Box 1289
Elyria, OH 44036
(800) 645-2876
(440) 327-1060
(440) 327-1064 (Fax)
www. beckett.com

Bell & Gossett
(*See* ITT Bell & Gossett)

Bryan Boilers/Bryan Steam Corporation
P.O. Box 27
783 N. Chili Avenue
Peru, IN 46970
(765) 473-6651
(765) 473-3074 (Fax)
www.bryanboilers.com

Burnham Hydronics
U.S. Boiler Co., Inc.
P.O. Box 3079
Lancaster, PA 17604
(717) 397-4701
(717) 293-5827 (Fax)
www.burnham.com

Carrier Corporation
World Headquarters
One Carrier Place
Farmington, CT 06034
(860) 674-3000
www.carrier.com

Cash Acme
2400 7th Avenue S.W.
Cullman, Alabama 35055
(256) 775-8200
(256) 775-8238 (Fax)
www.cashacme.com

Coleman Corporation
Unitary Products Group
5005 York Dr.
Norman, OK 73069
(405) 364-4040
www.colemanac.com

Columbia Boiler Company
P.O. Box 1070
Pottstown, PA 19464
(610) 323-2700
(610) 323-7292 (Fax)
www.columbiaboiler.com

Danfoss A/S
DK-6430 Nordborg
Denmark
+45 7488 2222
+45 7449 0949 (Fax)
www.danfoss.com

Domestic Pump
(*See* ITT Domestic Pump)

Dornback Furnace
9545 Granger Road
Garfield Heights, OH 44125
(216) 662-1600
(216) 587-6807
www.gamanet.org

Ernst Gage Co.
250 S. Livingston Ave.
Livingston, NJ 07039 4089
973-992-1400
888-229-4243
973-992-0036 (Fax)

General Filters Inc.
43800 Grand River Ave.
Novi, MI
(248) 476-5100
(248) 349-2366 (Fax)
www.generalfilters.com

Goodman Manufacturing Corp
2550 North Loop West #400
Houston, TX 77092
(713) 861-2500
(888) 593-9988
www.goodmanmfg.com

Heat Controller, Inc.
1900 Wellworth Avenue
Jackson, MI 49203
(517) 787-2100
(517) 787-9341
www.heatcontroller.com

Hoffman Specialty
(*See* ITT Hoffman Specialty)

Honeywell, Inc.

101 Columbia Road
Morristown, NJ 07962
(973) 455-2000
(800) 328-5111
(983) 455-4807 (Fax)
www.honeywell.com

Hydro Therm, A Division of Mastek, Inc.

260 North Elm Street
Westfield, MA 01085
(413) 564-5515
www.hydrotherm.com

Invensys Building Systems, Inc.

1354 Clifford Ave.
P.O. Box 2940
Loves Park, IL 61132-2940
(815) 637-3000
(815) 637-5350 (Fax)
www.invensys.com

ITT Bell & Gossett

8200 North Austin Avenue
Morton Grove, IL 60053
(847) 966-3700
(847) 966-9052
www.bellgossett.com

ITT Domestic Pump

8200 N. Austin Ave.
Morton Grove, IL 60053
(847) 966-3700
(847) 966-9052
www.domesticpump.com

ITT Hoffman Specialty

3500 N. Spaulding Avenue
Chicago, IL 60618
(773) 267-1600
(773) 267-0991
www.hoffmanspecialty.com

ITT McDonnell & Miller

3500 N. Spaulding Avenue
Chicago, IL 60618
(723) 267-1600
(773) 267-0991
www.mcdonnellmiller.com

Janitrol Air Conditioning and Heating

www.janitrol.com

(*See* Goodman Manufacturing Company)

S.T. Johnson Company

Innovative Combustion Technologies, Inc.
925 Stanford Avenue
Oakland, CA 94608
(510) 652-6000
(510) 652-4302 (Fax)
www.johnsonburners.com

Johnson Controls, Inc.

5757 North Green Bay Avenue
Milwaukee, WI 53209
(262) 524-3285
www.johnsoncontrols.com
www.jci.com

Lennox Industries Inc.

2100 Lake Park Boulevard
Richardson, TX 75080
(972) 497-5000

(972) 497-5392 (Fax)
www.davelennox.com

Marathon Electric, Inc.
P.O. Box 8003
Wausau, WI 54402
(715) 675-3359
(715) 675-8050 (Fax)

McDonnell & Miller
(*See* ITT McDonnell & Miller)

Midco International Inc.
4140 West Victoria Street
Chicago, IL 60646-6790
(773) 604-8700
(773) 604-4070 (Fax)
www.midco-intl.com

Nordyne
P.O. Box 8809
O'Fallon, MO 63366
(636) 561-7300
(800) 222-4328
(636) 561-7365 (Fax)
www.nordyne.com

Raypak
2151 Eastman Ave.
Oxnard, CA 93030
(805) 278-5300
(805) 278-5468 (Fax)
www.raypak.com

RBI, Mestek Canada, Inc.
1300 Midway Blvd.
Mississauga Ontario L5T 2G8
(905) 670-5888
www.rbimestek.com

Rheem Manufacturing
5600 Old Greenwood Road
Fort Smith, AR 72908
(479) 646-4311
(479) 648-4812 (Fax)
www.rheemac.com

Robertshaw
(See Invensys)

Smith Cast Iron Boilers
260 North Elm Street
Westfield, MA 01085
(413) 562-9631
www.smithboiler.com

SpacePak
125 North Elm Street
Westfield, MA 01085
(413) 564-5530
www.spacepak.com

Spirax Sarco Inc.
Northpoint Business Park
1150 Northpoint Blvd
Blythewood, SC 29016
(803) 714-2000
(803) 714-2222
www.spiraxsarco.com

Sterling Hydronics
260 North Elm Street
Westfield, MA 01085
(413) 564-5535
www.sterlingheat.com

Sterling HVAC
125 North Elm Street
Westfield, MA 01085

(413) 564-5540
www.sterlinghvac.com

Suntec Industries Incorporated
2210 Harrison Ave
P.O. Box 7010
Rockford IL 61125-7010
(815) 226-3700
(815) 226-3848 (Fax)
www.suntecpumps.com

Thermo Pride
P.O. Box 217
North Judson, IN 46366
(574) 896-2133
(574) 896-5301
www.thermopride.com

Trane
P.O. Box 9010
Tyler, TX 75711-9010
(903) 581-3200
www.trane.com

Triangle Tube/Phase III Company, Inc.
Blackwood, NJ
(856) 228-1881
(856) 228-3584 (Fax)
www.triangletube.com

Vulcan Radiator (Mastec)
515 John Fitch Blvd
South Windsor, CT 06074
(413) 568-9571
www.mestec.com

Water Heater Innovations, Inc.
3107 Sibley Memorial Highway
Eagan, MN 55121

(800) 321-6718
www.marathonheaters.com

Watts Regulator Company
815 Chestnut Street
North Andover, MA 01845
(976) 688-1811
(978) 794-848 (Fax)
www.wattsreg.com

Wayne Combustion Systems
801 Glasgow Ave.
Fort Wayne, IN 46803
(800) 443-4625
www.waynecombustion.com

Weil-McLain
500 Blaine St.
Michigan City, IN 46360
(219) 879-6561
(219) 879-4025
www.weil-mclain.com

White-Rodgers, Div. of Emerson Electric Co.
9797 Reavis Rd.
St. Louis, MO 63123
(314) 577-1300
(314) 577-1517
www.white-rodgers.com

Wm. Powell Company
2503 Spring Grove Avenue
Cincinnati, OH 45214
(513) 852-2000
(513) 852-2997 (Fax)
www.powellvalves.com

York International Corporation
P.O. Box 1592-232F
York, PA 17405

(717) 771-7890
(717) 771-7381 (Fax)
www.york.com

Yukon-Eagle Wood & Multifuel Furnaces
10 Industrial Blvd.
P.O. Box 20
Palisade, MN 56469
(800) 358-0060
(800) 440-1994 (Fax)
www.yukon-eagle.com

John Zink Company
Gordon-Piatt Group
11920 East Apache
Tulsa, OK 74116
(800) 638-6940
www.johnzink.com

Appendix C

HVAC/R Education, Training, Certification, and Licensing

A career in the heating, ventilating, air-conditioning, and refrigeration (HVAC/R) trades requires special education and training. Formal education and training in the HVAC/R trades is available in many local public colleges and proprietary schools. Certification requires passing a standardized test indicating a thorough knowledge of the subject matter. The states also require HVAC/R technicians and contractors to take and pass licensing examinations.

HVAC/R Education and Training Programs

HVAC/R education and training programs are offered by four-year colleges, community colleges, proprietary schools, professional and trade associations, and manufacturers of HVAC/R appliances and system components.

One way to find a local school offering courses in HVAC/R education and training is to go online to the Cool Careers Web site at www.coolcareers.org. On their "Schools with HVACR Programs" page, you will find a list of all fifty states. Each state has the names of all the schools in that state offering programs in HVAC/R training. According to Cool Careers, their database contains the names of over 1300 training schools. You will have to contact the schools to enquire about entrance requirements, course content, class schedules, and financial aid.

Note

> If you don't have a computer, or know how to use one, go to the reference section in your local public library and ask the reference librarian to download the information from the internet and provide a printout. They will be willing to do this for you. It's part of the many services offered by the local public library.

Some of these schools offer only courses; others offer both courses and degrees. The least expensive courses are found at community colleges. The level of instruction will vary, depending on the school and the instructors. Your best source of information in this regard is local word of mouth. If you are already working as an entrance level trainee with a local HVAC firm, they should be able to help you find the best school and courses. After all, they often hire the graduates.

Cool Careers-Hot Jobs

The Cool Careers-Hot Jobs web site was created in 2000 by a coalition of organizations representing the heating, air conditioning, refrigeration, and plumbing industry. Its purpose is to provide information about education, training, jobs, and careers in the HVAC/R trades.

HVAC/R Certification

Certification means that the individual has taken and passed a standardized examination that certifies the individual's knowledge level. After the basic certification has been obtained, the technician can then study for and take certification exams at more advanced levels.

The following four organizations provide guidance and/or testing for the certification of HVAC/R technicians. Their addresses, telephone numbers, and web site addresses are listed in Appendix A (Professional and Trade Associations).

1. **Air-Conditioning and Refrigeration Institute (ARI).** ARI is a national trade association whose members represent most of the manufacturers of central air conditioning and refrigeration equipment. ARI administers the Industry Competencies Exam (ICE), which is given primarily to students from vocational school HVAC/R programs. The ARI also provides textbooks and training materials for preparing for both the ICE and EPA certification exams.
2. **North American Technician Excellence, Inc. (NATE).** NATE is a nonprofit organization established in 1997 by members of the HVAC/RE industry to test and certify technicians working in the heating ventilation, air-conditioning, and refrigeration trades. The tests are intended for experienced technicians.
3. **Refrigeration Service Engineers Society (RSES).** The RSES Educational Foundation was established in 1983 as a separate nonprofit organization to develop a comprehensive *voluntary* technician certification program (NTC). The program guides, tests, and certifies members through each of five levels of HVAC/R technician competency ranging from Level I (Technician) to Level V (Mastertech specialist).

