3

HVAC DELIVERY SYSTEMS

COMPLETE HVAC SYSTEMS ARE MADE UP OF SUBsystems that produce heating and cooling, move heat transfer fluids, and control delivery to a space to maintain stable conditions. Heating and cooling are performed by head-end equipment, including refrigeration devices, furnaces, and boilers. Heat transfer fluids are moved by air-handling equipment, ductwork, grilles, and diffusers for air, and by pumps and piping systems for water. Heating and cooling is delivered according to concepts and by equipment described in this chapter.

Delivery methods vary greatly in their ability to maintain space conditions, in the complexity of their operation and maintenance, and in their energy consumption. Selecting appropriate delivery systems is critical to the successful performance of systems.

3.1 CONTROL OF HEATING AND COOLING

Heating and cooling loads vary with time; therefore, the amount of heating or cooling supplied to a space must vary to keep the temperature constant within certain limits. Heating and cooling must be controlled to match the load and vary the flow of energy. Load conditions are measured at a control device, generally a space thermostat.

Spaces with similar load characteristics will require either heating or cooling, but not both at the same time. Thus, HVAC services can be delivered by single packages or systems not capable of simultaneous heating and cooling. Examples include residential combination furnace and air conditioners, and rooftop heating and cooling units for small office buildings.

Large buildings are made up of interior and perimeter spaces. Interior spaces experience heat gains year-round, owing to lights, appliances, and people, and have no exterior exposure from which to lose heat during winter. Accordingly, interior spaces need air conditioning in both summer and winter. By contrast, perimeter spaces have walls and windows exposed to the outside. Hence, they will need heating during cold weather if the interior gains are not sufficient to compensate for heat losses to the outside.

Large buildings can be served by multiple small systems capable of providing either heating or cooling to individual spaces. They can also be served by larger central systems capable of simultaneously delivering heating and cooling as required by individual spaces.

Central systems most often use air-handling units with coils to raise or lower the temperature of air supplied to spaces. The air is delivered by fans, either directly to the space or through a distribution system with ducts. When the air-handling unit serves multiple spaces with different load conditions, there must be means for providing various degrees of heating and/or cooling to individual areas.

Air systems offer several methods of control to vary the amount of heating or cooling supply:

- Varying the temperature of the air supplied while holding the flow constant
- Varying the flow of warm or cold air supplied while holding the temperature constant
- Varying both the temperature and the flow of air supplied, or turning the system on or off.

These functions may be accommodated within the air-handling unit or by control devices located downstream of the unit.

Air systems are sometimes combined with convection and radiation devices for heating. These are generally controlled by turning them on and off, as in the case of electric heat, or by modulating the temperature or flow of the heat source, as in the case of hot-water or steam heat.

3.2 ZONING

In HVAC terminology, a *zone* is an area for which temperature is controlled by a single thermostat. For instance, a house with one furnace controlled by a single thermostat would be termed a *single-zone system.* If a larger house had two furnaces, each controlled by a separate thermostat, the house would have two zones. Zones are not to be confused with rooms. Several rooms, or even an entire building, might be controlled as a single zone. The term *zone* can also apply to areas of humidity control.

Complex buildings require many zones of control to accommodate load variations among their spaces.

Many systems use air-terminal devices to serve individual spaces or groups of spaces. In general, each terminal will correspond to a zone of control. Terminals can be physically located as shown in Figure 3–1.

3.3 CONTROLS AND AUTOMATION

3.3.1 Definition

Controls and automation provide the intelligence of mechanical and electrical systems. Automation is the function of having equipment react, without any intervention by an operator, to satisfy preset conditions. Control occurs when a signal to the equipment causes the movement or adjustment of a component to produce the desired result. Equipment is selected predominantly to provide adequate capacity for the needs of the building under the design conditions, whereas controls and automation make the equipment operate under all anticipated conditions. Once the equipment is selected, the design of the controls and automation system begins in earnest.

3.3.2 Basic Control Systems and Devices

All HVAC systems require some form of controls, either manual or automatic. Automatic controls enable the equipment or the entire system to operate more precisely and reliably for comfort, safety, and energy efficiency. They accomplish their task by controlling one or more of the following properties of the transporting medium, such as air or water, and the related equipment:

- *Temperature*—with sensors set for an operating temperature, a differential, or temperature limits
- *Pressure*—with sensors set for an operating pressure, a differential, or pressure limits
- *Flow rate*—with sensors set for an operating rate, a differential, or flow rate limits
- *Humidity*—with sensors set for an operating level, a differential, or humidity limits
- *Speed*—with sensors to control the equipment so that it is either on or off or has variable or multiple speeds
- *Time*—with a clock or a program to control the duration of operation of the equipment

Basic Control Systems

Control systems may be electric, electronic, pneumatic, direct digital, or a combination of these.

Electric controls use line voltage (120 volts) or low voltage (12 to 24 volts) to perform the basic functions. A low-voltage control system is more sensitive and is therefore preferred.

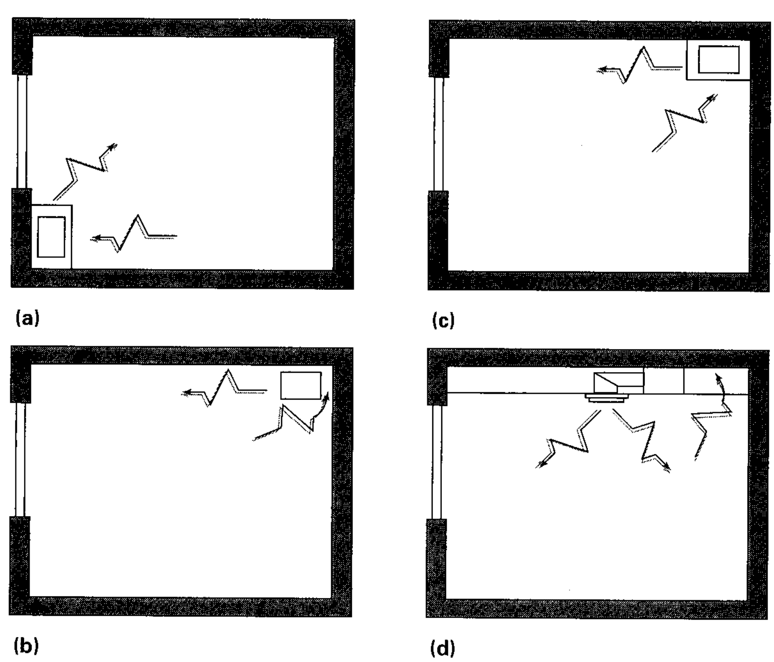


FIGURE 3–1
Typical placement of air terminals. (a) Sill line—applicable to fan-coil units, unit ventilators, induction units, water-source heat pumps, etc. (b) Ceiling-suspended—applicable to all systems. (c) Concealed in soffit—applicable to fan-coil units and water-source heat pumps. (d) Concealed in ceiling—applicable to all systems.

Pneumatic controls use 5- to 30-psi compressed air and receiver controllers with force-balance mechanisms. The receiver controllers constantly adjust output air pressure to actuators in response to input pressure from sensors to produce the desired result. Electronic control uses a similar form of controller, except that the signals are electronic rather than pneumatic. These basic systems require manual calibration and adjustment.

With the rapid development of computer chips and network technology during the 1990s, direct digital control (DDC) systems displaced pneumatic controls and to a lesser extent electric controls. With DDC, as with pneumatic or electric controls, an input signal to a controller results in an output to the appropriate device. The major difference is in the controller: instead of physically adjusting the controller components to result in the same reaction again and again, DDC system controllers contain microprocessors that are programmed to interpret the input signal, process the data in resident programs, and intelligently decide on the appropriate response. Figure 3–2 shows the typical hierarchy of a distributed control system.

Basic Control Devices

Control devices include sensors, controllers, and actuators. Sensors measure the monitored or controlled variable. The signal from the sensors is input to a controller for processing and decision making. The controller determines if a signal should be sent to a monitoring station or to an actuator. The controller also determines if the input or output signal is two-position or proportional, or direct- or reverse-acting. Actuators manipulate the equipment to meet the desired set point of the controlled variable.

Two-position input signals are used to indicate the operating status of the equipment, such as on or off, normal or alarm, open or closed. Two-position output signals are used to start, stop, open, or close the controlled equipment. Proportional signals are used to monitor and control variables that change continuously, such as temperature, pressure, or flow. Proportional signals can provide multiple levels of control and alarm through the use of a single sensor or actuator.

Thermostats are devices that sense and respond to temperature, combining the functions of the sensor and controller. Room (space) thermostats may be designed for heating or cooling alone or for heating and cooling in combination. The simplest combination thermostat normally contains a mode selection switch. If this switch is set on the heating mode, the thermostat allows more or less heating energy to be added to the space until a certain level is reached. If the space temperature is already higher than the thermostat setting, owing to an uncontrollable heat source, such as solar heat gain

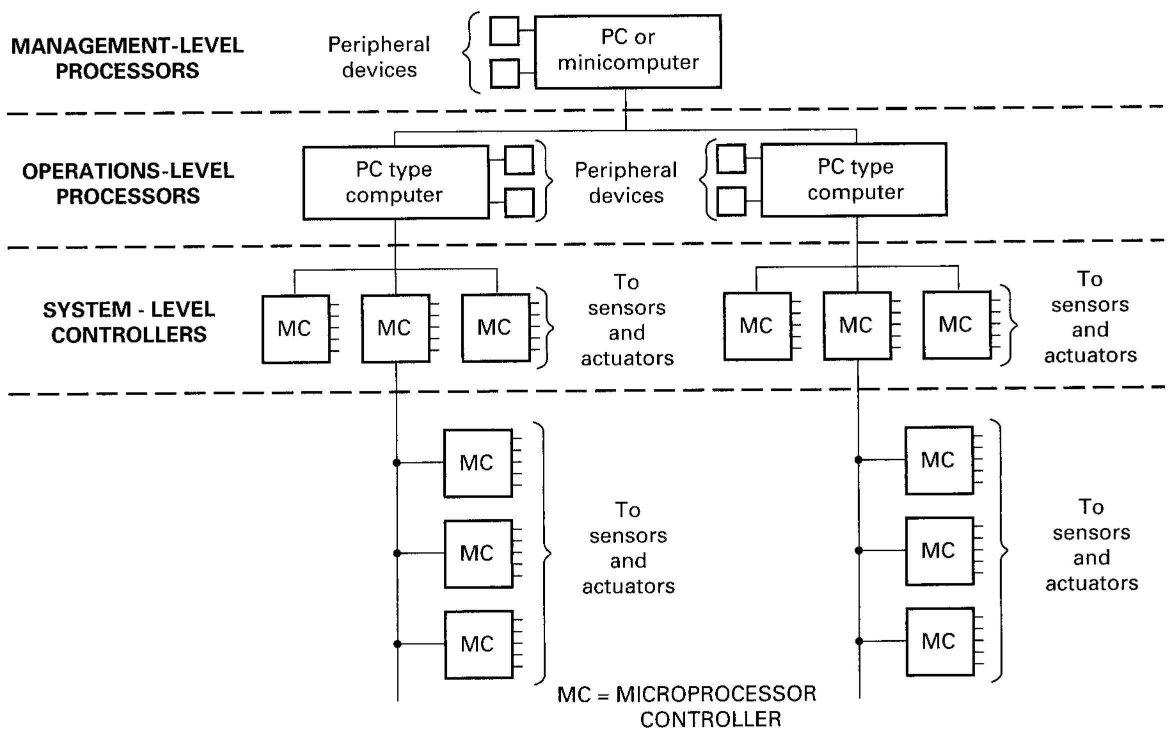


FIGURE 3–2
Configuration of a hierarchical control system.

through the windows, then lowering the thermostat set point will not bring down the space temperature. The reverse will be true when the mode switch is set in the cooling position. These simple facts are often misunderstood by most users or occupants of buildings.

More sophisticated, programmable electronic thermostats can be seasonally switched if they have 365-day programs. This, of course, requires the programmer to anticipate the beginning of the heating and cooling seasons in order to identify when the switch from heating to cooling should occur. A warm winter day or a cold spring or fall day can contribute to occupants' discomfort with such a system. DDC thermostats are capable of being tied into distributed communication networks and can share information, such as what the outdoor temperature is, to "decide" whether the HVAC system should be in heating or cooling mode, without any intervention by an operator.

Some thermostats can automatically change over from heating to cooling or vice versa, however, such changeovers usually require a more sophisticated HVAC system. A simple heating system using a thermostat is shown in Figure 3–3 (a). Adding other control components to a simple heating system can enhance the system control. An example of an expanded heating control arrangement is shown in Figure 3–3 (b).

Humidistats are devices that sense and respond to humidity—either relative or absolute. A space humidity sensor sends the appropriate signal to the controller to determine whether humidity should be added to or removed from the supply air. In order to control the space humidity, the airflow can have humidity added by a humidifier or removed by overcooling the air to remove excess humidity and then reheating the air to meet the requirements of the thermostat. All these functions are performed through controls, without any action by the occupants other than adjusting the set point of the humidistat to the appropriate level for space functions.

Other control sensors include pressure switches and transmitters, which respond to pressure; flow switches and transmitters, which respond to rates of flow; speed switches, which respond to flow, pressure, or a program in order to control the speed of the equipment; and position switches, which respond to signals to open, close, or modulate dampers, valves, etc.

Controllers provide the decision-making function of the control system. Controllers are available for all types of control systems: electric, pneumatic, electronic, and DDC. Output signals from these devices are typically two-position, proportional, direct-acting or reverse-acting. DDC controllers are available as preprogrammed or fully programmable. Various levels of control that are identified in Figure 3–2 are provided at the controller. Zone-level controllers are used to operate terminal units or small unitary equipment. Many control system manufacturers provide dedicated controllers for specific types of zone equipment. Preprogrammed controllers for unitary equipment such as heat pumps or VAV terminal units can be installed very inexpensively. System-level

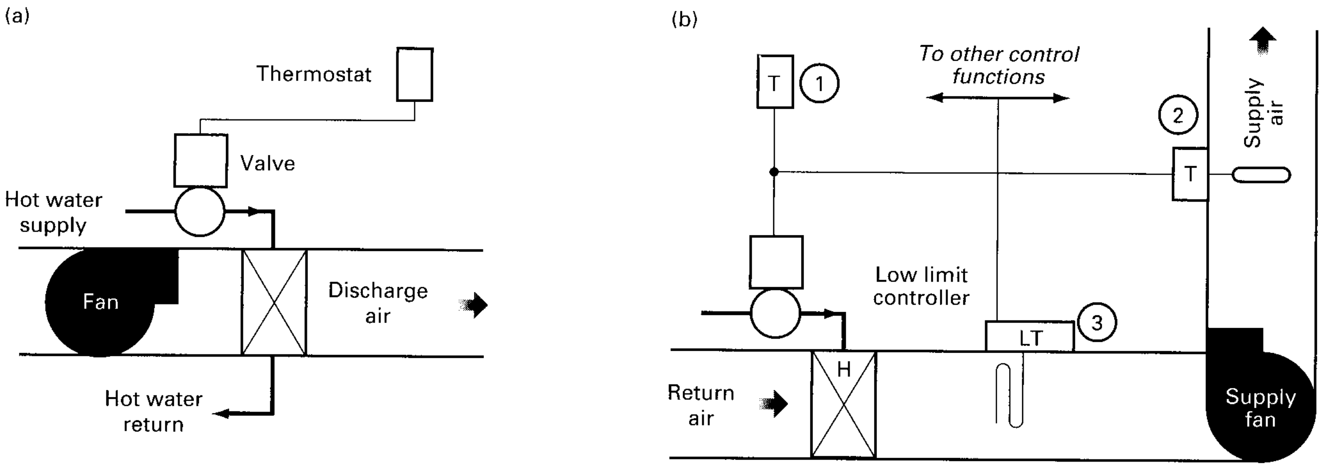


FIGURE 3–3
(a) Air-handling system with a hot-water coil. The thermostat modulates a two-way valve to control the flow of hot water through the coil for heating the discharge air. (Courtesy: Honeywell, Minneapolis, MN.) (b) Schematic of an expanded heating control system. (1) Space thermostat modulates a two-way coil valve to maintain space temperature. (2) Low limit discharge temperature controller overrides the thermostat to prevent the discharge air temperature from falling below a preset minimum temperature. (3) Separate controller may be installed to initiate a sequence of operations: to close a damper, to turn off the fan, to open the valves, etc. (Courtesy: Honeywell, Minneapolis, MN.)

controllers are typically provided without any programming because each installation is unique. These controllers are provided with additional input and output capabilities over the zone controllers. Also, the signals are usually "universal"; this results in a completely flexible system for adding or modifying inputs and outputs.