4. **Air Conditioning Contractors of America (ACCA).** ACCA works in conjunction with RSES and NATE to provide a national certification program for HVAC/R technicians.

HVAC/R State Licensing

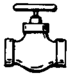
HVAC/R work is regulated at the state level by law. The law requires that a licensing exam must be taken and passed before working in an HVAC/R trade. It is the responsibility of the individual to contact the appropriate state office and obtain the necessary information about the state licensing examination. An easy way to locate the state office charged with licensing HVAC/R technicians and contractors is to ask the reference librarian at your local public library. You could also phone the state government and ask the operator to connect you to the office.

Appendix D

Data Tables

Table D-1 Equivalent Length of New Straight Pipe for Valves and Fittings for Turbulent Flow

Fittings			*Pipe Size* ¼	⅜	½	¾	1	1¼	1½	2	2½	3	4	5	6	8	10	12	14	16	18	20	24
 Regular 90° Ell	Screwed	Steel	2.3	3.1	3.6	4.4	5.2	6.6	7.4	8.5	9.3	11	13	—	—	—	—	—	—	—	—	—	—
		C. I.	—	—	—	—	—	—	—	—	—	9	11	—	—	—	—	—	—	—	—	—	—
	Flanged	Steel	—	—	0.92	1.2	1.6	2.1	2.4	3.1	3.6	4.4	5.9	7.3	8.9	12	14	17	18	21	23	25	30
		C. I.	—	—	—	—	—	—	—	—	—	3.6	4.8	—	7.2	9.8	12	15	17	19	22	24	28
 Long Radius 90° Ell	Screwed	Steel	1.5	2	2.2	2.3	2.7	3.2	3.4	3.6	3.6	4	4.6	—	—	—	—	—	—	—	—	—	—
		C. I.	—	—	—	—	—	—	—	—	—	3.3	3.7	—	—	—	—	—	—	—	—	—	—
	Flanged	Steel	—	—	1.1	1.3	1.6	2	2.3	2.7	2.9	3.4	4.2	5	5.7	7	8	9	9.4	10	11	12	14
		C. I.	—	—	—	—	—	—	—	—	—	2.8	3.4	—	4.7	5.7	6.8	7.8	8.6	9.6	11	11	13
 Regular 45° Ell	Screwed	Steel	0.34	0.52	0.71	0.92	1.3	1.7	2.1	2.7	3.2	4	5.5	—	—	—	—	—	—	—	—	—	—
		C. I.	—	—	—	—	—	—	—	—	—	3.3	4.5	—	—	—	—	—	—	—	—	—	—
	Flanged	Steel	—	—	0.45	0.59	0.81	1.1	1.3	1.7	2	2.6	3.5	4.5	5.6	7.7	9	11	13	15	16	18	22
		C. I.	—	—	—	—	—	—	—	—	—	2.1	2.9	—	4.5	6.3	8.1	9.7	12	13	15	17	20
 Tee-Line Flow	Screwed	Steel	0.79	1.2	1.7	2.4	3.2	4.6	5.6	7.7	9.3	12	17	—	—	—	—	—	—	—	—	—	—
		C. I.	—	—	—	—	—	—	—	—	—	9.9	14	—	—	—	—	—	—	—	—	—	—
	Flanged	Steel	—	—	0.69	0.82	1	1.3	1.5	1.8	1.9	2.2	2.8	3.3	3.8	4.7	5.2	6	6.4	7.2	7.6	8.2	9.6
		C. I.	—	—	—	—	—	—	—	—	—	1.9	2.2	—	3.1	3.9	4.6	5.2	5.9	6.5	7.2	7.7	8.8
 Tee-Branch Flow	Screwed	Steel	2.4	3.5	4.2	5.3	6.6	8.7	9.9	12	13	17	21	—	—	—	—	—	—	—	—	—	—
		C. I.	—	—	—	—	—	—	—	—	—	14	17	—	—	—	—	—	—	—	—	—	—
	Flanged	Steel	—	—	2	2.6	3.3	4.4	5.2	6.6	7.5	9.4	12	15	18	24	30	34	37	43	47	52	62
		C. I.	—	—	—	—	—	—	—	—	—	7.7	10	—	15	20	25	30	35	39	44	49	57

 180° Return Bend	Screwed	Steel	2.3	3.1	3.6	4.4	5.2	6.6	7.4	8.5	9.3	11	13	—	—	—	—	—	—	—	—	—	—
		C. I.	—	—	—	—	—	—	—	—	—	9	11	—	—	—	—	—	—	—	—	—	—
	Reg. Flanged	Steel	—	—	0.92	1.2	1.6	2.1	2.4	3.1	3.6	4.4	5.9	7.3	8.9	12	14	17	18	21	23	25	30
		C. I.	—	—	—	—	—	—	—	—	—	3.6	4.8	—	7.2	9.8	12	15	17	19	22	24	28
	Long Rad. Flanged	Steel	—	—	1.1	1.3	1.6	2	2.3	2.7	2.9	3.4	4.2	5	5.7	7	8	9	9.4	10	11	12	14
		C. I.	—	—	—	—	—	—	—	—	—	2.8	3.4	—	4.7	5.7	6.8	7.8	8.6	9.6	11	11	13
 Globe Valve	Screwed	Steel	21	22	22	24	29	37	42	54	62	79	110	—	—	—	—	—	—	—	—	—	—
		C. I.	—	—	—	—	—	—	—	—	—	65	86	—	—	—	—	—	—	—	—	—	—
	Flanged	Steel	—	—	38	40	45	54	59	70	77	94	120	150	190	260	310	390	—	—	—	—	—
		C. I.	—	—	—	—	—	—	—	—	—	77	99	—	150	210	270	330	—	—	—	—	—
 Gate Valve	Screwed	Steel	0.32	0.45	0.56	0.67	0.84	1.1	1.2	1.5	1.7	1.9	2.5	—	—	—	—	—	—	—	—	—	—
		C. I.	—	—	—	—	—	—	—	—	—	1.6	2	—	—	—	—	—	—	—	—	—	—
	Flanged	Steel	—	—	—	—	—	—	—	2.6	2.7	2.8	2.9	3.1	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
		C. I.	—	—	—	—	—	—	—	—	—	2.3	2.4	—	2.6	2.7	2.8	2.9	3	3	3	3	3
 Angle Valve	Screwed	Steel	12.8	15	15	15	17	18	18	18	18	18	18	—	—	—	—	—	—	—	—	—	—
		C. I.	—	—	—	—	—	—	—	—	—	15	15	—	—	—	—	—	—	—	—	—	—
	Flanged	Steel	—	—	15	15	17	18	18	21	22	28	38	50	63	90	120	140	160	190	210	240	300
		C. I.	—	—	—	—	—	—	—	—	—	23	31	—	52	74	98	120	150	170	200	230	280
 Swing Check Valve	Screwed	Steel	7.2	7.3	8	8.8	11	13	15	19	22	27	38	—	—	—	—	—	—	—	—	—	—
		C. I.	—	—	—	—	—	—	—	—	—	22	31	—	—	—	—	—	—	—	—	—	—
			—	—	3.8	5.3	7.2	10	12	17	21	27	38	50	63	90	120	140	—	—	—	—	—
	Flanged	Steel	—	—	—	—	—	—	—	—	—	22	31	—	52	74	98	120	—	—	—	—	—
		C. I.	0.14	0.18	0.21	0.24	0.29	0.36	0.39	0.45	0.47	0.53	0.65	—	—	—	—	—	—	—	—	—	—

(continued)

Table D-1 *(continued)*

Fittings			¼	⅜	½	¾	1	1¼	1½	2	2½	3	4	5	6	8	10	12	14	16	18	20	24
Coupling or Union	Screwed	Steel																					
		C. I.	—	—	—	—	—	—	—	—	—	0.44	0.62	—	—	—	—	—	—	—	—	—	—
	Bell Mouth Inlet	Steel	0.04	0.07	0.1	0.13	0.18	0.26	0.31	0.43	0.52	0.67	0.95	1.3	1.6	2.3	2.9	3.5	4	4.7	5.3	6.1	7.6
		C. I.	—	—	—	—	—	—	—	—	—	0.55	0.77	—	1.3	1.9	2.4	3	3.6	4.3	5	5.7	7
	Square Mouth Inlet	Steel	0.44	0.68	0.96	1.3	1.8	2.6	3.1	4.3	5.2	6.7	9.5	13	16	23	29	35	40	47	53	61	76
		C. I.	—	—	—	—	—	—	—	—	—	5.5	7.7	—	13	19	24	30	36	43	50	57	70
	Reentrant Pipe	Steel	0.88	1.4	1.9	2.6	3.6	5.1	6.2	8.5	10	13	19	25	32	45	58	70	80	95	110	120	150
		C. I.	—	—	—	—	—	—	—	—	—	11	15	—	26	37	49	61	73	86	100	110	140
	Y-Strainer		—	4.6	5	6.6	7.7	18	20	27	29	34	42	53	61								

V1 V2 Sudden Enlargement

$$h = \frac{(V_1 - V_2)^2}{(2g)} \text{ Feet of Liquid; If } V_2 = 0 \;\; h = \frac{V^2}{(2g)} \text{ Feet of Liquid}$$

Courtesy The Hydraulic Institute (reprinted from the Standards of the Hydraulic Institute, Eleventh Edition, Copyright 1965)

Table D-2 Schedule 80 Pipe Dimensions

	Diameters			Transverse Areas			Length of Pipe Per Square Foot of				
Size in	**External in**	**Internal in**	**Nominal Thickness in**	**External in^2**	**Internal in^2**	**Metal in^2**	**External Surface ft**	**Internal Surface ft**	**Cubic Feet per ft of Pipe**	**Weight per ft Pounds**	**Number Threads per in of Screw**
⅛	0.405	0.215	0.095	0.129	0.036	0.093	9.431	17.75	0.00025	0.314	27
¼	0.54	0.302	0.119	0.229	0.072	0.157	7.073	12.65	0.0005	0.535	18
⅜	0.675	0.423	0.126	0.358	0.141	0.217	5.658	9.03	0.00098	0.738	18
½	0.84	0.546	0.147	0.554	0.234	0.32	4.547	7	0.00163	1	14
¾	1.05	0.742	0.154	0.866	0.433	0.433	3.637	5.15	0.003	1.47	14
1	1.315	0.957	0.179	1.358	0.719	0.639	2.904	3.995	0.005	2.17	11½
1¼	1.66	1.278	0.191	2.164	1.283	0.881	2.301	2.99	0.00891	3	11½
1½	1.9	1.5	0.2	2.835	1.767	1.068	2.01	2.542	0.01227	3.65	11½
2	2.375	1.939	0.218	4.43	2.953	1.477	1.608	1.97	0.02051	5.02	11½
2½	2.875	2.323	0.276	6.492	4.238	2.254	1.328	1.645	0.02943	7.66	8
3	3.5	2.9	0.3	9.621	6.605	3.016	1.091	1.317	0.04587	10.3	8
3½	4	3.364	0.318	12.56	8.888	3.678	0.954	1.135	0.06172	12.5	8
4	4.5	3.826	0.337	15.9	11.497	4.407	0.848	0.995	0.0798	14.9	8
5	5.563	4.813	0.375	24.3	18.194	6.112	0.686	0.792	0.1263	20.8	8
6	6.625	5.761	0.432	34.47	26.067	8.3	0.576	0.673	0.181	28.6	8
8	8.625	7.625	0.5	58.42	46.663	12.76	0.442	0.501	0.3171	43.4	8

(continued)

Table D-2 *(continued)*

	Diameters			Transverse Areas			Length of Pipe Per Square Foot of				
Size in	External in	Internal in	Nominal Thickness in	External in^2	Internal in^2	Metal in^2	External Surface ft	Internal Surface ft	Cubic Feet per ft of Pipe	Weight per ft Pounds	Number Threads per in of Screw
10	10.75	9.564	0.593	90.76	71.84	18.92	0.355	0.4	0.4989	64.4	8
12	12.75	11.376	0.687	127.64	101.64	26	0.299	0.336	0.7058	88.6	
14	14	12.5	0.75	153.94	122.72	31.22	0.272	0.306	0.8522	107	
16	16	14.314	0.843	201.05	160.92	40.13	0.238	0.263	1.112	137	
18	18	16.126	0.937	254.85	204.24	50.61	0.212	0.237	1.418	171	
20	20	17.938	1.031	314.15	252.72	61.43	0.191	0.208	1.755	209	
24	24	21.564	1.218	452.4	365.22	87.18	0.159	0.177	2.536	297	

Courtesy Sarco Company, Inc.

Table D-3 Schedule 40 Pipe Dimensions

	Diameters			*Transverse Areas*			*Length of Pipe Per ft² of*				
Size in	***External in***	***Internal in***	***Nominal Thickness in***	***External in²***	***Internal in²***	***Metal in²***	***External Surface ft***	***Internal Surface ft***	***Cubic Feet per ft of Pipe***	***Weight per ft Pounds***	***Number Threads per in of Screw***
⅛	0.405	0.269	0.068	0.129	0.057	0.072	9.431	14.199	0.00039	0.244	27
¼	0.54	0.364	0.088	0.229	0.104	0.125	7.073	10.493	0.00072	0.424	18
⅜	0.675	0.493	0.091	0.358	0.191	0.167	5.658	7.747	0.00133	0.567	18
½	0.84	0.622	0.109	0.554	0.304	0.25	4.547	6.141	0.00211	0.85	14
¾	1.05	0.824	0.113	0.866	0.533	0.333	3.637	4.635	0.0037	1.13	14
1	1.315	1.049	0.133	1.358	0.864	0.494	2.904	3.641	0.006	1.678	11½
1¼	1.66	1.38	0.14	2.164	1.495	0.669	2.301	2.767	0.01039	2.272	11½
1½	1.9	1.61	0.145	2.835	2.036	0.799	2.01	2.372	0.01414	2.717	11½
2	2.375	2.067	0.154	4.43	3.355	1.075	1.608	1.847	0.0233	3.652	11½
2½	2.875	2.469	0.203	6.492	4.788	1.704	1.328	1.547	0.03325	5.793	8
3	3.5	3.068	0.216	9.621	7.393	2.228	1.091	1.245	0.05134	7.575	8
3½	4	3.548	0.226	12.56	9.886	2.68	0.954	1.076	0.06866	9.109	8
4	4.5	4.026	0.237	15.9	12.73	3.174	0.848	0.948	0.0884	10.79	8
5	5.563	5.047	0.258	24.3	20	4.3	0.686	0.756	0.1389	14.61	8
6	6.625	6.065	0.28	34.47	28.9	5.581	0.576	0.629	0.2006	18.97	8
8	8.625	7.981	0.322	58.42	50.02	8.399	0.442	0.478	0.3552	28.55	8

(continued)

Table D-3 *(continued)*

	Diameters			*Transverse Areas*			*Length of Pipe Per ft² of*				
Size in	***External in***	***Internal in***	***Nominal Thickness in***	***External in²***	***Internal in²***	***Metal in²***	***External Surface ft***	***Internal Surface ft***	***Cubic Feet per ft of Pipe***	***Weight per ft Pounds***	***Number Threads per in of Screw***
10	10.75	10.02	0.365	90.76	78.85	11.9	0.355	0.381	0.5476	40.48	8
12	12.75	11.938	0.406	127.64	111.9	15.74	0.299	0.318	0.7763	53.6	
14	14	13.125	0.437	153.94	135.3	18.64	0.272	0.28	0.9354	63	
16	16	15	0.5	201.05	176.7	24.35	0.238	0.254	1.223	78	
18	18	16.874	0.563	254.85	224	30.85	0.212	0.226	1.555	105	
20	20	18.814	0.593	314.15	278	36.15	0.191	0.203	1.926	123	
24	24	22.626	0.687	452.4	402.1	50.3	0.159	0.169	2.793	171	

Courtesy Sarco Company, Inc.

Table D-4 Properties of Saturated Steam

	Gauge Pressure psig	Temperature °F	Heat in Btu/lb Sensible	Heat in Btu/lb Latent	Heat in Btu/lb Total	Specific Volume ft^3/lb	Gauge Pressure psig	Temperature °F	Heat in Btu/lb Sensible	Heat in Btu/lb Latent	Heat in Btu/lb Total	Specific Volume ft^3 per lb
In Vac.	25	134	102	1017	1119	142	150	366	339	857	1196	2.74
In Vac.	20	162	129	1001	1130	73.9	155	368	341	885	1196	2.68
In Vac.	15	179	147	990	1137	51.3	160	371	344	853	1197	2.6
In Vac.	10	192	160	982	1142	39.4	165	373	346	851	1197	2.54
In Vac.	5	203	171	976	1147	31.8	170	375	348	849	1197	2.47
	0	212	180	970	1150	26.8	175	377	351	847	1198	2.41
	1	215	183	968	1151	25.2	180	380	353	845	1198	2.34
	2	219	187	966	1153	23.5	185	382	355	843	1198	2.29
	3	222	190	964	1154	22.3	190	384	358	841	1199	2.24
	4	224	192	962	1154	21.4	195	386	360	839	1199	2.19
	5	227	195	960	1155	20.1	200	388	362	837	1199	2.14
	6	230	198	959	1157	19.4	205	390	364	836	1200	2.09
	7	232	200	957	1157	18.7	210	392	366	834	1200	2.05
	8	233	201	956	1157	18.4	215	394	368	832	1200	2
	9	237	205	954	1159	17.1	220	396	370	830	1200	1.96
	10	239	207	953	1160	16.5	225	397	372	828	1200	1.92
	12	244	212	949	1161	15.3	230	399	374	827	1201	1.89
	14	248	216	947	1163	14.3	235	401	376	825	1201	1.85

(continued)

Table D-4 *(continued)*

Gauge Pressure psig	Temperature °F	Heat in Btu/lb			Specific Volume ft³/lb	Gauge Pressure psig	Temperature °F	Heat in Btu/lb			Specific Volume ft³ per lb
		Sensible	Latent	Total				Sensible	Latent	Total	
16	252	220	944	1164	13.4	240	403	378	823	1201	1.81
18	256	224	941	1165	12.6	245	404	380	822	1202	1.78
20	**259**	**227**	**939**	**1166**	**11.9**	**250**	**406**	**382**	**820**	**1202**	**1.75**
22	262	230	937	1167	11.3	255	408	383	819	1202	1.72
24	265	233	934	1167	10.8	260	409	385	817	1202	1.69
26	268	236	933	1169	10.3	265	411	387	815	1202	1.66
28	271	239	930	1169	9.85	270	413	389	814	1203	1.63
30	**274**	**243**	**929**	**1172**	**9.46**	**275**	**414**	**391**	**812**	**1203**	**1.6**
32	277	246	927	1173	9.1	280	416	392	811	1203	1.57
34	279	248	925	1173	8.75	285	417	394	809	1203	1.55
36	282	251	923	1174	8.42	290	418	395	808	1203	1.53
38	284	253	922	1175	8.08	295	420	397	806	1203	1.49
40	**286**	**256**	**920**	**1176**	**7.82**	**300**	**421**	**398**	**805**	**1203**	**1.47**
42	289	258	918	1176	7.57	305	423	400	803	1203	1.45
44	291	260	917	1177	7.31	310	425	402	802	1204	1.43
46	293	262	915	1177	7.14	315	426	404	800	1204	1.41
48	295	264	914	1178	6.94	320	427	405	799	1204	1.38
50	**298**	**267**	**912**	**1179**	**6.68**	**325**	**429**	**407**	**797**	**1204**	**1.36**
55	300	271	909	1180	6.27	330	430	408	796	1204	1.34

Table D-4 *(continued)*

Gauge Pressure psig	*Temperature °F*	*Heat in Btu/lb*			*Specific Volume* ft^3/lb	*Gauge Pressure psig*	*Temperature °F*	*Heat in Btu/lb*			*Specific Volume* ft^3 *per lb*
		Sensible	*Latent*	*Total*				*Sensible*	*Latent*	*Total*	
60	307	277	906	1183	5.84	335	432	410	794	1204	1.33
65	312	282	901	1183	5.49	340	433	411	793	1204	1.31
70	316	286	898	1184	5.18	345	434	413	791	1204	1.29
75	**320**	**290**	**895**	**1185**	**4.91**	**350**	**435**	**414**	**790**	**1204**	**1.28**
80	324	294	891	1185	4.67	355	437	416	789	1205	1.26
85	328	298	889	1187	4.44	360	438	417	788	1205	1.24
90	331	302	886	1188	4.24	365	440	419	786	1205	1.22
95	335	305	883	1188	4.05	370	441	420	785	1205	1.2
100	**338**	**309**	**880**	**1189**	**3.89**	**375**	**442**	**421**	**784**	**1205**	**1.19**
105	341	312	878	1190	3.74	380	443	422	783	1205	1.18
110	344	316	875	1191	3.59	385	445	424	781	1205	1.16
115	347	319	873	1192	3.46	390	446	425	780	1205	1.14
120	350	322	871	1193	3.34	395	447	427	778	1205	1.13
125	**353**	**325**	**868**	**1193**	**3.23**	**400**	**448**	**428**	**777**	**1205**	**1.12**
130	356	328	866	1194	3.12	450	460	439	766	1205	1
140	361	333	861	1194	2.92	500	470	453	751	1204	0.89
145	363	336	859	1195	2.84	550	479	464	740	1204	0.82
						600	489	475	728	1203	0.74

Courtesy Sarco Company, Inc.