Actuators provide the physical control of the equipment, typically dampers and valves. Movement of the actuator results in a two-position or proportional response of the controlled equipment. Actuators are provided as normally open or normally closed. Normally open actuators return to the open position if the control signal is off; normally closed actuators return to the closed position.

Control valves are used to control the flow of fluids. The valve can be either direct-acting or reverse-acting. A direct-acting valve allows flow with the stem up; a reverse-acting valve shuts off flow with the stem up. The combination of valve body and actuator (called the valve assembly) determines the valve stem position. Figure 3–4 (left) shows a direct-acting two-way valve; Figure 3–4 (right) shows a reverse-acting two-way valve. A two-way valve is a valve with one inlet and one outlet port; a three-way valve may have either one inlet and two outlets or two inlets and one outlet port.

3.3.3 Energy Management

Automation and controls play a major role in managing a building's energy costs. As a rule, the more segregated the equipment (numerous zones, multiple thermostats, etc.), the less control technology is required to make the systems perform at their most efficient energy level. In order to manage energy usage effectively, the controllers of the energy management system must be able to "speak" to one another. Addition of a local area network for dedicated communication among all controllers is the most common arrangement. Communication by telephone lines is a method more commonly used between buildings or sites. A common head-end computer is the interface for an operator to monitor, control, program, and generate reports.

The most basic option for managing energy is to shut down unnecessary equipment. Scheduling equipment on and off is easy with multiple HVAC systems, and it can be done without disturbing areas served by other systems. Hotels, for instance, can schedule room air conditioners on and off based on occupancy. On the other hand, large central HVAC systems provide needed service to all areas covered by the system. With a more sophisticated automation and control system, zone terminal units can be shut down through the automation and control equipment. With proper programming, similar energy savings can result.

Operating equipment at optimum conditions is another way to save energy with controls. Evaluation of loads and conditions leads to a decision about what to operate at that time. An excellent example is operating multiples of a single type of equipment. The energy management system can determine if it is more economical to operate one at high loading, two at low loading, or some other combination that results in minimum energy consumption.

Energy can also be saved through monitoring demand and shutting down equipment to prevent consumption from exceeding a preset limit. This requires an interface with the main electrical service and individual panels or circuits to achieve the desired results.

Another method of energy management is to record equipment trends. When a mechanical or electrical system begins operating outside its normal range, a typical indicator is increased energy usage. By tracking the energy usage of the equipment, it is possible to identify when operations are outside the normal range, and then to perform the required maintenance.

3.3.4 Human Safety

Although safety is not a required part of automation and controls systems, one must be aware of the potential uses

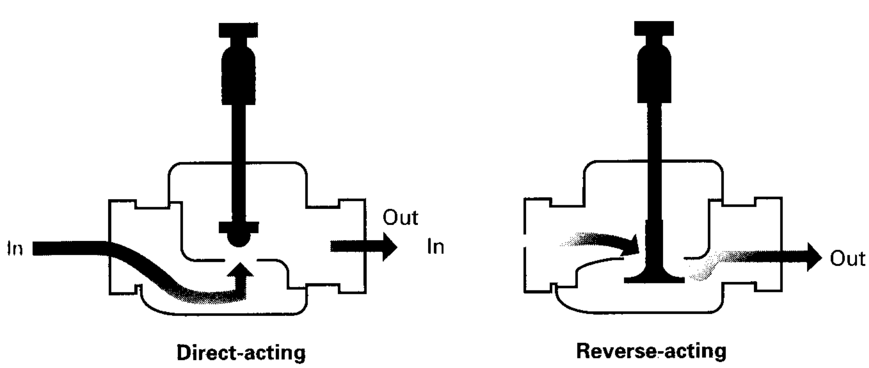


FIGURE 3–4
Two-way valves: the selection of valve body, whether direct-acting or reverse-acting, depends on the combination of valve body and actuator.

of such systems in that regard. The most significant example is providing an interface with the building fire alarm system to activate stair pressurization fans, smoke exhaust fans, and sophisticated air pressure "sandwiches" around fire floors in a high-rise building. Most buildings have fire alarm systems that can be either directly interfaced with the automation and controls or indirectly interfaced through a simple relay cabinet. Most current systems will identify the exact location of the event. On the basis of that information, the automation and controls system can "decide" whether it is necessary to activate any predefined sequences for removing and containing smoke and, if so, which areas will be affected. "Sandwiching" of fire floors requires information on the exact location of the event and floor-to-floor control of the HVAC systems through equipment zoning or zone segregation by dampers. This arrangement creates a negative pressure on the fire floor and a positive pressure on the floors immediately above and below the fire floor. The intent is to allow occupants to evacuate the fire floor and to minimize the opportunity for smoke to migrate to surrounding floors. Other typical interfaces with the fire alarm system include a smoke exhaust fan and a stair pressurization fan. Also, a shutdown of equipment due to smoke or fire can be monitored by both the fire alarm and automation system and the control system. Such monitoring allows HVAC operators to know whether the abnormal off condition is due merely to a mechanical failure or to a potentially life-threatening situation.

3.3.5 Equipment Protection

Equipment protection is typically provided by monitoring specific components for their hours of operation, temperature, and other parameters and then providing the appropriate maintenance response. Additional safety features of the control system include devices in air systems that prevent their operation if damage could occur. Typical examples of these devices are "freezestats" to protect water coils from low temperatures, and smoke detectors or "firestats" to prevent equipment from operating if a fire occurs in the motor.

3.4 COMMONLY USED SYSTEMS FOR ZONE CONTROL

A wide variety of systems are available for building applications. They differ with respect to comfort, cost, energy efficiency, maintainability, and flexibility in terms of altering them.

3.4.1 Constant-Temperature, Variable Volume (On-Off)

A simple residential system will provide hot or cold air. The supply temperature in either the cooling mode or the heating mode is fairly constant. Controls can be set to allow the fan to operate only when heating or cooling is being furnished. As the space temperature falls below or rises above the thermostat set point, the system is activated, and hot or cold air is supplied to the space at a constant rate until the space warms or cools and trips the thermostat. The volume of air supplied to the space will depend on how long the fan is activated. When the proper amount of warm or cold air has been supplied, the system deactivates.

3.4.2 Single-Zone Constant Air Volume

In commercial buildings, fans must generally run continuously to provide ventilation while the building is occupied. This mode of operation is called *constant volume.* Single-zone constant volume is the simplest of systems. Air is supplied to the space at a constant rate. The air-handling unit includes a cooling coil and/or a heating coil that varies the temperature of the air in response to a space thermostat. Heating and cooling may be on-off or proportional. (See Figure 3–5.)

If the space is composed of rooms or areas with different load characteristics, single-zone constant volume will not be a good choice. Good control can be achieved at the location of the thermostat, but the temperature will not be controlled elsewhere. In general, single-zone constant volume is satisfactory only for small simple buildings consisting of spaces with similar load characteristics or for large open spaces; however, single-zone constant-volume systems used in multiples can provide satisfactory control for large or complex buildings.

3.4.3 Single-Zone Reheat

Single-zone reheat is a constant-volume system used for air conditioning when humidity control is especially important. Like the single-zone constant-volume system, the single-zone reheat system is satisfactory only for single spaces with similar load characteristics or for large open spaces. The single-zone reheat system uses a cooling coil to cool and dehumidify air, along with a reheat coil for temperature control. Humidifiers may also be used. (See Figure 3–6.)

A space humidistat may be used to adjust the air temperature to condense enough moisture so that the supply air is sufficiently dry for maintaining proper

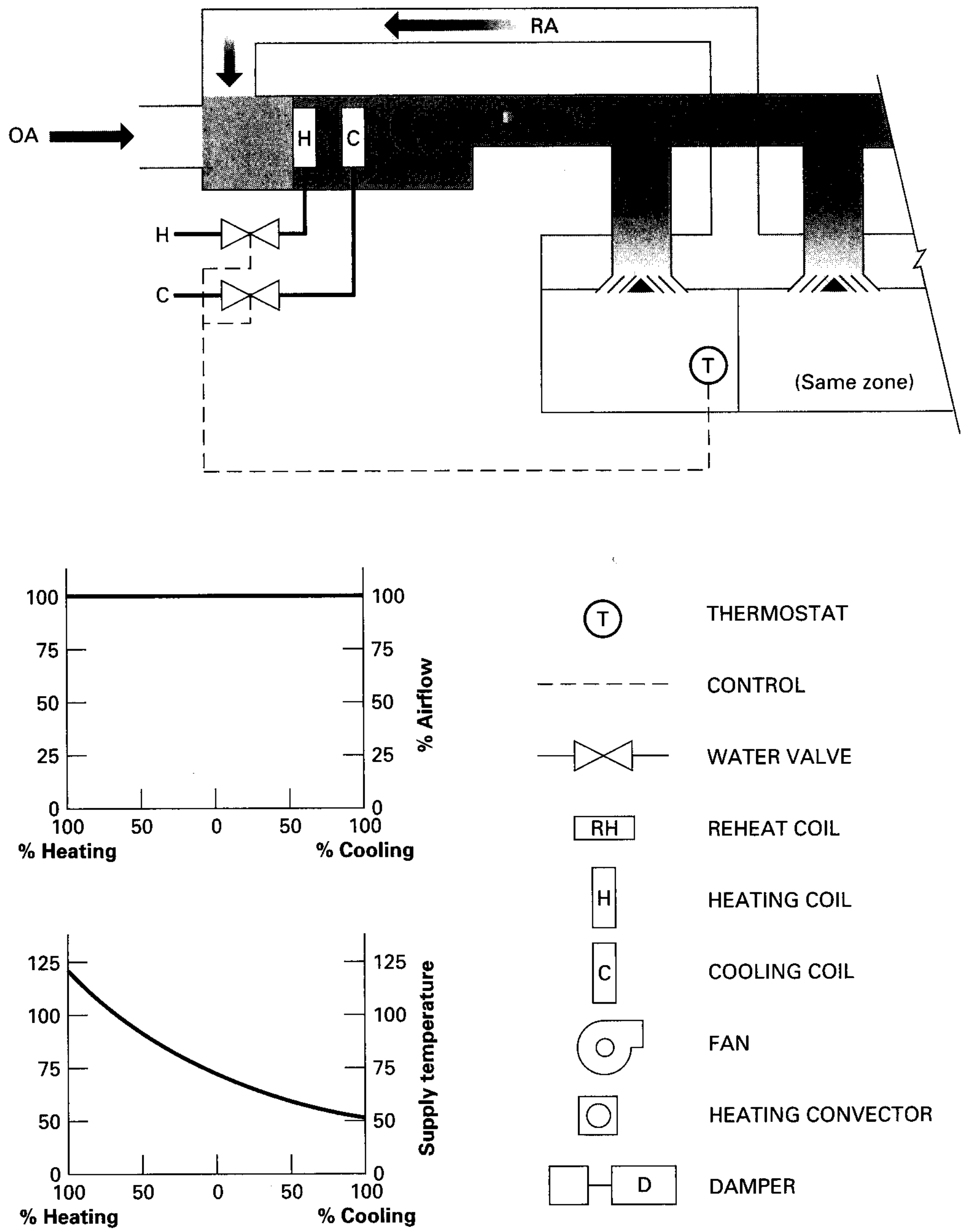


FIGURE 3-5
Single-zone constant air volume system.

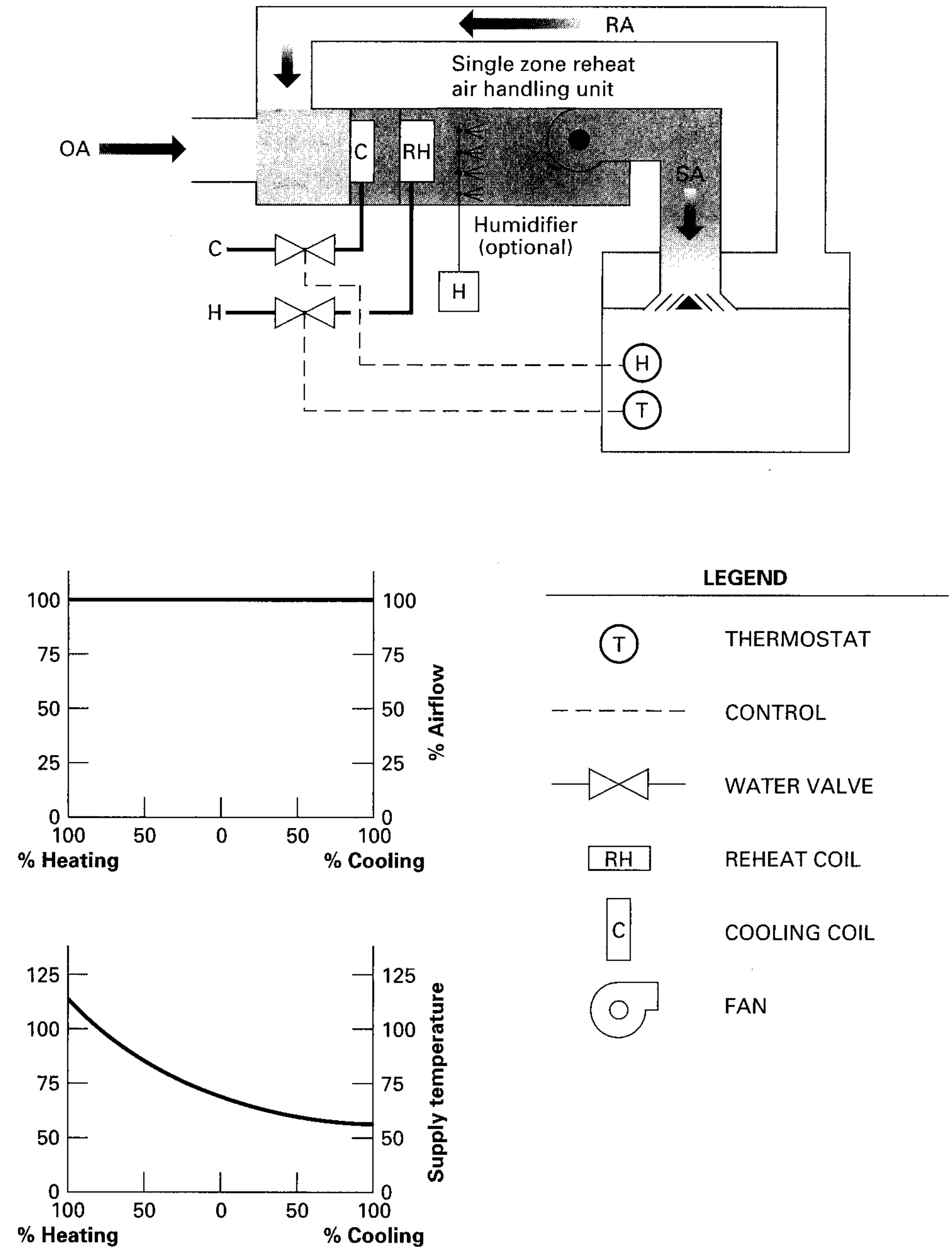
humidity levels in the space. Since the cooling coil is controlled in order to maintain the humidity level, the air temperature will generally be too cold to maintain a proper space temperature. Therefore, a heating coil is placed downstream of the cooling coil to reheat the air. The heating coil is controlled by the space thermostat.

Single-zone reheat systems are characterized by high energy usage. Air may be overcooled to maintain humidity and reheated to compensate for the overcooling. These systems are used only for special applications, such as hospital operating rooms and computer rooms.

3.4.4 Constant-Volume Terminal-Reheat, Multiple Zones

Constant-volume terminal-reheat systems (Figure 3–7) are similar in principle to single-zone reheat systems, except that multiple zones of temperature control can

■ **FIGURE 3-6**
Single-zone constant-volume reheat system.



be achieved. The air-handling unit contains a cooling coil that chills all the air supplied to the various zones. One or more main trunk ducts are used to distribute air throughout the area served, and a terminal box containing a reheat coil is installed for each zone. The cooling coil chills air to the same temperature for all zones. The reheat coils respond to their respective thermostats to maintain temperature control in each zone.

Terminal-reheat systems are capable of serving multiple zones from a single air-handling unit. Reheat terminals, often called *boxes*, are modular devices that are available in sizes from approximately 50 cfm to 3000 cfm. Other types of terminals are available in similar sizes. These sizes are adequate for spaces ranging from individual small offices to large open areas up to approximately 5000 sq ft. A typical reheat box with hot-water and electric coils is shown in Figure 3–8. Reheat coils are normally installed above the ceiling. Hot-water coils require piping and accessories, which may leak.

Constant-volume terminal-reheat systems are flexible enough that one may add or rearrange reheat boxes on their main trunk as space is reconfigured. Excellent humidity control is another characteristic. These advantages led terminal-reheat systems to be

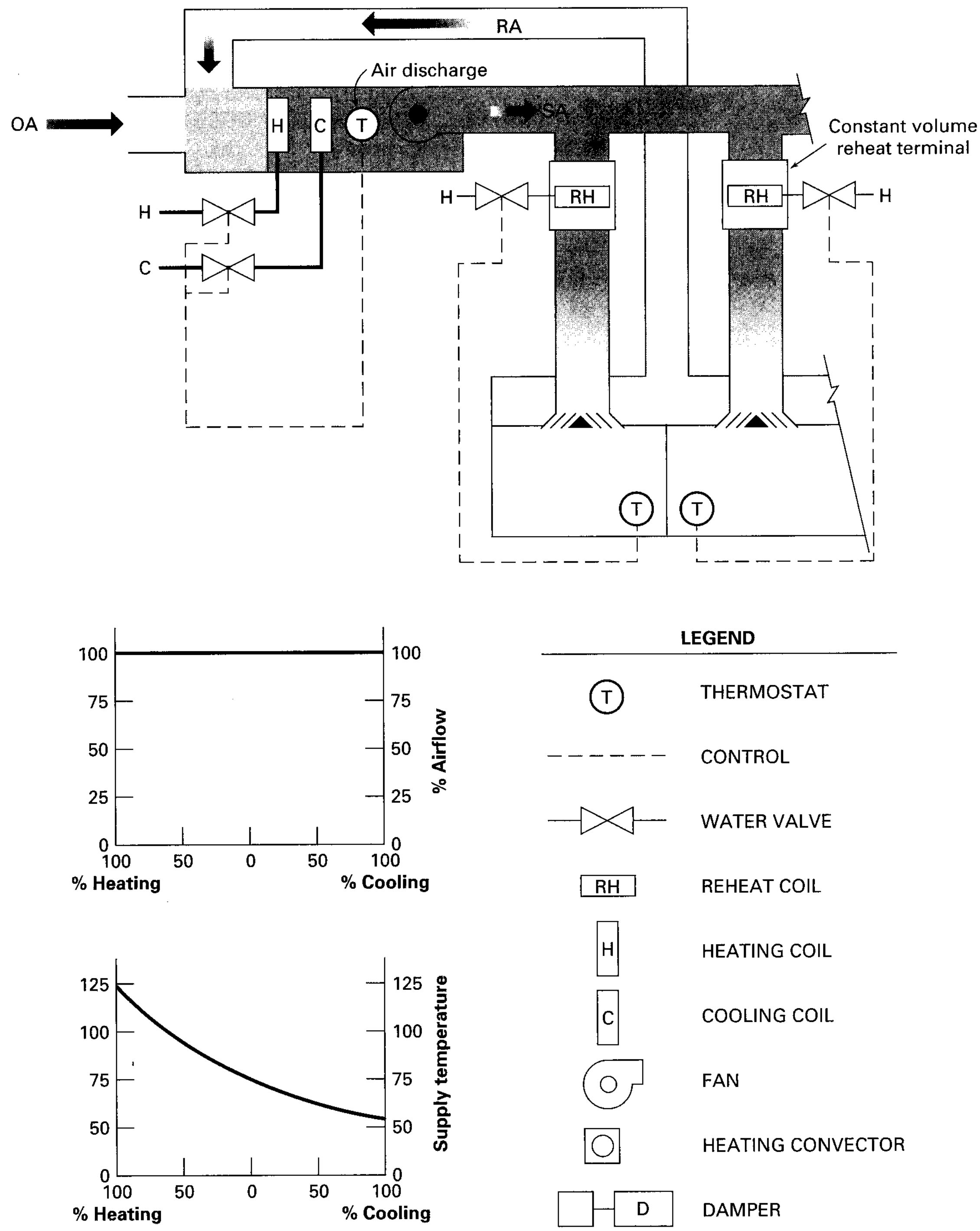
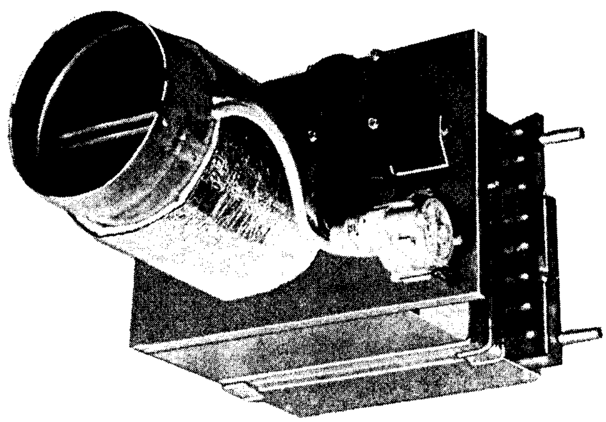


FIGURE 3-7
Constant-volume terminal-reheat system.

used extensively in commercial and institutional buildings designed from the 1950s through the early 1970s. During the mid-1970s, reheat systems lost favor because of concern for energy conservation and operating costs.

3.4.5 Constant-Volume Dual Duct

Constant-volume dual-duct systems (Figure 3–9) send warm and chilled air through a pair of main trunk ducts to the areas being served. At the air-handling unit,



■ **FIGURE 3-8**
A typical single-duct terminal with hot-water reheat coil. The coil may also be electric. (Courtesy: Carnes Company, Inc., Verona, WI.)

a single fan blows air through a heating coil and a cooling coil into a warm-air trunk duct and a chilled-air trunk duct. Constant-volume dual-duct systems are capable of controlling multiple zones, with each zone served by an individual mixing box. (See Figure 3–10.)

Mixing boxes are controlled with dampers to vary the quantity of warm and chilled air in response to the zone thermostat. A typical box is shown in Figure 3–7. If a zone needs more cooling, the dampers will be positioned to deliver more chilled air and less warm air. Conversely, the dampers will be positioned to deliver more warm air and less chilled air if a space needs heating or less cooling. The total airflow, consisting of warm and chilled air, stays fairly constant, since each damper closes as the other opens.

During warm weather, the cooling coil operates to provide air conditioning, but the heating coil can be inactive, as there will be no spaces requiring heating. The return air will be sufficiently warm to mix with chilled air for space temperature control. During cold weather, the heating coil must be activated to provide warmer air. At the same time, interior spaces will require cooling. When cooling and heating are operated simultaneously, the mixing of warm and cold air wastes energy, a problem similar to that caused by reheating.

The constant-volume dual-duct system has the flexibility to add or rearrange mixing boxes on the main trunks as space is reconfigured. It also has the advantage of being an all-air system. Unlike the constant-volume terminal-reheat system, it has no coils installed over occupied spaces; thus it reduces maintenance and avoids the possibility of water leaks.

3.4.6 Multizone

Multizone systems are very similar in operation to dual-duct systems. Warm and cold air are mixed to produce the right air temperature for conditioning, according to signals from the zone thermostats; however, in multizone systems, unlike dual-duct systems, the mixing is done by dampers located at the air-handling unit rather than at terminals located near the spaces served. Figures 3–11 and 3–12 show the operating concept and configuration of a multizone air-handling unit. An individual duct is run from the air-handling unit to each zone of control. A single multizone unit can serve up to approximately 12 zones.

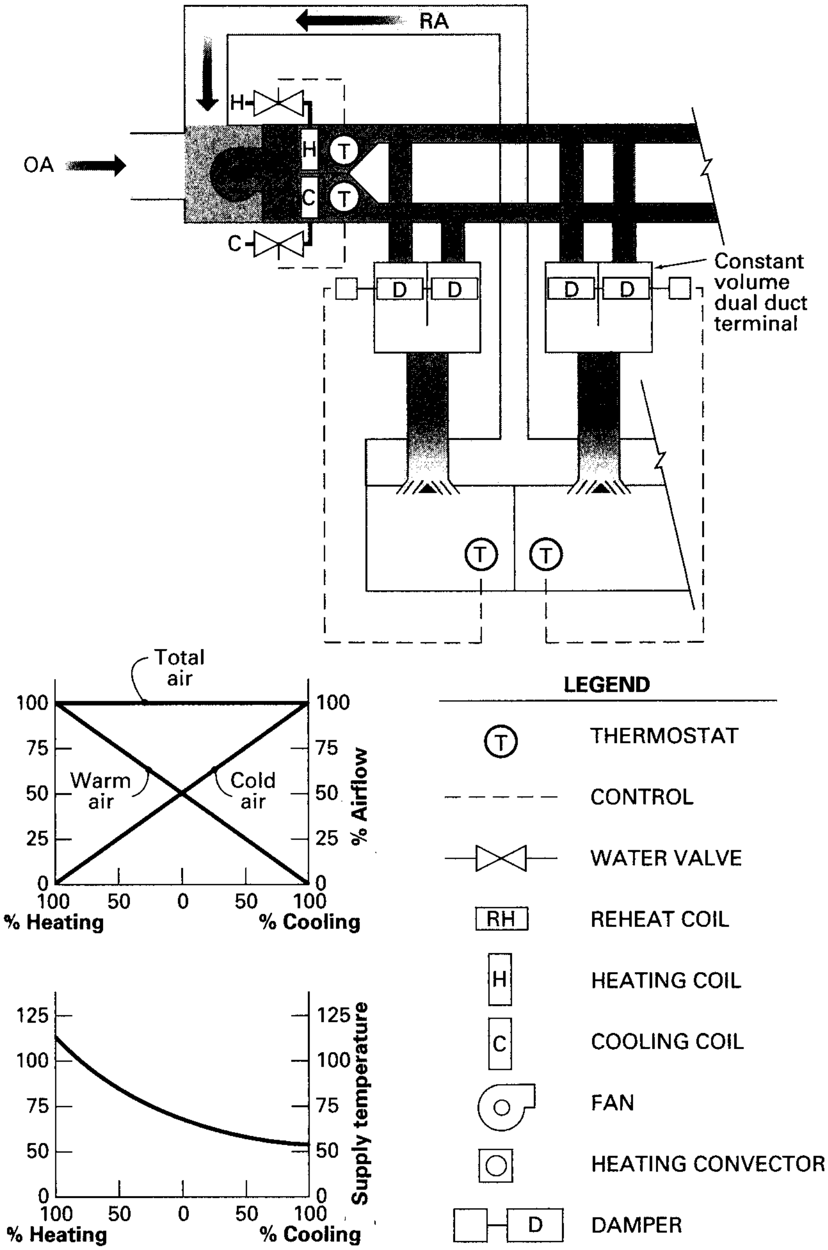
Like dual-duct systems, multizone systems waste energy because they mix warm and cold air. Multizones can have two sets of dampers (warm air and cold air) or three sets (warm, cold, and bypass). The latter, called a *triple-deck multizone,* saves energy by mixing warm and bypass or cold and bypass rather than warm and cold air.

Multizone systems have the disadvantage of being inflexible with regard to change. Rearranging or adding zones will involve considerable ductwork and modification of the unit. Multizone does, however, have the advantage of centralizing controls within the equipment room for easier maintenance and less intrusion into occupied spaces. This is important where security is an issue or where ceiling terminals may be difficult to access.

3.4.7 Single-Zone Variable Air Volume

Single-zone variable air volume (VAV) systems gained popularity during the mid-1970s as an energy-efficient alternative to constant-volume terminal-reheat and constant-volume dual-duct systems. VAV systems used for cooling vary the quantity of air supplied to the space in response to the space thermostat. The air-handling unit supplies chilled air. If the cooling load is high, the chilled airflow will be high. As the load diminishes, the airflow is reduced accordingly. No energy is wasted by reheating or mixing warm and chilled air. In addition, varying the air quantities offers energy savings in terms of operation of the fan, in comparison with constant-volume systems.

Single-zone VAV systems use a cooling coil to produce chilled air at a constant temperature. Airflow is increased or decreased in response to the space thermostat by adjusting dampers or the speed of the fan. Such a unit may also be equipped with an additional coil for heating. Because the unit can serve just one zone, it is suitable only for small, simple buildings or, in multiples, for large buildings. (See Figure 3–13.)