Table D-5 Friction Loss for Water in Feet per 100 Feet of Schedule 40 Steel Pipe

U.S. gal/min	***Velocity ft/sc***	***hf Friction***	***U.S. gal/min***	***Vel. ft/sec***	***hf Friction***
	3/8" Pipe			***1/2" Pipe***	
1.4	2.25	9.03	2	2.11	5.5
1.6	2.68	11.6	2.5	2.64	8.24
1.8	3.02	14.3	3	3.17	11.5
2	3.36	17.3	3.5	3.7	15.3
2.5	4.2	26	4	4.22	19.7
3	5.04	36.6	5	5.28	29.7
3.5	5.88	49	6	6.34	42
4	6.72	63.2	7	7.39	56
5	8.4	96.1	8	8.45	72.1
6	10.08	136	9	9.5	90.1
7	11.8	182	10	10.56	110.6
8	13.4	236	12	12.7	156
9	15.1	297	14	14.8	211
10	16.8	364	16	16.9	270
	3/4" Pipe			***1" Pipe***	
4	2.41	4.85	6	2.23	3.16
5	3.01	7.27	8	2.97	5.2
6	3.61	10.2	10	3.71	7.9
7	4.21	13.6	12	4.45	11.1
8	4.81	17.3	14	5.2	14.7
9	5.42	21.6	16	5.94	19
10	6.02	26.5	18	6.68	23.7
12	7.22	37.5	20	7.42	28.9
14	8.42	50	22	8.17	34.8
16	9.63	64.8	24	8.91	41
18	10.8	80.9	26	9.65	47.8
20	12	99	28	10.39	55.1
22	13.2	120	30	11.1	62.9
24	14.4	141	35	13	84.4
26	15.6	165	40	14.8	109
28	16.8	189	45	16.7	137
			50	18.6	168

(continued)

Table D-5 (continued)

U.S. gal/min	Velocity ft/sc	hf Friction	U.S. gal/min	Vel. ft/sec	hf Friction
	1¼" Pipe			***1½" Pipe***	
12	2.57	2.85	16	2.52	2.26
14	3	3.77	18	2.84	2.79
16	3.43	4.83	20	3.15	3.38
18	3.86	6	22	3.47	4.05
20	4.29	7.3	24	3.78	4.76
22	4.72	8.72	26	4.1	5.54
24	5.15	10.27	28	4.41	6.34
26	5.58	11.94	30	4.73	7.2
28	6.01	13.7	35	5.51	9.63
30	6.44	15.6	40	6.3	12.41
35	7.51	21.9	45	7.04	15.49
40	8.58	27.1	50	7.88	18.9
45	9.65	33.8	55	8.67	22.7
50	10.7	41.4	60	9.46	26.7
55	11.8	49.7	65	10.24	31.2
60	12.9	58.6	70	11.03	36
65	13.9	68.6	75	11.8	41.2
70	15	79.2	80	12.6	46.6
75	16.1	90.6	85	13.4	52.4
			90	14.2	58.7
			95	15	65
			100	15.8	71.6
	2" Pipe			***2½" Pipe***	
25	2.39	1.48	35	2.35	1.15
30	2.87	2.1	40	2.68	1.47
35	3.35	2.79	45	3.02	1.84
40	3.82	3.57	50	3.35	2.23
45	4.3	4.4	60	4.02	3.13
50	4.78	5.37	70	4.69	4.18
60	5.74	7.58	80	5.36	5.36
70	6.69	10.2	90	6.03	6.69
80	7.65	13.1	100	6.7	8.18
90	8.6	16.3	120	8.04	11.5

(continued)

Table D-5 *(continued)*

U.S. gal/min	***Velocity ft/sc***	***hf Friction***	***U.S. gal/min***	***Vel. ft/sec***	***hf Friction***
	2" Pipe			***2½" Pipe***	
100	4.34	2.72	200	5.04	12.61
120	11.5	28.5	160	10.7	20
140	13.4	38.2	180	12.1	25.2
160	15.3	49.5	200	13.4	30.7
			220	14.7	37.1
			240	16.1	43.8
	3" Pipe			***4" Pipe***	
50	2.17	0.762	100	2.52	0.718
60	2.6	1.06	120	3.02	1.01
70	3.04	1.4	140	3.53	1.35
80	3.47	1.81	160	4.03	1.71
90	3.91	2.26	180	4.54	2.14
100	3.34	2.75	200	5.04	2.61
120	5.21	3.88	220	5.54	3.13
140	6.08	5.19	240	6.05	3.7
160	6.94	6.68	260	6.55	4.3
180	7.81	8.38	280	7.06	4.95
200	8.68	10.2	300	7.56	5.63
220	9.55	12.3	350	8.82	7.54
240	10.4	14.5	400	10.1	9.75
260	11.3	16.9	450	11.4	12.3
280	12.2	19.5	500	12.6	14.4
300	13	22.1	550	13.9	18.1
350	15.2	30	600	15.1	21.4
	5" Pipe			***6" Pipe***	
160	2.57	0.557	220	2.44	0.411
180	2.89	0.698	240	2.66	0.482
200	3.21	0.847	260	2.89	0.56
220	3.53	1.01	300	3.33	0.733
240	3.85	1.19	350	3.89	0.98
260	4.17	1.38	400	4.44	1.25
300	4.81	1.82	450	5	1.56

(continued)

Table D-5 (continued)

U.S. gal/min	*Velocity ft/sc*	*hf Friction*	*U.S. gal/min*	*Vel. ft/sec*	*hf Friction*
350	5.61	2.43	500	5.55	1.91
400	6.41	3.13	600	6.66	2.69
450	7.22	3.92	700	7.77	3.6
500	8.02	4.79	800	8.88	4.64
600	9.62	6.77	900	9.99	5.81
700	11.2	9.13	1000	11.1	7.1
800	12.8	11.8	1100	12.2	8.52
900	14.4	14.8	1200	13.3	10.1
1000	16	18.2	1300	14.4	11.7
			1400	15.5	13.6

Courtesy Sarco Company, Inc.

Table D-6 Flow of Water through Schedule 40 Steel Pipe

Pressure Drop 1000 Feet of Schedule 40 Steel Pipe, in Pounds per Square Inch

Discharge gal/min	Velocity ft/sec	Pressure Drop	Velocity ft/sec	Pressure Drop	Velocity ft/sec	Pressure Drop	Velocity ft/sec	Pressure Drop	Velocity ft/sec	Pressure Drop	Velocity ft/sec	Pressure Drop	Velocity ft/sec	Pressure Drop	Velocity ft/sec	Pressure Drop	Velocity ft/sec	Pressure Drop
	1"																	
1	0.37	0.49	1¼"															
2	0.74	1.7	0.43	0.45	1½"													
3	1.12	3.53	0.64	0.94	0.47	0.44												
4	1.49	5.94	0.86	1.55	0.63	0.74	2"											
5	1.86	9.02	1.07	2.36	0.79	1.12												
6	2.24	12.25	1.28	3.3	0.95	1.53	0.57	0.46										
8	2.98	21.1	1.72	5.52	1.26	2.63	0.76	0.75	2½"									
10	3.72	30.8	2.14	8.34	1.57	3.86	0.96	1.14	0.67	0.48								
15	5.6	64.6	3.21	17.6	2.36	8.13	1.43	2.33	1	0.99	3"							
20	7.44	110.5	4.29	29.1	3.15	13.5	1.91	3.86	1.34	1.64	0.87	0.59	3½"					
25			5.36	43.7	3.94	20.2	2.39	5.81	1.68	2.48	1.08	0.67	0.81	0.42				
30			6.43	62.9	4.72	29.1	2.87	8.04	2.01	3.43	1.3	1.21	0.97	0.6	4"			
35			7.51	82.5	5.51	38.2	3.35	10.95	2.35	4.49	1.52	1.58	1.14	0.79	0.88	0.42		
40					6.3	47.8	3.82	13.7	2.68	5.88	1.74	2.06	1.3	1	1.01	0.53		
45					7.08	60.6	4.3	17.4	3	7.14	1.95	2.51	1.46	1.21	1.13	0.67		
50					7.87	74.7	4.78	20.6	3.35	8.82	2.17	3.1	1.62	1.44	1.26	0.8		
60							5.74	29.6	4.02	12.2	2.6	4.29	1.95	2.07	1.51	1.1	5"	
70							6.69	38.6	4.69	15.3	3.04	5.84	2.27	2.71	1.76	1.5	1.12	0.48

Table D-6 *(continued)*

Pressure Drop 1000 Feet of Schedule 40 Steel Pipe, in Pounds per Square Inch																		
Discharge gal/min	***Velocity ft/sec***	***Pressure Drop***	***Velocity ft/sec***	***Pressure Drop***	***Velocity ft/sec***	***Pressure Drop***	***Velocity ft/sec***	***Pressure Drop***	***Velocity ft/sec***	***Pressure Drop***	***Velocity ft/sec***	***Pressure Drop***	***Velocity ft/sec***	***Pressure Drop***	***Velocity ft/sec***	***Pressure Drop***	***Velocity ft/sec***	***Pressure Drop***
80		6"					7.65	50.3	5.37	21.7	3.48	7.62	2.59	3.53	2.01	1.87	1.28	0.63
90							8.6	63.6	6.04	26.1	3.91	9.22	2.92	4.46	2.26	2.37	1.44	0.8
100	1.11	0.39					9.56	75.1	6.71	32.3	4.34	11.4	3.24	5.27	2.52	2.81	1.6	0.95
125	1.39	0.56							8.38	48.2	5.45	17.1	4.05	7.86	3.15	4.38	2	1.48
150	1.67	0.78							10.06	60.4	6.51	23.3	4.86	11.3	3.78	6.02	2.41	2.04
175	1.94	1.06		8"					11.73	90	7.59	32	5.67	14.7	4.41	8.2	2.81	2.78
200	2.22	1.32									8.68	39.7	6.48	19.2	5.04	10.2	3.21	3.46
225	2.5	1.66	1.44	0.44							9.77	50.2	7.29	23.1	5.67	12.9	3.61	4.37
250	2.78	2.05	1.6	0.55							10.85	61.9	8.1	28.5	6.3	15.9	4.01	5.14
275	3.06	2.36	1.76	0.63							11.94	75	8.91	34.4	6.93	18.3	4.41	6.22
300	3.33	2.8	1.92	0.75							13.02	84.7	9.72	40.9	7.56	21.8	4.81	7.41
325	3.61	3.29	2.08	0.88									10.53	45.5	8.18	25.5	5.21	8.25
350	3.89	3.62	2.24	0.97									11.35	52.7	8.82	29.7	5.61	9.57
375	4.16	4.16	2.4	1.11									12.17	60.7	9.45	32.3	6.01	11
400	4.44	4.72	2.56	1.27									13.78	77.8	10.7	41.5	6.82	14.1
425	4.72	5.34	2.27	1.43									12.97	68.9	10.08	39.7	6.41	12.9
450	5	5.96	2.88	1.6		10"							14.59	87.3	11.33	46.5	7.22	15
475	5.27	6.66	3.04	1.69	1.93	0.3									11.96	51.7	7.62	16.7