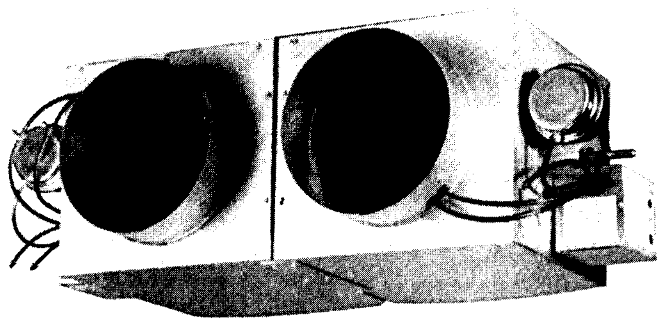
■ **FIGURE 3-9**
Constant-volume dual-duct system.

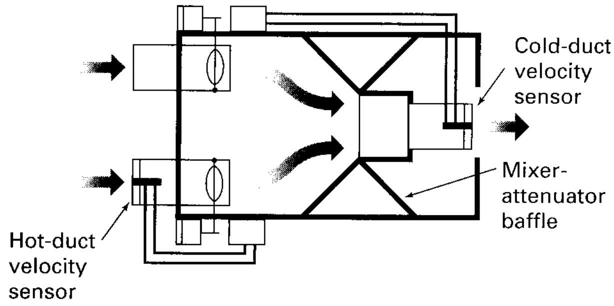
3.4.8 Multiple-Zone Variable Air Volume

Multiple-zone VAV systems use a VAV air-handling unit to supply chilled air into a main trunk duct feeding multiple VAV terminals that in turn serve individual zones of control. VAV terminals, or boxes, contain dampers that vary the airflow to individual zones of control in response to their thermostats. A typical box is shown in Figure 3–14. This form of VAV system can serve large, complex buildings, offering the flexibility of being able to add or rearrange zones by adding or rearranging terminals on the main trunk ducts.

VAV terminals are inexpensive and energy-efficient. Despite complaints that they produce stuffiness at low airflow, they are used extensively in commercial and institutional buildings. VAV terminals are designed to provide only cooling. For buildings with heating loads, they must be used in combination with other devices to provide heat. Figure 3–15 shows the operation of a typical multizone VAV terminal.

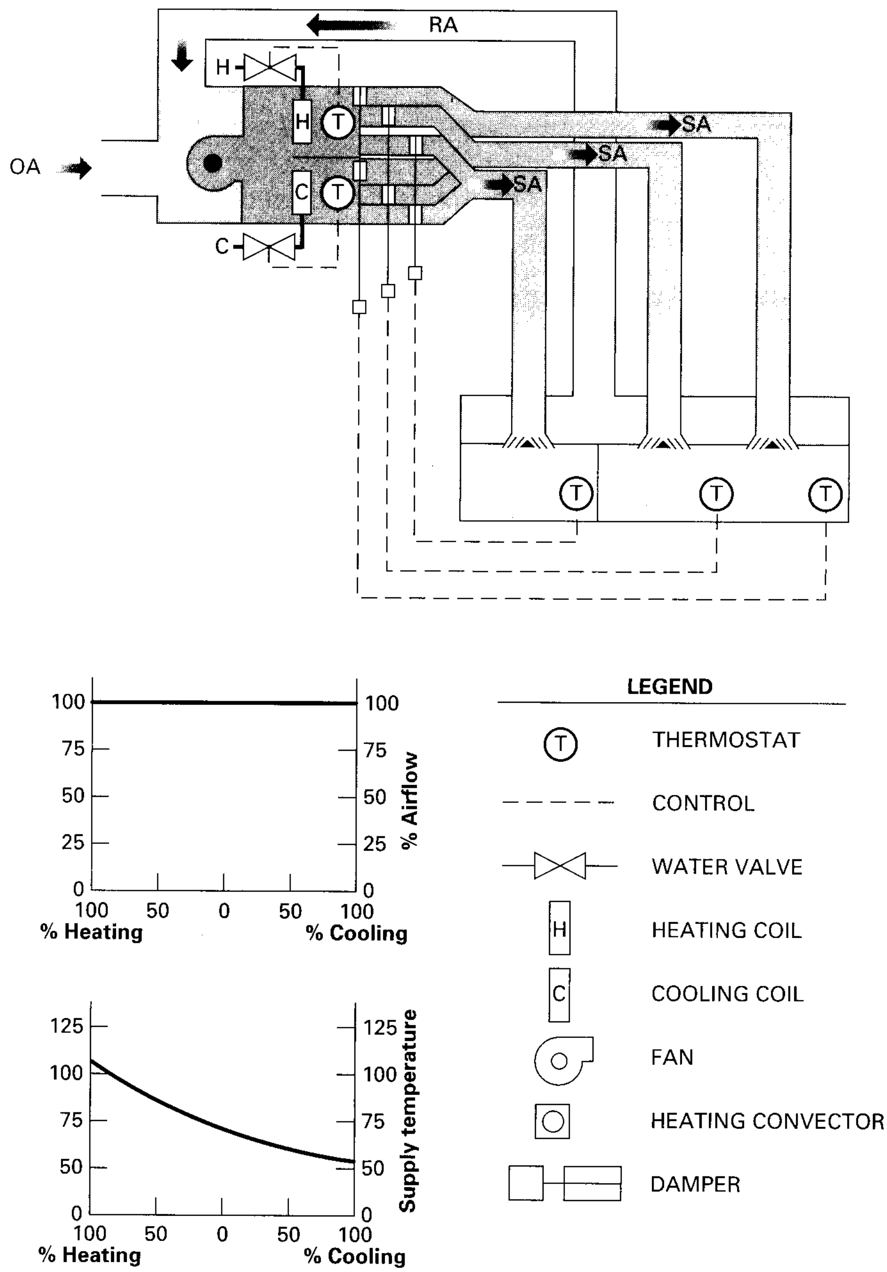
Interior spaces of large buildings need cooling year-round, and VAV systems often meet this need. Perimeter spaces need heating during cold weather and

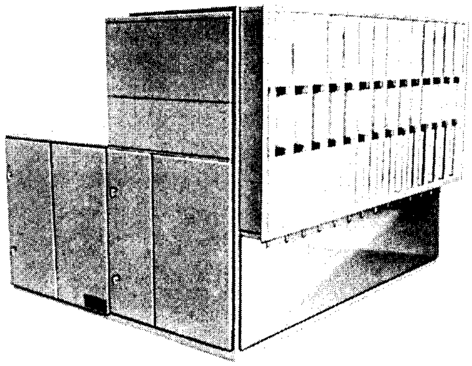




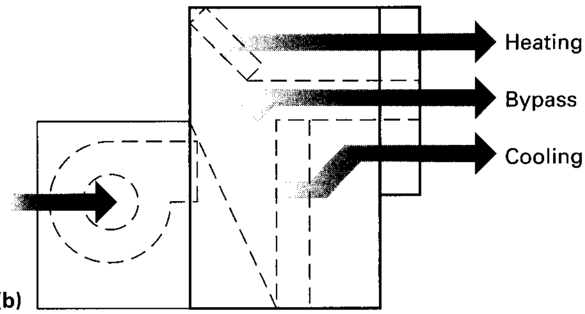
■ **FIGURE 3–10**
Typical dual-duct terminal and its internal section. (Courtesy: Titus, Richardson, TX.)

■ **FIGURE 3–11**
Constant-volume multizone system. (Sketch shown is a triple-zone, double-deck multizone unit.)





(a)



(b)

■ **FIGURE 3–12**
(a) Triple-deck multizone unit. (b) Schematic of the triple-deck unit. The three decks are the standard hot and cold decks plus a bypass deck. This configuration offers significant energy conservation by allowing return or outside air to bypass both coils, and the thermal inefficiency of mixing heated and cooled air is eliminated. (Courtesy: McQuay International, Minneapolis, MN.)

can be served by several means, including convectors, radiant panels, or air terminals with heating capability as well as cooling.

Perimeter convectors are often used as a source of heat in conjunction with VAV terminals for cooling. Perimeter convectors use electric resistance elements or hot-water piping equipped with fins to enhance heat transfer. Often called *finned tube,* this equipment is placed in a low, linear enclosure called a ***baseboard*** or in a taller configuration called a *sill line.* Baseboard or sill line convectors are excellent at preventing downdrafts under windows. They have the disadvantage, however, of taking up several inches of perimeter floor space and sometimes impairing the flexibility of furniture arrangement. (See Figure 3–16 and Figure 3–17.) A combination system, including perimeter convectors with VAV, is shown in Figure 3–18.

Radiant panels are generally located at the ceiling and use electric resistance elements or hot-water piping to warm their surface and radiate infrared heat downward. Infrared heat offers little protection against downdrafts and is directional. Areas under desks and tables may not be adequately exposed to the heating effect.

The top story of a building poses another perimeter problem: heat lost through the roof. Convectors or unit heaters can be installed to prevent cold air from entering occupied spaces served by cooling-only systems.

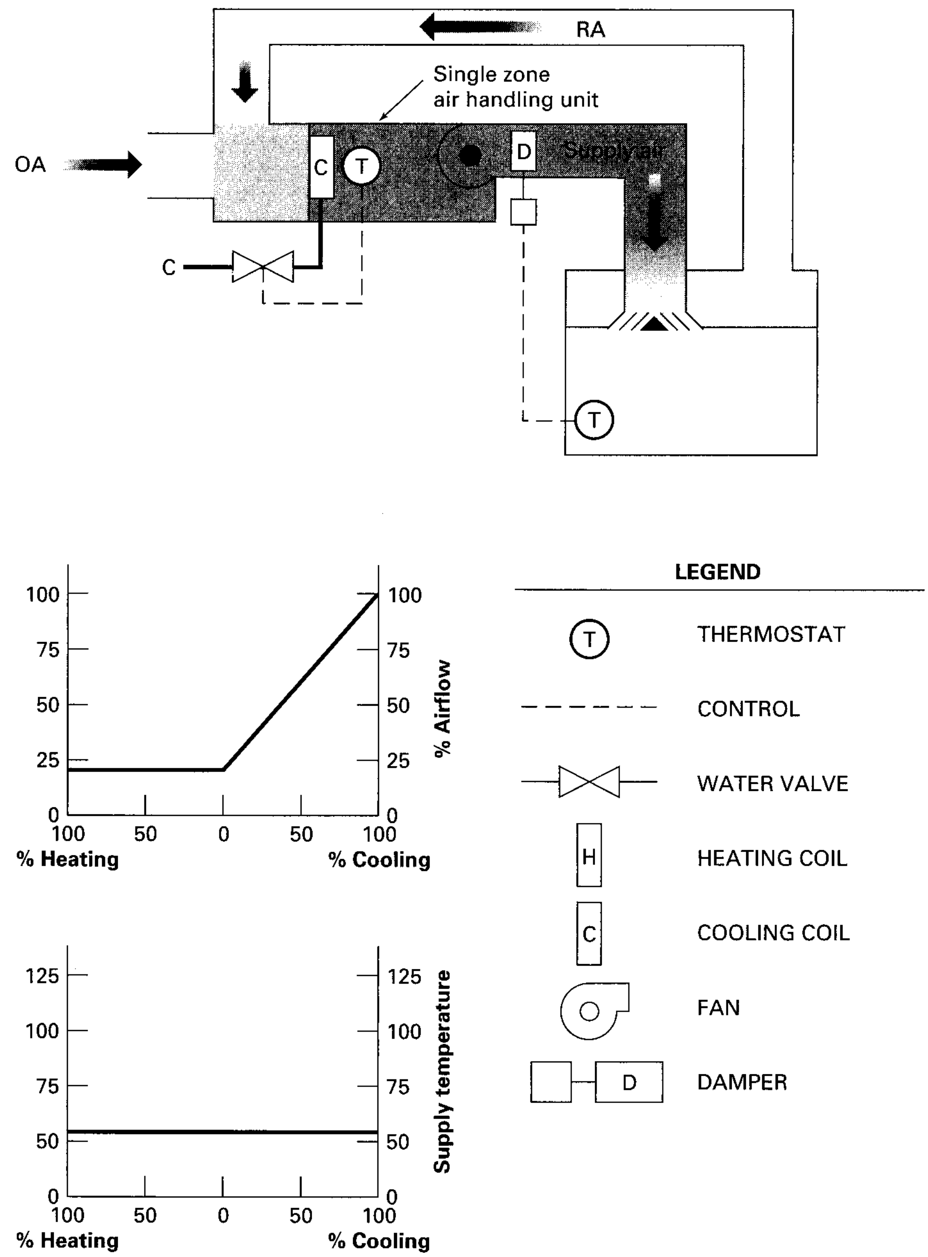
3.4.9 Variable Air Volume Reheat Terminals

VAV reheat terminals are equipped with electric or hot-water heating coils (see Figure 3–19) and are similar to constant-volume reheat terminals except for control of the airflow. While the space requires cooling the VAV reheat terminal supplies chilled air. As the cooling load diminishes, the amount of chilled air is reduced accordingly, to a preset minimum quantity. When heating is required, the heating coil warms the minimum quantity of chilled air to a temperature that is suitable for heating the space. The energy waste due to reheat is much less than in constant-volume reheating. Figure 3–20 illustrates the operation of a VAV reheat terminal.

VAV reheat terminals are equipped with electric or hot-water heating coils, and VAV reheat terminals are often used for perimeter heating in combination with simple VAV terminals for the interior (Figure 3–17). VAV reheating uses more energy than VAV with perimeter convectors and offers little resistance to downdrafts. On the other hand, VAV reheating is generally less expensive and does not require locating equipment on the floor, so that space can be used more flexibly.

3.4.10 Variable Air Volume Dual-Duct Terminals

VAV dual-duct terminals are arranged for operation at a variable rather than a constant air volume in order to conserve energy. They are served from a warm-air duct and a chilled-air duct. While the space requires cooling the VAV dual-duct terminal supplies chilled air through a damper from the chilled-air duct. As the cooling load diminishes, the amount of chilled air is reduced accordingly, while the damper from the warm-air duct remains closed. When heating is required, the chilled-air damper will be at or near the closed position, and the warm-air damper will start to open and increase the flow of warm



■ **FIGURE 3–13**
Single-zone variable air volume (VAV) system.