(continued)

Table D-6 *(continued)*

Pressure Drop 1000 Feet of Schedule 40 Steel Pipe, in Pounds per Square Inch

Dis-charge gal/min	*Veloc-ity ft/sec*	*Pres-sure Drop*	*Veloc-ity ft/sec*	*Pres-sure Drop*	*Veloc-ity ft/sec*	*Pres-sure Drop*	*Veloc-ity ft/sec*	*Pres-sure Drop*	*Veloc-ity ft/sec*	*Pres-sure Drop*	*Veloc-ity ft/sec*	*Pres-sure Drop*	*Veloc-ity ft/sec*	*Pres-sure Drop*	*Veloc-ity ft/sec*	*Pres-sure Drop*	*Veloc-ity ft/sec*	*Pres-sure Drop*
500	5.55	7.39	3.2	1.87	2.04	0.63									12.59	57.3	8.02	18.5
550	6.11	8.94	3.53	2.26	2.24	0.7									13.84	69.3	8.82	22.4
600	6.66	10.6	3.85	2.7	2.44	0.86	12"								15.1	82.5	9.62	26.7
650	7.21	11.8	4.17	3.16	2.65	1.01											10.42	31.3
700	7.77	13.7	4.49	3.69	2.85	1.18	2.01	0.48									11.22	36.3
750	8.32	15.7	4.81	4.21	3.05	1.35	2.15	0.55									12.02	41.6
800	8.88	17.8	5.13	4.79	3.26	1.54	2.29	0.62	14"								12.82	44.7
850	9.44	20.2	5.45	5.11	3.46	1.74	2.44	0.7	2.02	0.43							13.62	50.5
900	10	22.6	5.77	5.73	3.66	1.94	2.58	0.79	2.14	0.48							14.42	56.6
950	10.55	23.7	6.09	6.38	3.87	2.23	2.72	0.88	2.25	0.53							15.22	63.1
1,000	11.1	26.3	6.41	7.08	4.07	2.4	2.87	0.98	2.38	0.59							16.02	70
1,100	12.22	31.8	7.05	8.56	4.48	2.74	3.16	1.18	2.61	0.68	16"						17.63	84.6
1,200	13.32	37.8	7.69	10.2	4.88	3.27	3.45	1.4	2.85	0.81	2.18	0.4						
1,300	14.43	44.4	8.33	11.3	5.29	3.86	3.73	1.56	3.09	0.95	2.36	0.47						
1,400	15.54	51.5	8.97	13	5.7	4.44	4.02	1.8	3.32	1.1	2.54	0.54						
1,500	16.65	55.5	9.62	15	6.1	5.11	4.3	2.07	3.55	1.19	2.73	0.62						
1,600	17.76	68.1	10.26	17	6.51	5.46	4.59	2.36	3.8	1.35	2.91	0.71	18"					
1,800	19.98	79.8	11.54	21.6	7.32	6.91	5.16	2.98	4.27	1.71	3.27	0.85	2.58	0.48				

Table D-6 *(continued)*

Pressure Drop 1000 Feet of Schedule 40 Steel Pipe, in Pounds per Square Inch																		
Dis-charge gal/min	***Veloc-ity ft/sec***	***Pres-sure Drop***	***Veloc-ity ft/sec***	***Pres-sure Drop***	***Veloc-ity ft/sec***	***Pres-sure Drop***	***Veloc-ity ft/sec***	***Pres-sure Drop***	***Veloc-ity ft/sec***	***Pres-sure Drop***	***Veloc-ity ft/sec***	***Pres-sure Drop***	***Veloc-ity ft/sec***	***Pres-sure Drop***	***Veloc-ity ft/sec***	***Pres-sure Drop***	***Veloc-ity ft/sec***	***Pres-sure Drop***
2,000	22.2	98.5	12.83	25	8.13	8.54	5.73	3.47	4.74	2.11	3.63	1.05	2.88	0.56				
2,500			16.03	39	10.18	12.5	7.17	5.41	5.92	3.09	4.54	1.63	3.59	0.88	20"			
3,000			19.24	52.4	12.21	18	8.6	7.31	7.12	4.45	5.45	2.21	4.31	1.27	3.45	0.73		
3,500			22.43	71.4	14.25	22.9	10.03	9.95	8.32	6.18	6.35	3	5.03	1.52	4.03	0.94	24"	
4,000			25.65	93.3	16.28	29.9	11.48	13	9.49	7.92	7.25	3.92	5.74	2.12	4.61	1.22	3.19	0.51
4,500					18.31	37.8	12.9	15.4	10.67	9.36	8.17	4.97	6.47	2.5	5.19	1.55	3.59	0.6
5,000					20.35	46.7	14.34	18.9	11.84	11.6	9.08	5.72	7.17	3.08	5.76	1.78	3.99	0.74
6,000					24.42	67.2	17.21	27.3	14.32	15.4	10.88	8.24	8.62	4.45	6.92	2.57	4.8	1
7,000					28.5	85.1	20.08	37.2	16.6	21	12.69	12.2	10.04	6.06	8.06	3.5	5.68	1.36
8,000							22.95	45.1	18.98	27.4	14.52	13.6	11.48	7.34	9.23	4.57	6.38	1.78
9,000							25.8	57	21.35	34.7	16.32	17.2	12.92	9.2	10.37	5.36	7.19	2.25
10,000							28.63	70.4	23.75	42.9	18.16	21.2	14.37	11.5	11.53	6.63	7.96	2.78
12,000							34.38	93.6	28.5	61.8	21.8	30.9	17.23	16.5	13.83	9.54	9.57	3.71
14,000									33.2	84	25.42	41.6	20.1	20.7	16.14	12	11.18	5.05
16,000											29.05	54.4	22.96	27.1	18.43	15.7	12.77	6.6

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Table D-7 Warmup Load in Pounds of Steam per 100 Feet of Steam Main (Ambient Temperature 70°F)[a]*

Steam Pressure (psig)	Main Size														0°F Correction Factor†
	2"	2½"	3"	4"	5"	6"	8"	10"	12"	14"	16"	18"	20"	24"	
0	6.2	9.7	12.8	18.2	24.6	31.9	48	68	90	107	140	176	207	208	1.5
5	6.9	11	14.4	20.4	27.7	35.9	48	77	101	120	157	198	233	324	1.44
10	7.5	11.8	15.5	22	29.9	38.8	58	83	109	130	169	213	251	350	1.41
20	8.4	13.4	17.5	24.9	33.8	43.9	66	93	124	146	191	241	284	396	1.37
40	3.9	15.8	20.6	29.3	39.7	51.6	78	110	145	172	225	284	334	465	1.32
60	11	17.5	22.9	32.6	44.2	57.3	86	122	162	192	250	316	372	518	1.29
80	12	19	24.9	35.3	47.9	62.1	93	132	175	208	271	342	403	561	1.27
100	12.8	20.3	26.6	37.8	51.2	66.5	100	142	188	222	290	366	431	600	1.26
125	13.7	21.7	28.4	40.4	54.8	71.1	107	152	200	238	310	391	461	642	1.25
150	14.5	23	30	42.8	58	75.2	113	160	212	251	328	414	487	679	1.24
175	15.3	24.2	31.7	45.1	61.2	79.4	119	169	224	265	347	437	514	716	1.23
200	16	25.3	33.1	47.1	63.8	82.8	125	177	234	277	362	456	537	748	1.22
250	17.2	27.3	35.8	50.8	68.9	89.4	134	191	252	299	390	492	579	807	1.21
300	25	38.3	51.3	74.8	104	142.7	217	322	443	531	682	854	1045	1182	1.2
400	27.8	42.6	57.1	83.2	115.7	158.7	241	358	493	590	759	971	1163	1650	1.18
500	30.2	46.3	62.1	90.5	125.7	172.6	262	389	535	642	825	1033	1263	1793	1.17
600	32.7	50.1	67.1	97.9	136	186.6	284	421	579	694	893	1118	1367	1939	1.16

**Loads based on Schedule 40 pipe for pressures up to and including 250 psig and on Schedule 80 pipe for pressures above 250 psig.*

†For outdoor temperature of 0°F, multiply load value in table for each main size by correction factor corresponding to steam pressure.

Courtesy Sarco Company, Inc.

Table D-8 Condensation Load in Pounds per Hour per 100 Feet of Insulated Steam Main (Ambient Temperature 70°F; Insulation 80% Efficient)[a]*

Steam Pressure (psig)	*Main Size*														*0°F Correction Factor*†
	2"	*2½"*	*3"*	*4"*	*5"*	*6"*	*8"*	*10"*	*12"*	*14"*	*16"*	*18"*	*20"*	*24"*	
10	6	7	9	11	13	16	20	24	29	32	36	39	44	53	1.58
30	8	9	11	14	17	20	26	32	38	42	48	51	57	68	1.5
60	10	12	14	18	24	27	33	41	49	54	62	67	74	89	1.45
100	12	15	18	22	28	33	41	51	61	67	77	83	93	111	1.41
125	13	16	20	24	30	36	45	56	66	73	84	90	101	121	1.39
175	16	19	23	26	33	38	53	66	78	86	98	107	119	142	1.38
250	18	22	27	34	42	50	62	77	92	101	116	126	140	168	1.36
300	20	25	30	37	46	54	68	85	101	111	126	138	154	184	1.35
400	23	28	34	43	53	63	80	99	118	130	148	162	180	216	1.33
500	27	33	39	49	61	73	91	114	135	148	170	185	206	246	1.32
600	30	37	44	55	68	82	103	128	152	167	191	208	232	277	1.31

**Chart loads represent losses due to radiation and convection for saturated steam.*

†For outdoor temperature of 0°F, multiply load value in table for each main size by correction factor corresponding to steam pressure.

Courtesy Sarco Company, Inc.

Table D-9 Flange Standards (All dimensions are in inches)

	125-lb Cast Iron		*ASA B16.1*												
Pipe Size	***½***	***¾***	***1***	***1¼***	***1½***	***2***	***2½***	***3***	***3½***	***4***	***5***	***6***	***8***	***10***	***12***
Diameter of Flange			4¼	4⅝	5	6	7	7½	8½	9	10	11	13½	16	19
Thickness of Flange (min)[1]			7/16	½	9/16	⅝	11/16	¾	13/16	15/16	15/16	1	1⅛	1 3/16	1¼
Diameter of Bolt Circle			3⅛	3½	3⅞	4¾	5½	6	7	7½	8½	9½	11¾	14¼	17
Number of Bolts			4	4	4	4	4	4	8	8	8	8	8	12	12
Diameter of Bolts			½	½	½	⅝	⅝	⅝	⅝	⅝	¾	¾	¾	⅞	⅞

	250-lb Cast Iron		ASA B16.2												
Pipe Size	***1/2***	***3/4***	***1***	***1 1/4***	***1 1/2***	***2***	***2 1/2***	***3***	***3 1/2***	***4***	***5***	***6***	***8***	***10***	***12***
Diameter of Flange			4 7/8	5 1/4	6 1/8	6 1/2	7 1/2	8 1/4	9	10	11	12 1/2	15	17 1/2	20 1/2
Thickness of Flange (min)[2]			11/16	3/4	13/16	7/8	1	1 1/8	1 3/16	1 1/4	1 3/8	1 7/16	1 5/8	1 7/8	2
Diameter of Raised Face			2 11/16	3 1/16	3 9/16	4 3/16	4 15/16	6 5/16	6 5/16	6 15/16	8 5/16	9 11/16	11 15/16	14 1/16	16 7/16
Diameter of Bolt Circle			3 1/2	3 7/8	4 1/2	5	5 7/8	6 5/8	7 1/4	7 7/8	9 1/4	10 5/8	13	15 1/4	17 3/4
Number of Bolts			4	4	4	8	8	8	8	8	8	12	12	16	16
Diameter of Bolts			5/8	5/8	3/4	5/8	3/4	3/4	3/4	3/4	3/4	3/4	7/8	1	1 1/8

(continued)

Table D-9 *(continued)*

	150-lb Bronze		ASA B16.24												
Pipe Size	***½***	***¾***	***1***	***1¼***	***1½***	***2***	***2½***	***3***	***3½***	***4***	***5***	***6***	***8***	***10***	***12***
Diameter of Flange	3½	3⅞	4¼	4⅝	5	6	7	7½	8½	9	10	11	13½	16	19
Thickness of Flange (min)[3]	5⁄16	11⁄32	⅜	13⁄32	7⁄16	½	9⁄16	⅝	11⁄16	11⁄16	¾	13⁄16	15⁄16	1	1 1⁄16
Diameter of Bolt Circle	2⅜	2¾	3⅛	3½	3⅞	4¾	5½	6	7	7½	8½	9½	11¾	14¼	17
Number of Bolts	4	4	4	4	4	4	4	4	8	8	8	8	8	12	12
Diameter of Bolts	½	½	½	½	½	⅝	⅝	⅝	⅝	⅝	¾	¾	¾	⅞	⅞

	300-lb Bronze		ASA B16.24												
Pipe Size	***½***	***¾***	***1***	***1¼***	***1½***	***2***	***2½***	***3***	***3½***	***4***	***5***	***6***	***8***	***10***	***12***
Diameter of Flange	3¾	4⅝	4⅞	5¼	6⅛	6½	7½	8¼	9	10	11	12½	15		
Thickness of Flange (min)[4]	½	17/32	19/32	⅝	11/16	¾	13/16	29/32	31/32	1 1/16	1⅛	1 3/16	1⅜		
Diameter of Bolt Circle	2⅝	3¼	3½	3⅞	4½	5	5⅞	6⅝	7¼	7⅞	9¼	10⅝	13		
Number of Bolts	4	4	4	4	4	8	8	8	8	8	8	12	12		
Diameter of Bolts	½	⅝	⅝	⅝	¾	⅝	¾	¾	¾	¾	¾	¾	⅞		

(continued)

Table D-9 ***(continued)***

	150-lb Steel		***ASA B16.5***												
Pipe Size	***1/2***	***3/4***	***1***	***1 1/4***	***1 1/2***	***2***	***2 1/2***	***3***	***3 1/2***	***4***	***5***	***6***	***8***	***10***	***12***
			4 1/4	4 5/8	5	6	7	7 1/2	8 1/2	9	10	11	13 1/2	16	19
Thickness of Flange (min)[5]			7/16	1/2	9/16	5/8	13/16	3/4	13/16	15/16	15/16	1	1 1/8	1 3/16	1 1/4
Diameter of Raised Face			2	2 1/2	2 7/8	3 5/8	4 1/8	5	5 1/2	6 3/16	7 5/16	8 1/2	10 5/8	12 3/4	15
Diameter of Bolt Circle			3 1/8	3 1/2	3 7/8	4 3/4	5 1/2	6	7	7 1/2	8 1/2	9 1/2	11 3/4	14 1/4	17
Number of Bolts			4	4	4	4	4	4	8	8	8	8	8	12	12
Diameter of Bolts			1/2	1/2	1/2	5/8	5/8	5/8	5/8	5/8	3/4	3/4	3/4	7/8	7/8

Pipe Size	300-lb Steel ½	¾	ASA B16.5 1	1¼	1½	2	2½	3	3½	4	5	6	8	10	12
Diameter of Flange	4⅞	5¼	6⅛	6½	7½	8¼	9	10	11	12½	15	17½	20½		
Thickness of Flange (min)[6]	11/16	¾		13/16	⅞	1	1⅛	1 3/16	1¼	1⅜	1 7/16	1⅝	1⅞	2	
Diameter of Raised Face	2	2½	2⅞	3⅝	4⅛	5	5½	6 3/16	7 5/16	8½	10⅝	12¾	15		
Diameter of Bolt Circle	3½	3⅞	4½	5	5⅞	6⅝	7¼	7⅞	9¼	10⅝	13	15¼	17¾		
Number of Bolts	4	4	4	8	8	8	8	8	8	12	12	16	16		
Diameter of Bolts	⅝	⅝	¾	⅝	¾	¾	¾	¾	¾	¾	⅞	1	1⅛		

(continued)

Table D-9 *(continued)*

	400-lb Steel		ASA B16.5												
Pipe Size	***1/2***	***3/4***	***1***	***1 1/4***	***1 1/2***	***2***	***2 1/2***	***3***	***3 1/2***	***4***	***5***	***6***	***8***	***10***	***12***
Diameter of Flange	3 3/4	4 5/8	4 7/8	5 1/4	6 1/8	6 1/2	7 1/2	8 1/4	9	10	11	12 1/2	15	17 1/2	20 1/2
Thickness of Flange (min)[7]	9/16	5/8	11/16	13/16	7/8	1	1 1/8	1 1/4	1 3/8	1 3/8	1 1/2	1 5/8	7/8	2 1/8	2 1/4
Diameter of Raised	1 3/8	1 11/16	2	2 1/2	2 7/8	3 5/8	4 1/8	5	5 1/2	6 3/16	7 5/16	8 1/2	10 5/8	12 3/4	15
Diameter of Bolt Circle	2 5/8	3 1/4	3 1/2	3 7/8	4 1/2	5	5 7/8	6 5/8	7 1/4	7 7/8	9 1/4	10 5/8	13	15 1/4	17 3/4
Number of Bolts	4	4	4	4	4	8	8	8	8	8	8	12	12	16	16
Diameter of Bolts	1/2	5/8	5/8	5/8	3/4	3/4	7/8	7/8	7/8	7/8	1	1 1/8	1 1/4		

	600-lb Steel		ASA B16.5												
Pipe Size	**½**	**¾**	**1**	**1¼**	**1½**	**2**	**2½**	**3**	**3½**	**4**	**5**	**6**	**8**	**10**	**12**
Diameter of Flange	3¾	4⅝	4⅞	5¼	6⅛	6½	7½	8¼	9	10¾	13	14	16½	10	12
Thickness of Flange (min)[8]	9⁄16	⅝	11⁄16	13⁄16	⅞	1	1⅛	1¼	1⅜	1½	1¾	1⅞	2 3⁄16	2½	2⅝
Diameter of Raised	1⅜	1 11⁄16	2	2½	2⅞	3⅝	4⅛	5	5½	6 3⁄16	7 5⁄16	8½	10⅝	12¾	15
Diameter of Bolt Circle	2⅝	3¼	3½	3⅞	4½	5	5⅞	6⅝	7¼	8½	10½	11½	13¼	17	19½
Number of Bolts	4	4	4	4	4	8	8	8	8	8	8	12	12	16	20
Diameter of Bolts	½	⅝	⅝	⅝	¾	⅝	¾	¾	⅞	⅞	1	1	1⅛	1¼	1¼

[1] 125-lb. flanges have plain faces.
[2] 250-lb. flanges have a 1⁄16" raised face, which is included in the flange thickness dimensions.
[3] 150-lb. bronze flanges have plain faces with two concentric gasket-retaining grooves between the port and the bolt holes.
[4] 300-lb. bronze flanges have plain faces with two concentric gasket-retaining grooves between the port and the bolt holes.
[5] 150-lb. steel flanges have a 1⁄16" raised face, which is included in the flange thickness dimensions.
[6] 300-lb. steel flanges have a 1⁄16" raised face, which is included in the flange thickness dimensions.
[7] 400-lb. steel flanges have a ¼" raised face, which is NOT included in the flange dimensions.
[8] 600-lb. steel flanges have a ¼" raised face, which is NOT included in the flange dimensions.