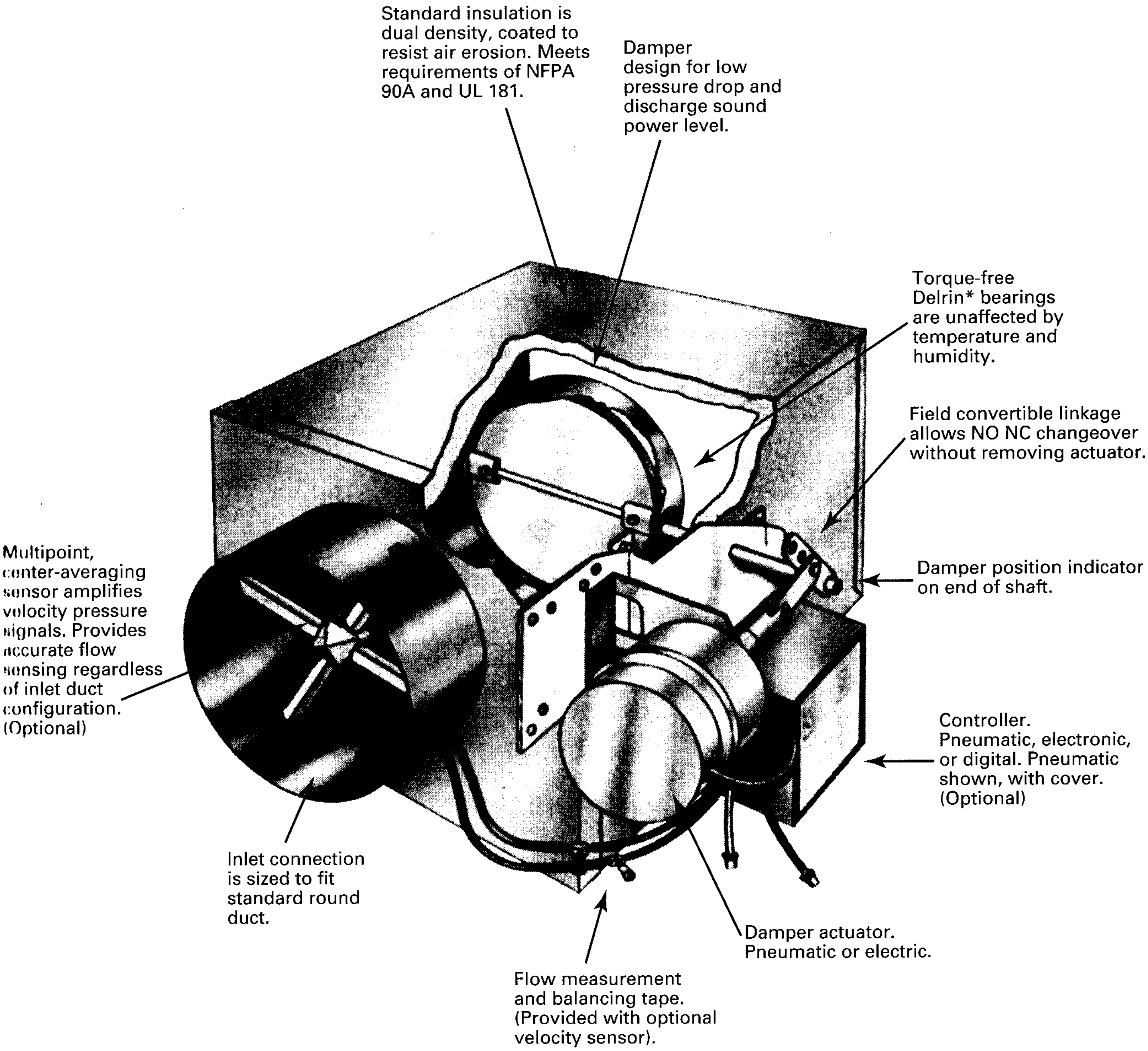
air as the heating load increases. With this mode of operation, there is minimal overuse of energy due to mixing of warm and cold air at the terminal. Figure 3–21 illustrates the operation of a VAV dual-duct terminal.

VAV dual-duct terminals are another common choice for perimeter heating with an interior system using cooling-only VAV terminals. The central air-handling unit is arranged to provide both warm- and chilled-air. VAV terminals serving interior spaces are connected to the chilled-air supply. Dual-duct terminals are connected to both the warm- and the chilled-air supply.

VAV dual-duct terminal systems are relatively energy-efficient and have several advantages over VAV with perimeter convectors and VAV reheat. VAV dual duct does not require any electric or hot-water devices to be maintained in occupied spaces at the perimeter; all heating equipment is confined to the mechanical room.

3.4.11 Variable Air Volume Multizone

VAV multizone is similar in operation to VAV dual duct. Separate dampers are used for the warm and cold portions of the mixing section. (See Figure 3–22.) The cold-air damper is almost closed before the warm-air

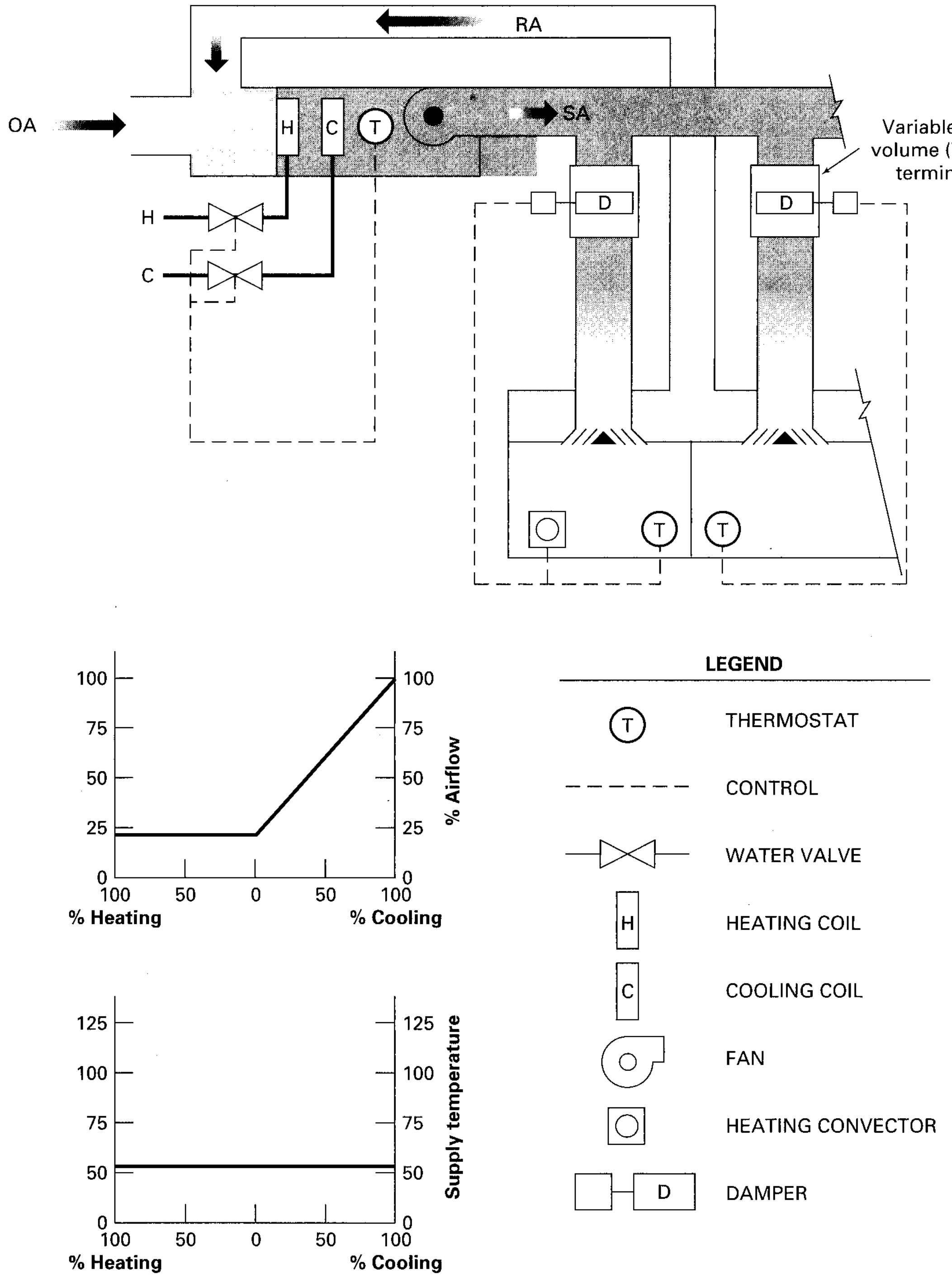


■ FIGURE 3–14
Variable air volume terminal or box. Air terminals come in a number of designs, including constant air volume (CAV) or variable air volume (VAV) and single duct or dual duct, and the airflow rate may be dependent on or independent of the system pressure. Control power may be electric, pneumatic, electronic, or direct digital. The flow of air to a room or a zone is in response to a room thermostat or other signaling devices. The illustration shows a pneumatic-controlled single-duct terminal. (Courtesy: Titus, Richardson, TX.)

damper is allowed to open. This prevents energy waste due to mixing.

3.4.12 Fan Terminal Units

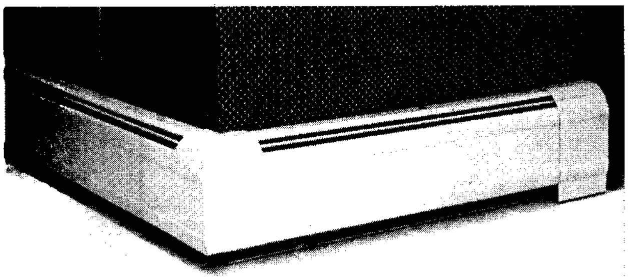
Fan terminal units are designed to overcome several of the complaints about the performance of VAV terminals. The nature of VAV is to decrease the flow of cooling air under light load conditions. This can create stuffiness in occupied spaces. The fan terminal unit contains a VAV damper that responds to the space thermostat. Chilled air passing through the VAV damper is mixed with return air from above the ceiling and delivered to the space via a small constant-volume fan within the unit. Since the fans within the fan terminal units have only a short length



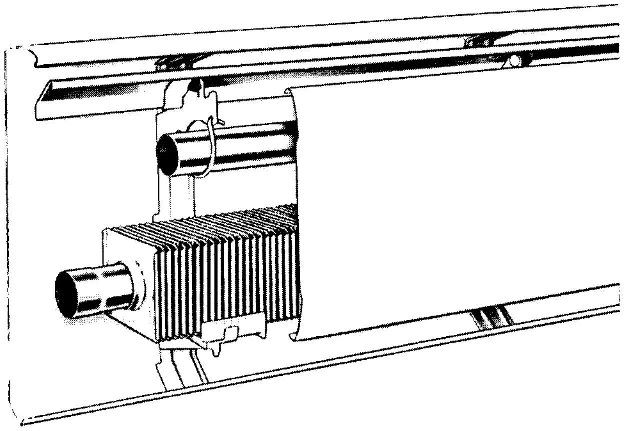
■ **FIGURE 3–15**
Multiple-zone VAV system.

for distribution to the space, their pressure requirements are low, and energy consumption is accordingly modest. The central air-handling unit takes full advantage of reduced chilled-air requirements at partial load, and overall energy savings are achieved at the central fan. Fan terminal units can also be equipped with heating coils and are sometimes used in combination with VAV systems. Figure 3–23 shows a typical fan terminal unit; its operation is diagrammed in Figure 3–24.

Figures 3–18 and Figure 3–25 illustrate two of many possible choices of heating and cooling systems for a typical building. Figure 3–18, a single-duct VAV



■ **FIGURE 3–16**
Typical convector installed at the base of a perimeter wall to overcome the downdraft during cold weather.



■ **FIGURE 3–17**
Cutaway view of a hot-water convector showing the finned tube and supply pipe. Convectors may use steam or electric power and come in various designs and heights. (Courtesy: Sterling Co., Westfield, MA.)

interior system with a hot-water convector exterior system, is sometimes described as a "split" system which incorporates both air and water (or steam) as the means of energy distribution. Figure 3–25, a single-duct VAV interior system with dual-duct VAV for the exterior zones, is sometimes described as an "all-air" system which incorporates air only as the means of energy distribution. The application of each system depends on a number of factors, such as the availability of hot water or steam, relative cost of energy, building construction, floor-to-floor height, depth of ceiling cavity, depth of structural members, aesthetics, and the number of exterior zones desired. Although no generalized conclusion can be made, the all-air system is usually lower in cost but requires more space, for both the high-velocity and the low-velocity ducts. In specific building applications, the increased duct sizes and number of terminal units may preclude the use of an all-air system regardless of the economics.

3.4.13 Fan Coils

Fan coils are another system that can be used to provide multiple zones of control. A fan coil consists of a filter, a cooling and/or heating coil, a fan, and controls. Units can be located above the ceiling, in wall cabinets, or in soffits. Typical fan coil units are shown in Figure 3–26. Fan coils can also be mounted above ceilings or in soffits. Each fan coil can be controlled by an independent thermostat.

Fan coils can be designed with two or four pipes, as shown in Figure 3–27. Two-pipe fan coils are served by a set of supply and return pipes that can carry either hot or chilled water; thus a particular unit is capable of heating or cooling, depending on which water service is available. The piping may be zoned by its exposure to the sun, with some portions of the building capable of cooling while the rest is heating. Obviously, some compromises in comfort can be expected with a two-pipe system.

A four-pipe fan coil system has two sets of piping—one set of supply and return for chilled water and another set for hot water. The four-pipe system is more flexible than the two-pipe system but also more expensive to install.

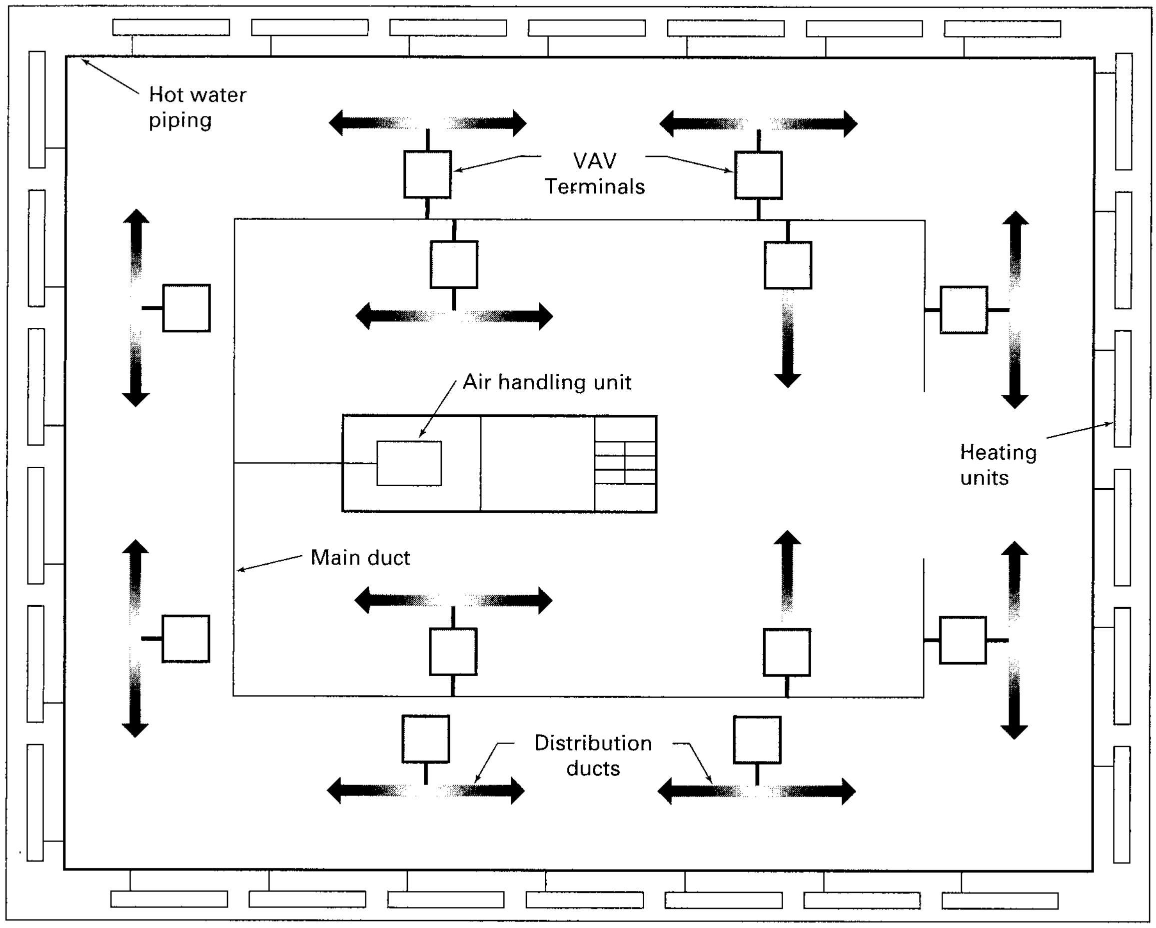
Fan coil units can be used at building perimeters in combination with VAV cooling-only systems serving interior spaces.