Table D-10 Pressure Drop in Schedule 40 Pipe

100 PSIG SATURATED STEAM

FOR OTHER PRESSURES USE CORRECTION FACTORS

PSI	0	2	5	10	15	20	30	40	60	75	90	100	110	125	150	175	200	225	250	300	350	400	500	600
FACTOR	6.9	6.0	5.2	4.3	3.6	3.1	2.4	2.0	1.5	1.3	1.1	1.0	0.92	0.83	0.70	0.62	0.55	0.49	0.45	0.38	0.33	0.29	0.23	0.19

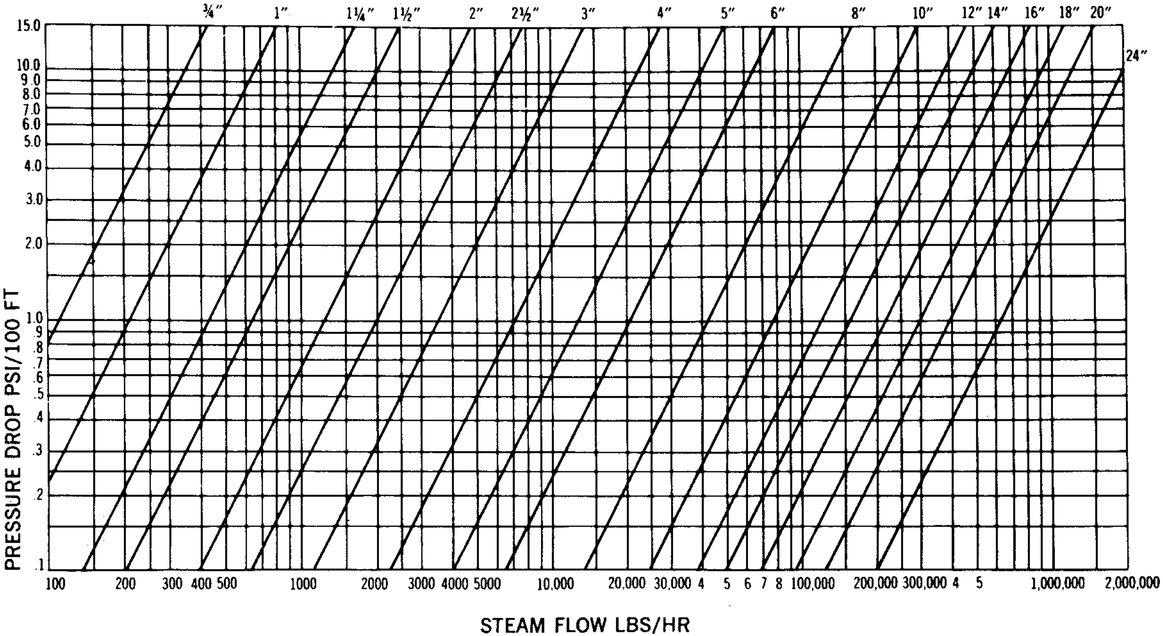

Table D-11 Steam Velocity Chart

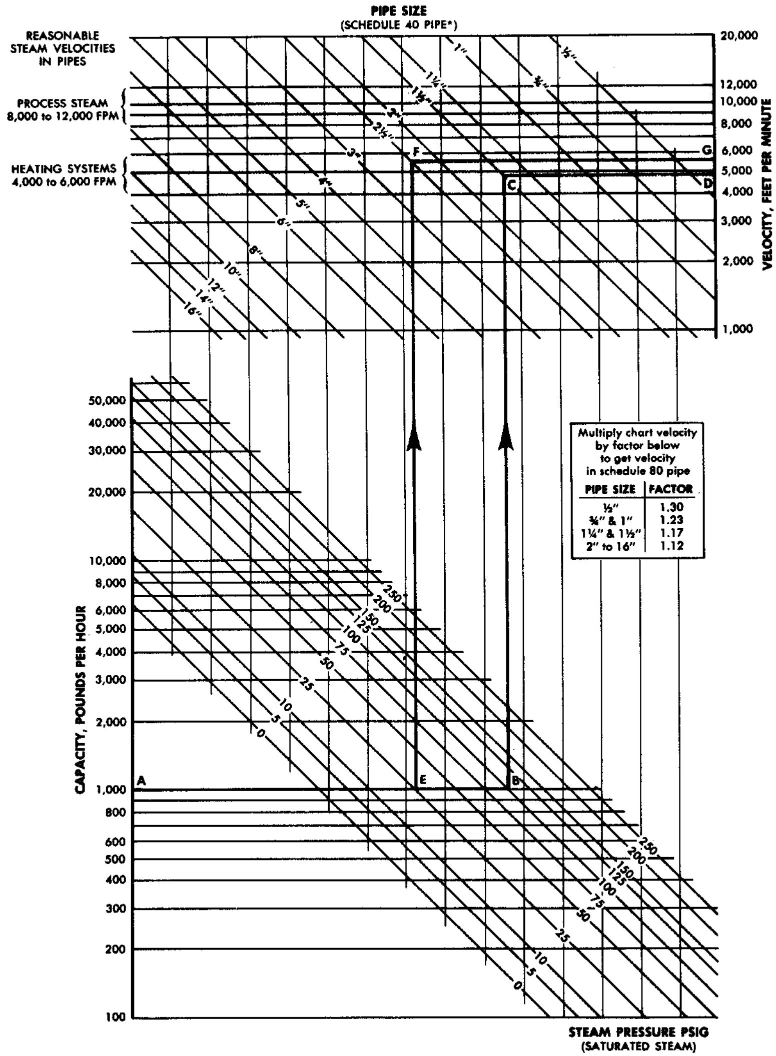

Table D-12 Pressure Drop in Schedule 80 Pipe

100 PSIG SATURATED STEAM

FOR OTHER PRESSURES USE CORRECTION FACTORS

PSI	0	2	5	10	15	20	30	40	60	75	90	100	110	125	150	175	200	225	250	300	350	400	500	600
FACTOR	6.9	6.0	5.2	4.3	3.6	3.1	2.4	2.0	1.5	1.3	1.1	1.0	0.92	0.83	0.70	0.62	0.55	0.49	0.45	0.38	0.33	0.29	0.23	0.19

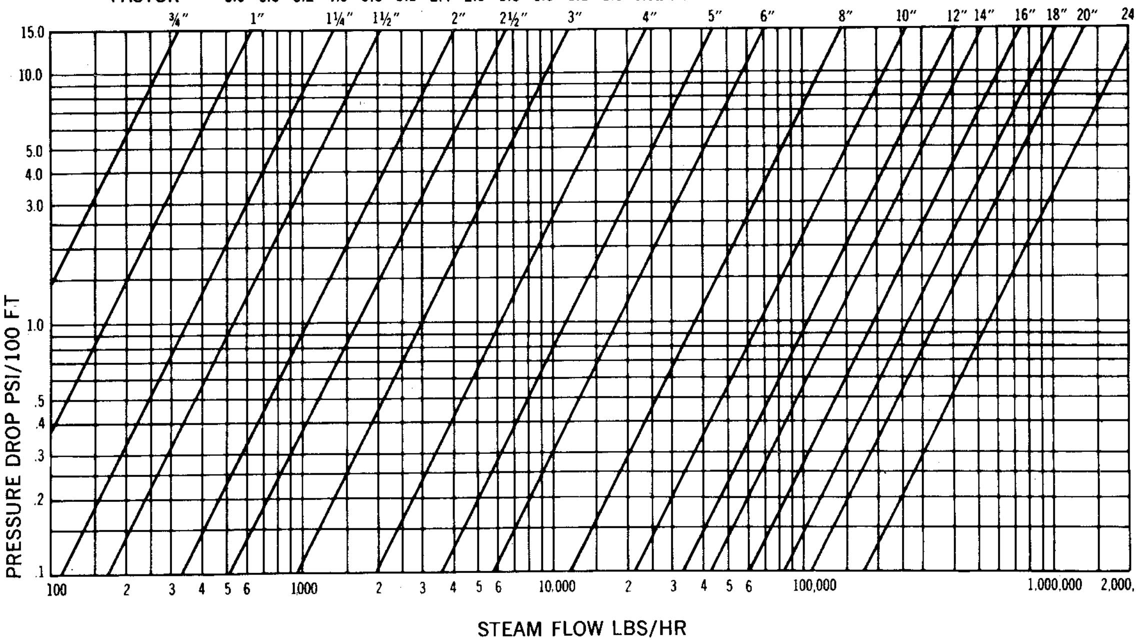

Table D-13 Chimney Connector and Vent Connector Clearance from Combustible Materials

Description of Appliance	***Minimum Clearance, Inches****
Residential Appliances	
Single-Wall, Metal Pipe Connector	
Electric, gas, and oil incinerators	18
Oil and solid-fuel appliances	18
Oil appliances listed as suitable for use with Type L venting system, but only when connected to chimneys	9
Type L Venting-System Piping Connectors	
Electric, gas, and oil incinerators	9
Oil and solid-fuel appliances	9
Oil appliances listed as suitable for use with Type L venting systems	†
Commercial and Industrial Appliances	
Low-Heat Appliances	
Single-Wall, Metal Pipe Connectors	
Gas, oil, and solid-fuel boilers, furnaces, and water heaters	18
Ranges, restaurant type	18
Oil unit heaters	18
Other low-heat industrial appliances	18
Medium-Heat Appliances	
Single-Wall, Metal Pipe Connectors	
All gas, oil, and solid-fuel appliances	36

**These clearances apply except if the listing of an appliance specifies different clearances, in which case the listed clearance takes precedence.*

†If listed Type L venting-system piping is used, the clearance may be in accordance with the venting-system listing.

If listed Type B or Type L venting-system piping is used, the clearance may be in accordance with the venting-system listing.

The clearances from connectors to combustible materials may be reduced if the combustible material is protected in accordance with Table 1C.

Courtesy National Oil Fuel Institute

Table D-14 Standard Clearances for Heat-Producing Appliances in Residential Installations

		Appliance				
Residential-Type Appliances for Installation in Rooms That Are Large[*]		***Above Top of Casing or Appliance***	***From Top and Sides of Warm-Air Bonnet or Plenum***	***From Front***[†]	***From Back***	***From Sides***
Boilers and Water Heaters						
Steam boilers—15 psi; water boilers—250°F; water heaters—200°F; all water walled or jacketed	Automatic oil or combination gas-oil	6	—	24	6	6
Furnaces—Central						
gravity, upflow, downflow, horizontal and duct. warm-air—250°F max.	Automatic oil or combination gas-oil	6[†]	6[c]	24	6	6

Table D-14 *(continued)*

		Appliance				
Residential-Type Appliances for Installation in Rooms That Are Large*		***Above Top of Casing or Appliance***	***From Top and Sides of Warm-Air Bonnet or Plenum***	***From Front†***	***From Back***	***From Sides***
Furnaces—Floor						
For mounting in combustible floors	Automatic oil or combination gas-oil	36	—	12	12	12

**Rooms that are large in comparison to the size of the appliance are those having a volume equal to at least 12 times the total volume of a furnace and at least 16 times the total volume of a boiler. If the actual ceiling height of a room is greater than 8 ft, the volume of a room shall be figured on the basis of a ceiling height of 8 ft.*

†The minimum dimension should be that necessary for servicing the appliance including access for cleaning and normal care, tube removal, etc.

‡For a listed oil, combination gas-oil, gas, or electric furnace, this dimension may be 2 in if the furnace limit control cannot be set higher than 250°F or 1 in if the limit control cannot be set higher than 200°F.

Courtesy National Oil Fuel Institute

Table D-15 Standard Clearances for Heat-Producing Appliances in Commercial and Industrial Installations

Commercial-Industrial Type Low Heat Appliance (Any and All Physical Sizes Expect As Noted)		***Appliance*** ***Above Top of Casing or Appliance****	***From Top and Sides of Warm-Air Bonnet or Plenum***	***From Front***	***From Back****	***From Sides****
Boiler and Water Heaters						
100 ft^3 or less, any psi, steam	All fuels	18	—	48	18	18
50 psi or less, any size	All fuels	18	—	48	18	18
Unit Heaters						
Floor mounted or suspended—	Steam or hot water	1	—	—	1	1
Suspended—100 ft^3 or less	Oil or combination gas-oil	6	—	24	18	18
Suspended —over 100 ft^3	All fuels	18	—	48	18	18
Floor mounted any	All fuels	18	—	48	18	18

**If the appliance is encased in brick, the 18 in clearance above and at sides and rear may be reduced to not less than 12 in*

Courtesy National Oil Fuel Institute

Table D-16 Clearance (in Inches) with Specified Forms of Protection

Input heat units	Efficiency %	Usable Btu/h	gph 100°F rise	Tank size, gal	Available Hot-Water Storage Plus Recovery: 100°F Rise, 15 min	30 min	45 min	60 min	Continuous Draw, gph
Electricity, kW									
1.5	92.5	4,750	5.7*	20	21.4	22.8	24.3	25.7	5.7
2.5	92.5	7,900	9.5*	20	32.4	34.8	37.1	39.5	9.5
4.5	92.5	14,200	17.1*	30	44.3	48.6	52.9	57.1	17.1
4.5	92.5	14,200	17.1*	50	54.3	58.6	62.9	67.1	17.1
6	92.5	19,000	22.8*	66	71.6	77.2	82.8	88.8	22.8
7	92.5	22,100	26.5	80	86.6	93.2	99.8	106.5	26.5
Gas, Btu/h									
34,000	75	25,500	30.6	30	37.7	45.3	53	55.6†	25.6†
42,000	75	31,600	38	30	39.5	49	58.8	61.7†	31.7†
50,000	75	37,400	45	40	51.3	62.6	73.9	77.6†	37.6†
60,000	75	45,000	54	50	63.5	77	90.5	95.0†	45.0†
Oil, gph									
0.5	75	52,500	63	30	45.8	61.6	77.4	82.5†	52.5†
0.75	75	78,700	94.6	30	53.6	77.2	100.8	109.0†	79.0†
0.85	75	89,100	107	30	57.7	83.4	110.1	119.1†	89.0†
1	75	105,000	126	50	81.5	13	144.5	155.0†	105.0†
1.2	75	126,000	151.5	50	87.9	125.8	163.7	176.0†	126.0†
1.35	75	145,000	174	50	93.5	137	180.5	195.0†	145.0†
1.5	75	157,000	188.5	85	132.1	179.2	226.3	242.0†	157.0†
1.65	75	174,000	204.5	85	136.1	187.2	238.4	259.0†	174.0†

Assumes simultaneous operation of upper and lower elements.

†Based on 50 minute-per-hour operation.

Courtesy National Oil Fuel Institute

Appendix E

Psychrometric Charts

The atmosphere around us is made up essentially of dry air and water vapor in various percentages, each with its own characteristics. The water vapor is not dissolved in the air in the sense that it loses its own individuality, but merely serves to moisten the air.

Psychrometry is that branch of physics concerned with the measurement or determination of atmospheric conditions, particularly the moisture content of air. These measurements are obtained with a psychrometer and are graphically represented on a *psychrometric chart*. Insofar as air-conditioning is concerned, psychrometry is specifically concerned with the thermodynamic properties of moist air. The technical application of thermodynamics to air-conditioning is called *psychrometrics*.

The typical *sling psychrometer* consists of a handle and an attached unit containing the wet-bulb and dry-bulb thermometers. The thermometer unit fits inside the handle when not in use. The wet-bulb, dry-bulb, and relative humidity scales are read from the handle. Temperature readings are obtained by twirling the thermometer unit around the handle and then allowing the thermometers time to stabilize.

The readings given on a psychrometric chart are represented by the relative positions of a number of different lines running vertically, horizontally, and diagonally. These lines are simplified for purposes of explanation in Figures E-1, E-2, E-3, and E-4.

In Figure E-1, the horizontal distances on the chart are a measure of sensible heat as obtained from dry-bulb temperatures. The vertical distances are a measure of latent heat as obtained from the dew-point temperatures. The inclined (solid) lines are a measure of the total heat (not including the heat of the liquid) and are constant for a given wet-bulb temperature.

The curved lines indicate the relative humidity between the limiting conditions of dry and saturated air. As shown in Figure E-2, the grains in water vapor per pound of dry air in the mixture can be obtained by proceeding to the left through the dew-point temperature to the scale of grains at the left of the chart.

The cubic feet of mixture per pound of dry air in the mixture can be obtained by proceeding from the intersection of dry-bulb, wet-bulb, and dew-point temperature upward and parallel with the

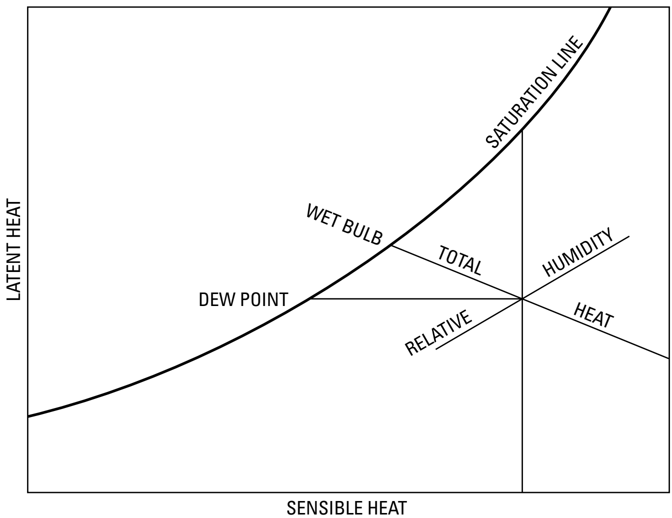

Figure E-1 Horizontal distances as measure of sensible heat; vertical distances of latent heat.

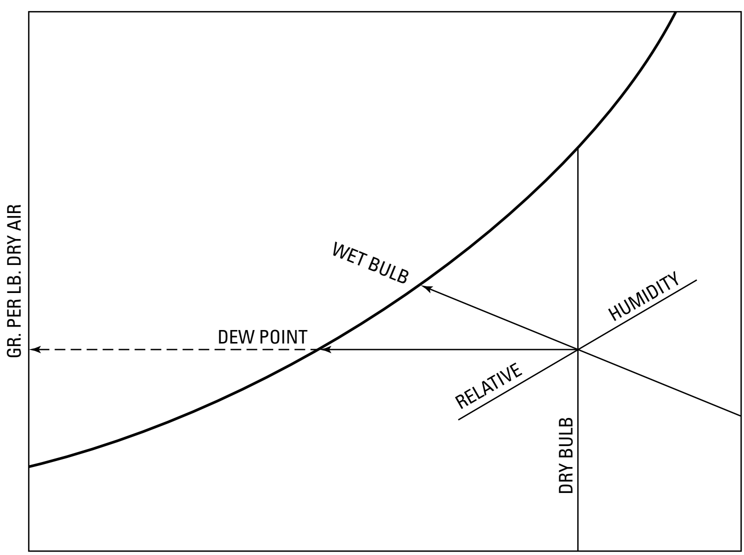

Figure E-2 Curved lines indicate relative humidity.

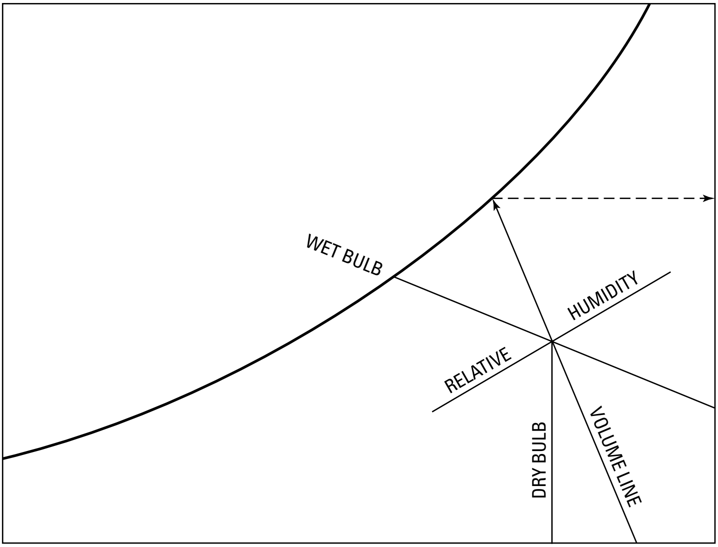

Figure E-3 Obtaining cubic feet of mixture per pound of dry air.

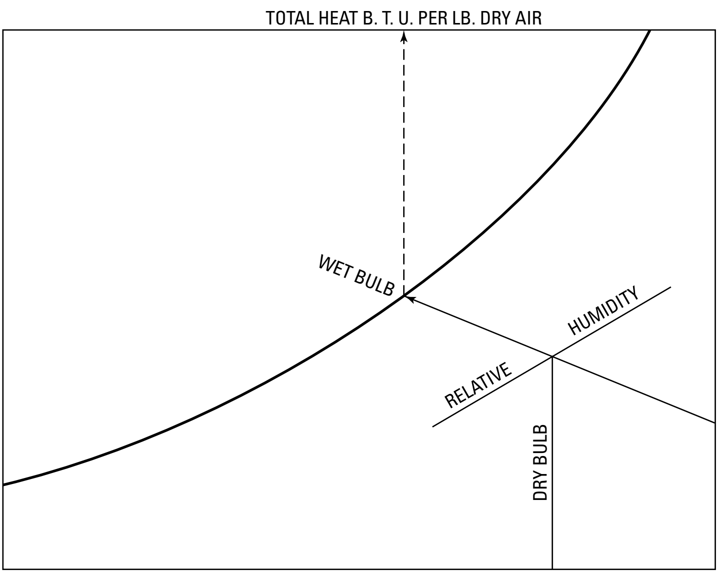

Figure E-4 Obtaining total heat per pound of dry air.

inclined volume lines (shown dotted) to the saturation curve and then directly to the volume scale at the right of the chart (see Figure E-3). The grains of water vapor per cubic feet of mixture is obtained by dividing the reading obtained through Figure E-2 by that obtained through Figure E-3.

The total heat per pound of dry air in the mixture can be obtained by following up along the inclined wet-bulb temperature line to the saturation curve and then vertically upward to the total heat scale at the top of the chart (see Figure E-4).

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