3.4.14 Radiant Panel Heating and Cooling

Radiant heating panels can be used as perimeter heating devices in conjunction with VAV systems, or as heating/cooling devices in conjunction with reduced-flow ventilation systems. Used only for heating, radiant panels can be electric or hydronic. Electric panels use heating wire or tape on the back side of drywall or metal.

Hydronic radiant ceiling panels are generally constructed of aluminum with copper tubing bonded to the back surface. In the heating mode the tubing carries hot water for perimeter heat. In the cooling mode, the tubing carries chilled water at a temperature controlled to prevent condensation on the surface of the panel. Room cooling results from convection and absorption of heat by radiant heat transfer from the room to the panel. Similar suspended devices are also available.

Systems in cold climates require the same attention to interior/perimeter zoning as conventional air systems. Perimeter piping needs to provide either heating or cooling. Piping serving interior zones need only cool

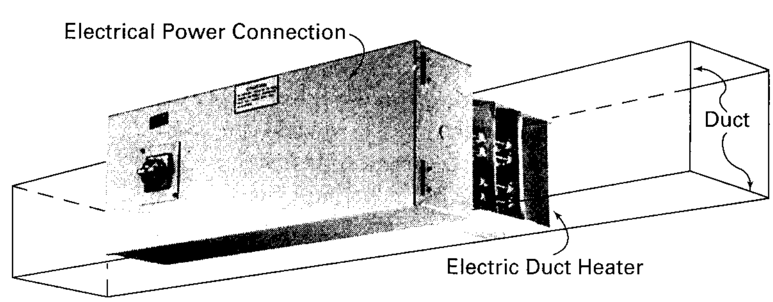


■ **FIGURE 3–18**
Multiple VAV interior and hot-water convector exterior zone system.

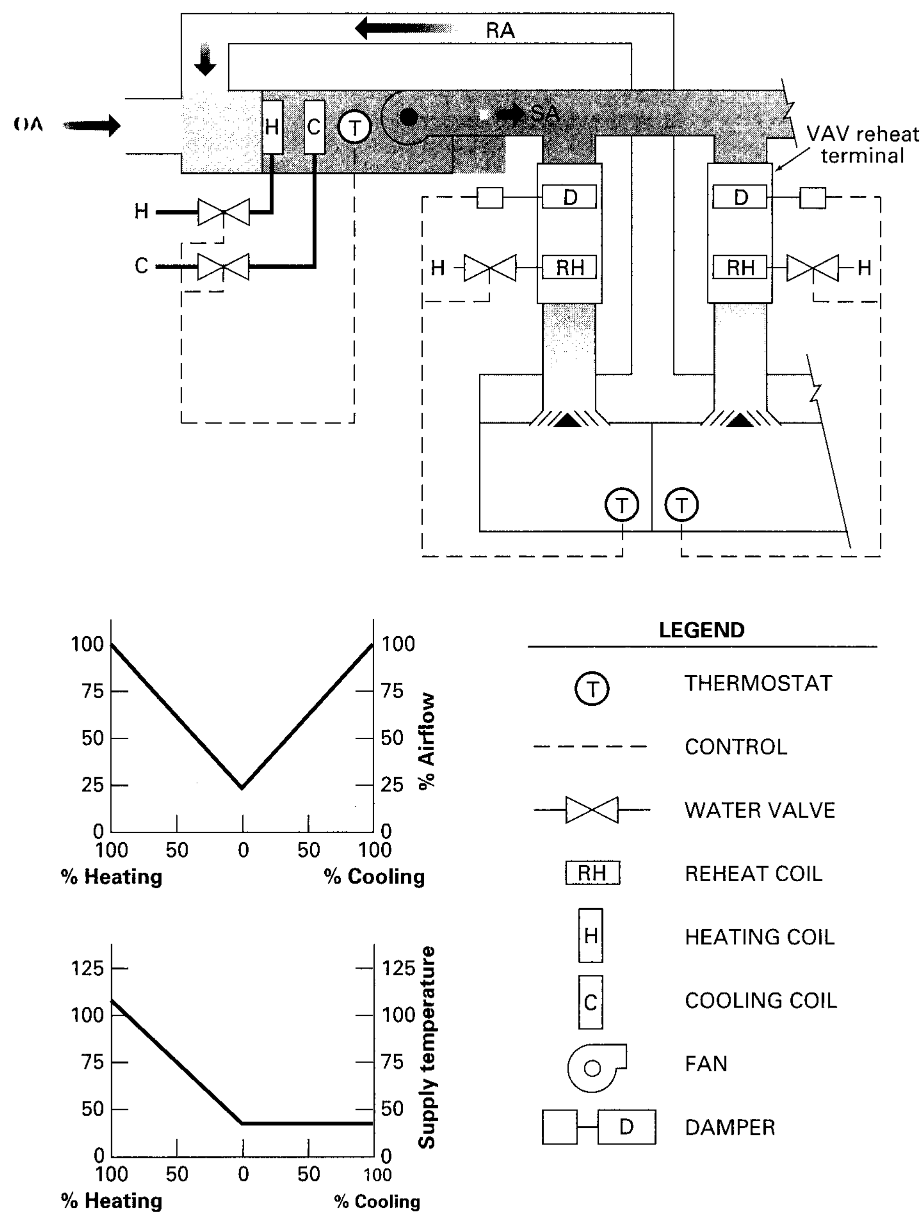
when the building is occupied but may also need to heat to restore temperature after winter night setback.

Radiant cooling panels must be used in combination with ventilation air systems, which provide latent cooling and supplementary sensible cooling. With cooling capacities of 30 to 60 Btuh/sq ft of surface, radiant panels covering 15 to 30 percent of the ceiling can provide up to 100 percent of the sensible load for typical office space.

The advantage of radiant cooling panels is that they are energy-efficient, eliminating fan power for the portion of the load they satisfy. The ventilation air system can be designed with sufficient capacity only to accommodate code-required outside air rates based on occupancy plus sufficient air to pressurize the building. Attention to pressurization is critical to prevent infiltration, which might raise interior humidity and cause condensation on the panels. Radiant cooling systems are



■ **FIGURE 3–19**
Construction of an electrical reheat coil in the ductwork. The coil may be a hot-water or an electric coil. (Courtesy: Titus, Richardson, TX.)



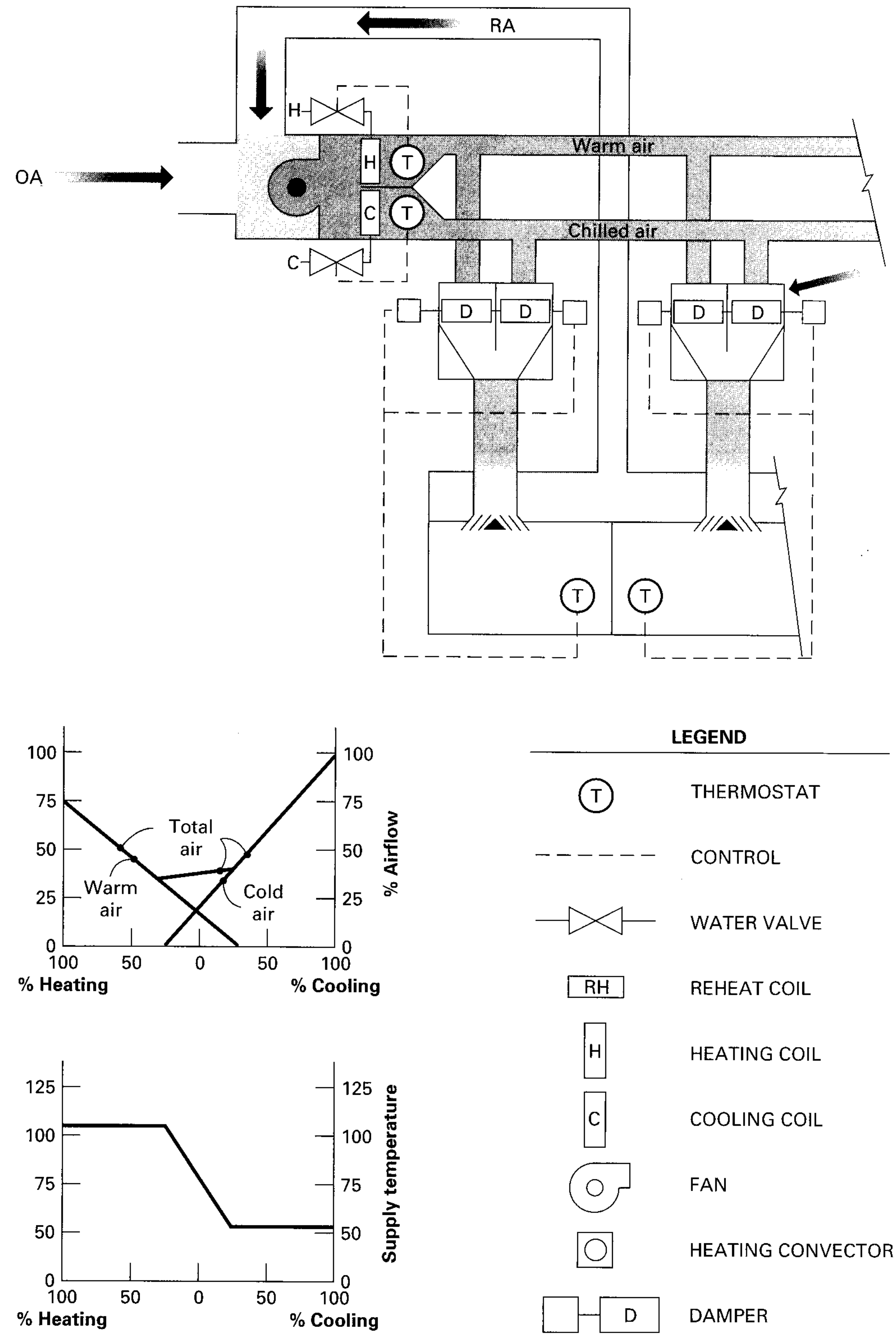
■ **FIGURE 3-20**
Variable air volume reheat system.

not appropriate for buildings with high ventilation needs, such as classroom buildings and laboratories.

Radiant panel systems can be comparable in cost to conventional VAV systems if all factors are considered. The high cost of panels, piping, and controls is offset by smaller air systems, smaller refrigeration equipment, and potentially lower building volume requirements because of the reduced need for air handling and transport. Energy savings, primarily by reducing fan power, are significant, and radiant systems can show a life-cycle cost advantage.

3.4.15 Package Terminal Air Conditioners

Package terminal air conditioners (PTACs) are window or through-wall units containing their own compressors and air-cooled condensers. (See Figure 3–29.) Small package rooftop units with limited ductwork can also be classified as PTACs. PTACs can be installed with or without electric heat and may be designed as heat pumps for more economical operation. PTACs are limited to rooms with outside exposure or spaces with suitable



■ **FIGURE 3–21**
Variable air volume dual-duct system.

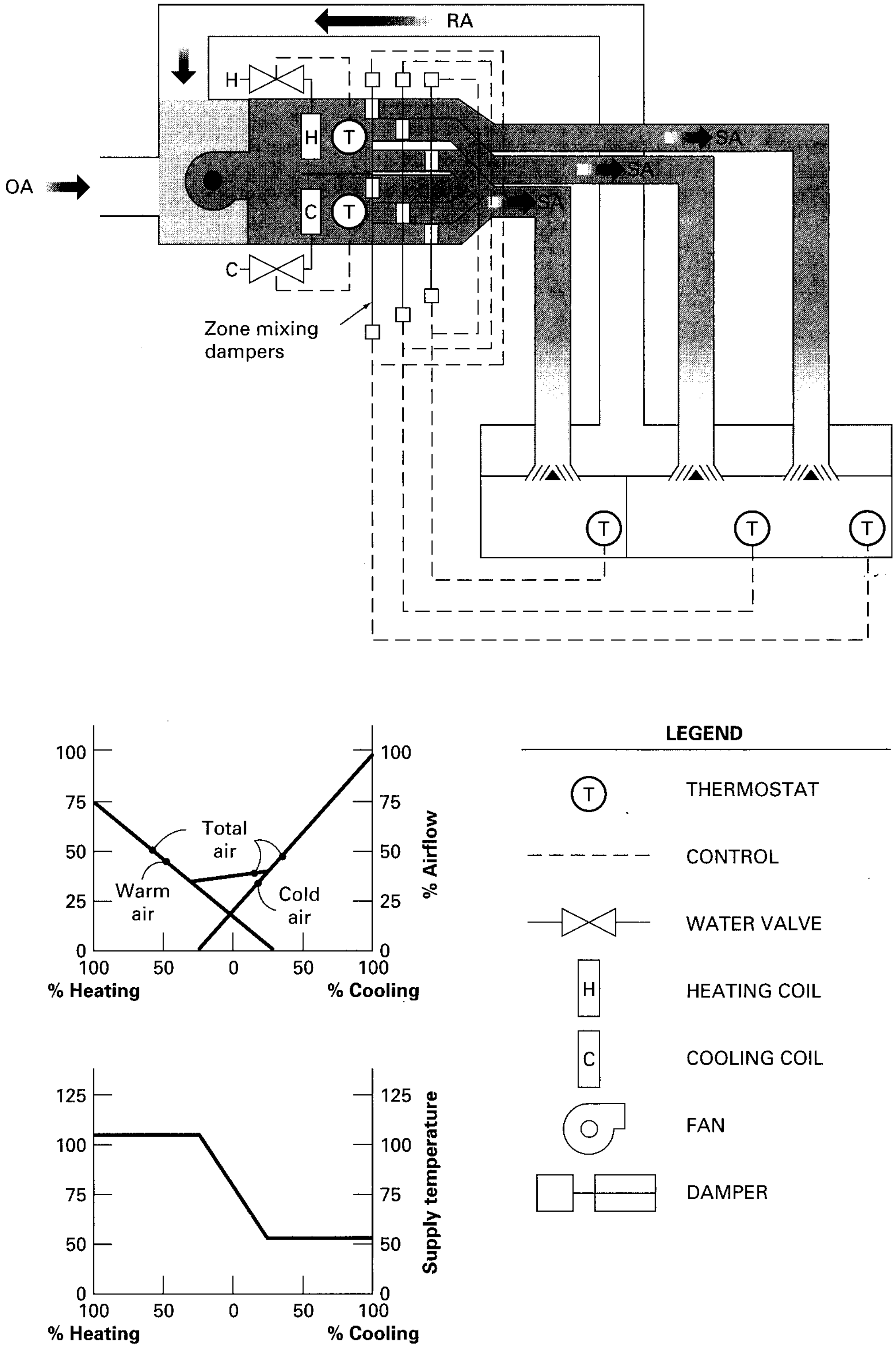
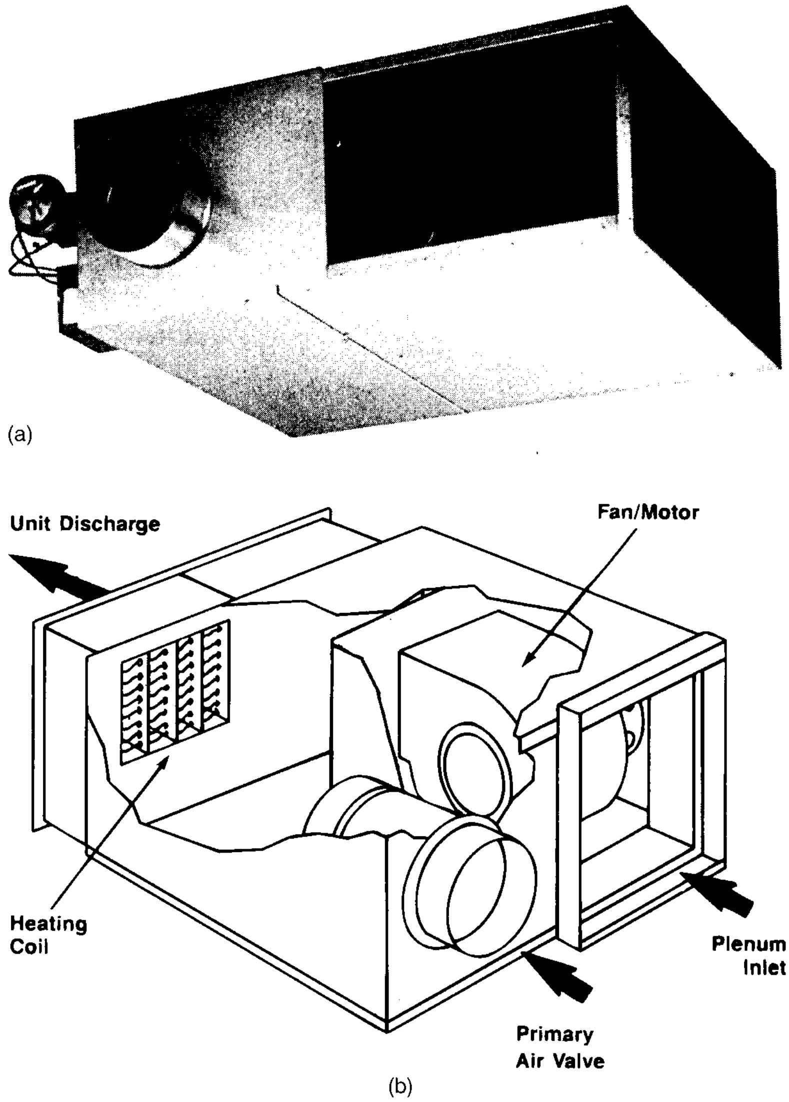


FIGURE 3-22
Variable air volume multizone system.



■ **FIGURE 3-23**
(a) Typical fan terminal, which contains a fan drawing air from the space or the return air plenum, a primary air duct connection (behind photo, not visible), and an air outlet. (b) Side and top view of a fan terminal box with arrows indicating the mixing of primary air and induced air. (Courtesy: Titus, Richardson, TX.)

adjacent places to reject heat from refrigeration. PTACs tend to be noisy and require high maintenance as their compressors age.

Operating as a heat pump, the unit can reverse the refrigeration process to move heat from outdoors to indoors, thus acting as a heater instead of an air conditioner.

3.4.16 Water-Source Heat Pumps

Water-source heat pumps are unitary (contain compressors) terminal devices with reversible-cycle refrigeration, so that they can operate for either heating or cooling. They use refrigerant-to-air coils and water-to-refrigerant heat exchangers. In the cooling mode the coil absorbs heat from the air to boil refrigerant. Suction gas is compressed in the compressor, and hot gas is condensed in the refrigerant-to-water heat exchanger. In the heating mode the refrigerant flow circuit is reversed by a reversing valve. The coil acts as a condenser, and the heat exchanger acts as an evaporator.

The heat exchangers of multiple water-source heat pumps are connected by a water loop, which is maintained at appropriate temperatures for operation of the heat pumps in the cooling mode and/or the heating mode depending on individual heat pump operating modes.

If the net HVAC requirement is cooling, heat will need to be rejected from the overall system. Generally, one or more closed-circuit evaporative water coolers are

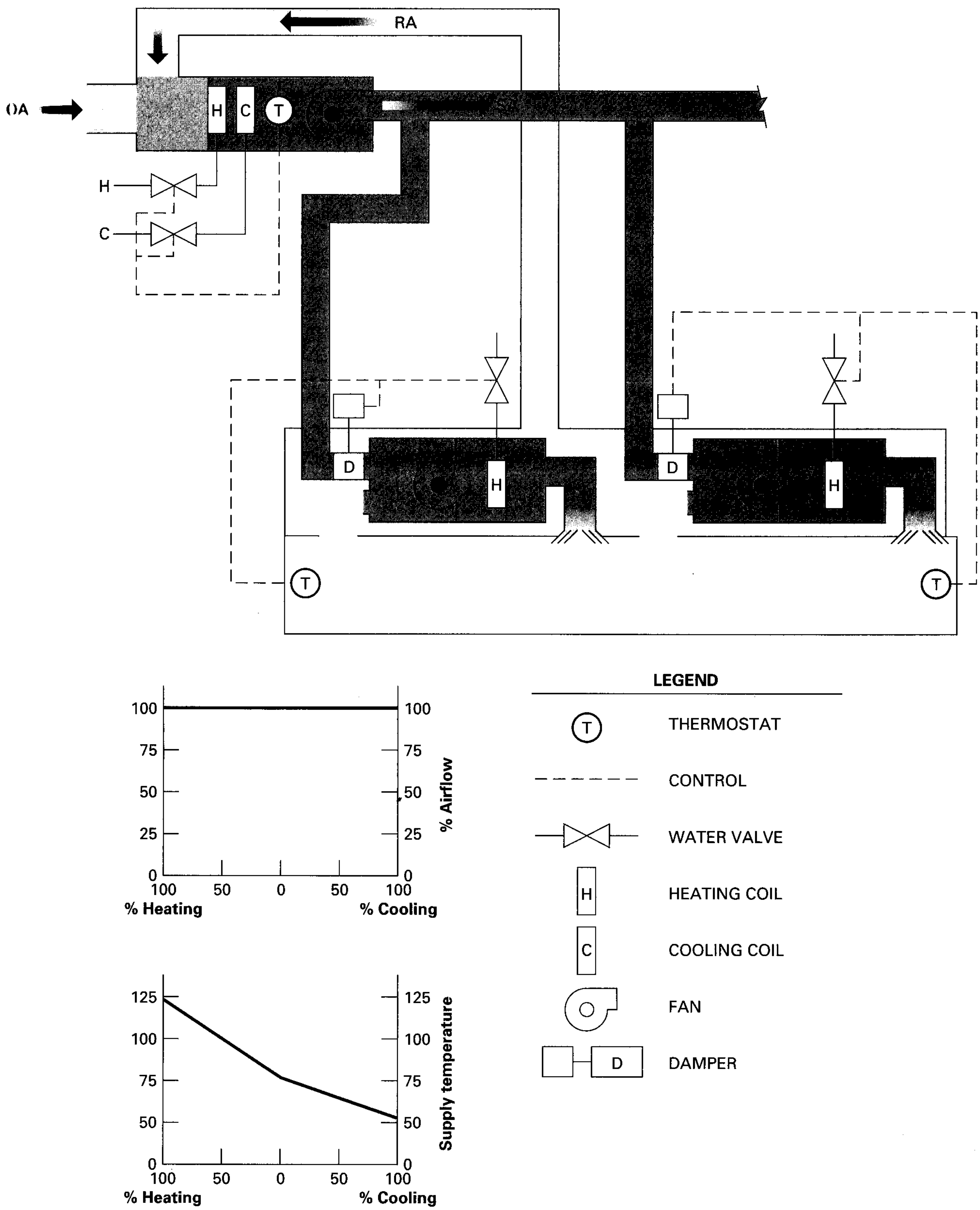
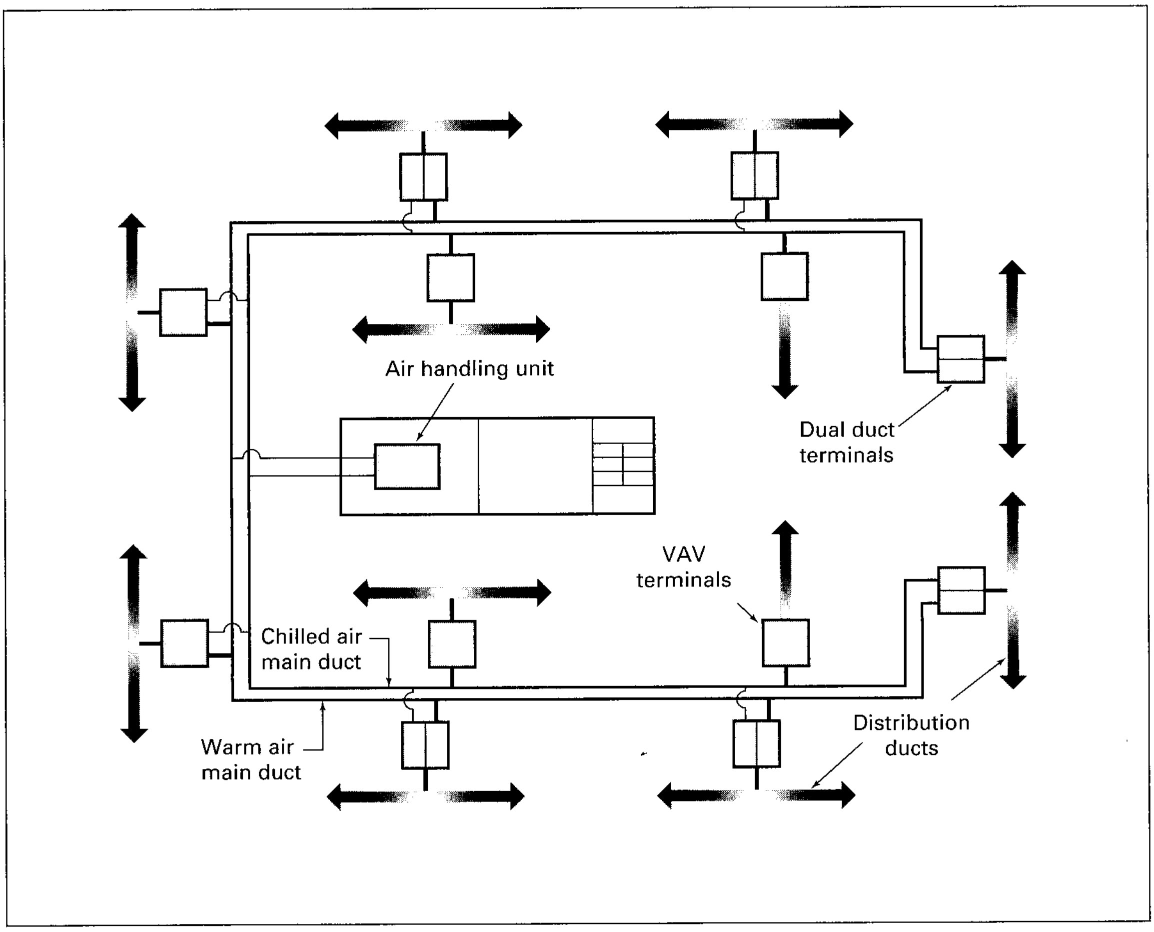


FIGURE 3–24
Fan terminal units.



■ **FIGURE 3–25**
Typical layout of an air distribution system with single-duct VAV for the interior zones and dual-duct constant or variable air volume for the exterior zones.

used to reject heat to outdoors. If the net HVAC requirement is heating, heat will be added to the water circuit by one or more boilers. During cold weather some of the heat pumps will require heating and some, cooling owing to solar loads and internal heat gains. When this is the case, heat from the zones requiring cooling is transferred to the units requiring heating. This heat-reclaim feature is the energy advantage of water-source heat pump systems.

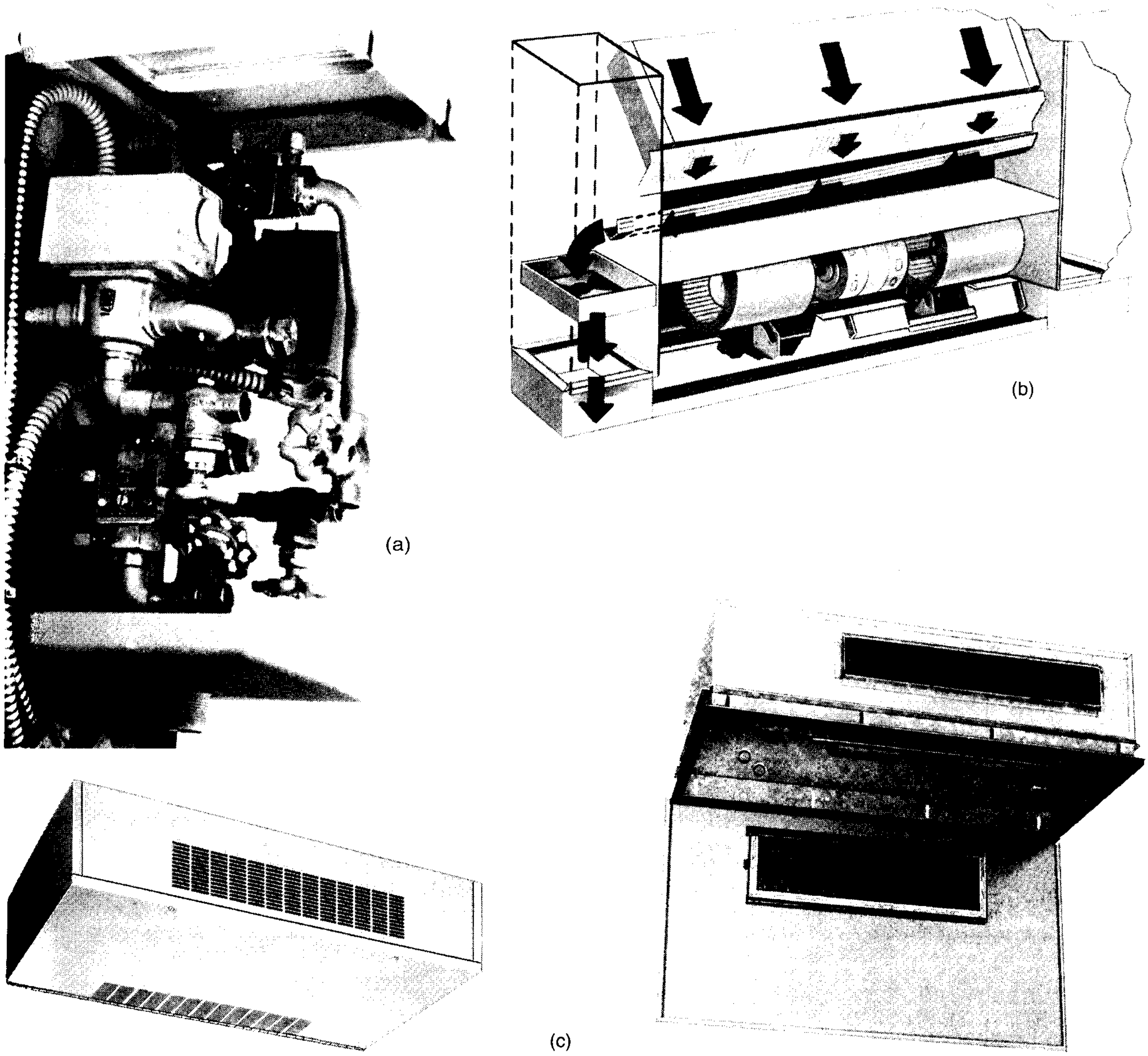
Water-source heat pumps can be floor-mounted cabinet units or concealed ceiling-mounted units. The water circuit is generally operated between 80°F and 110°F, so there is no need for insulation, and plastic can be used rather than steel or copper for economy installations.

Outside air for ventilation can be introduced at individual heat pumps or can be provided by a separate ventilation system.

Water-source heat pumps do not need access to outside air for condensing, so they can be located at the interior of the building. Small units are generally located above ceilings; larger units can be located in equipment rooms.

Condensing water for water-source heat pumps is produced by a central evaporative fluid cooler and circulated through the heat pump condensers to absorb heat generated by the air-conditioning process. A boiler is also included to provide heat for units operating in the heating mode by reversal of the refrigeration process. During winter, units serving interior spaces function in the cooling mode, and units serving perimeter spaces operate in the heating mode. Energy rejected from the cooling units is used to supplement heat from the boiler.

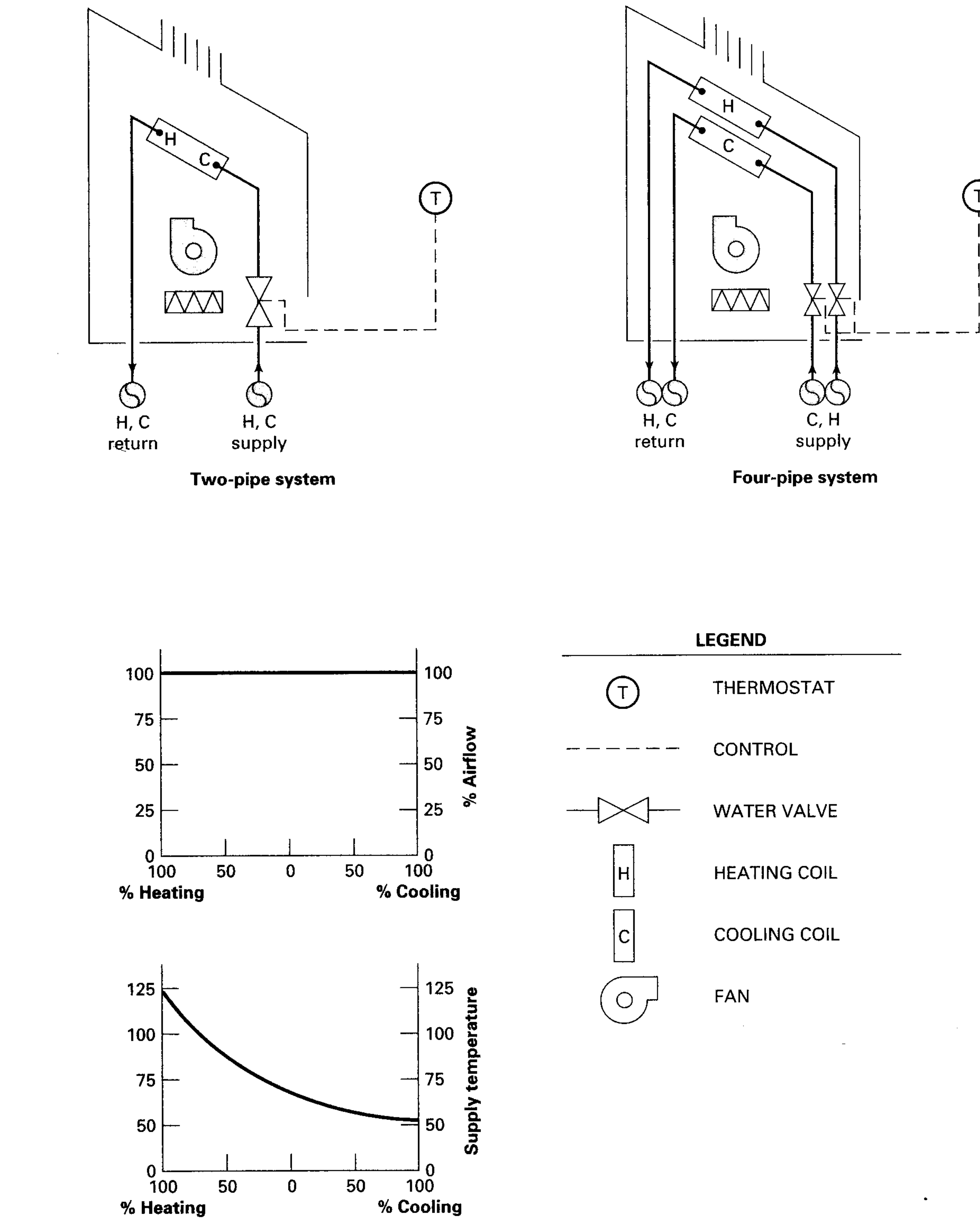
Water-cooled condensers are much more effective at heat transfer than air-cooled condensers. In addition,



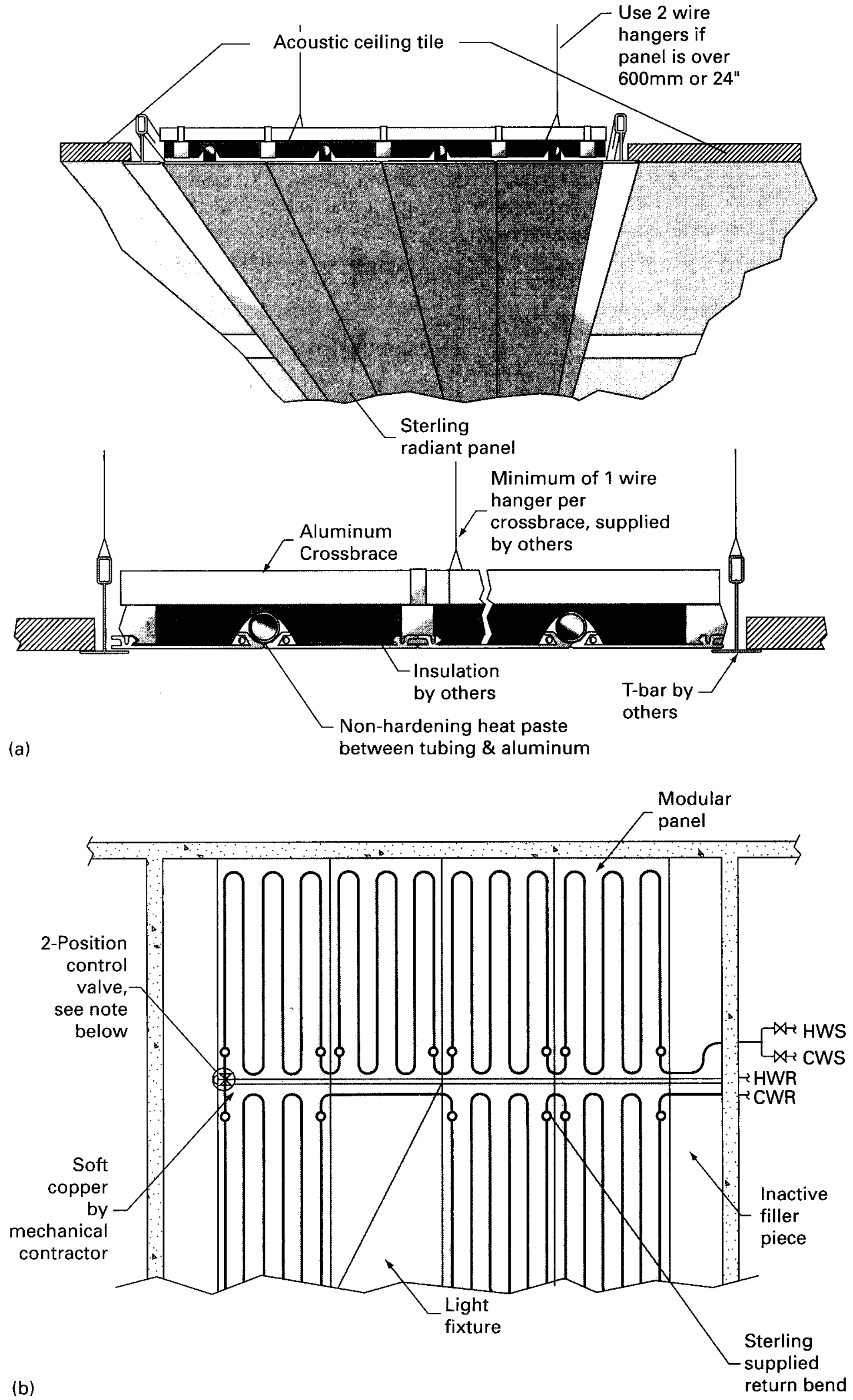
■ **FIGURE 3-26**
(a) Fan coil. A close-up view of the valve assembly showing control and shutoff valves. The small pan under the valves is the auxiliary drain pan, which receives collected condensate from the drain pan under the coil and condensate occurring on the valve assembly. Drain pans require periodic cleaning to avoid clogging. (b) A cutaway view of floor-mounted fan coil units with enclosed coil. The coil is totally enclosed for effective air distribution. (Courtesy: Airtherm Manufacturing Co., St. Louis, MO.) (c) Ceiling-surface and ceiling-recess-mounted fan coil units. (Courtesy: Airtherm Manufacturing Co., St. Louis, MO.)

with proper control of the boiler and evaporative cooler refrigerant, condensing temperatures will be more moderate than with outside air. The result is that the compressors need not work as hard, and water-source heat pumps are more energy-efficient and have a longer life than air-cooled PTACs.

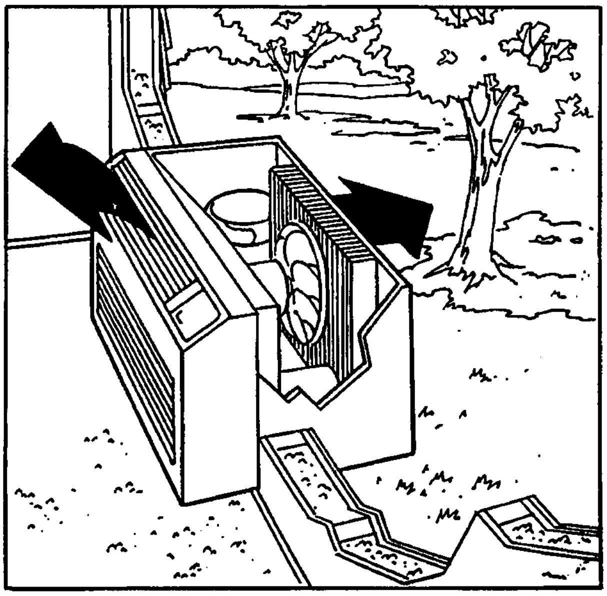
Water-source heat pump systems are often used in office buildings, schools, and hotels as a low-cost solution for HVAC. Economy is achieved by combining heating and cooling piping into one system, which need not be insulated. Economy is also achieved by avoiding central air-handling equipment and space for fan rooms;



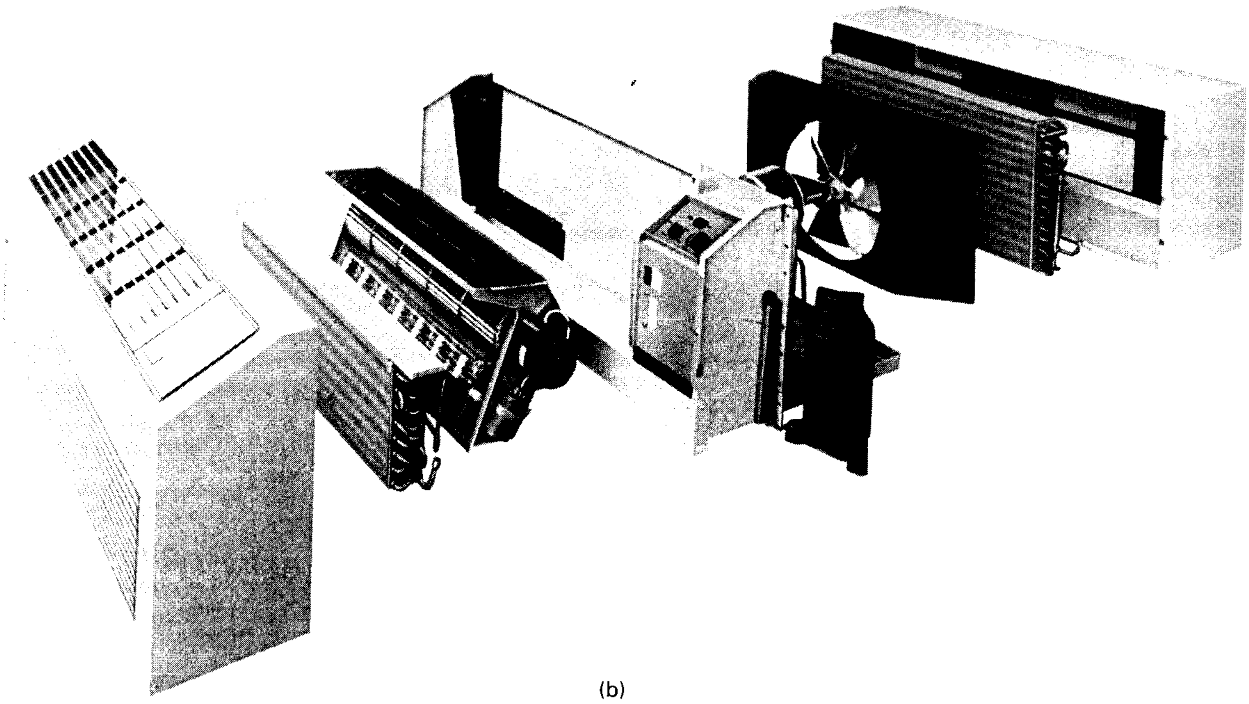
■ **FIGURE 3–27**
Fan coil systems.



■ **FIGURE 3–28**
(a) Section through radiant panel shows water tube bonded to ceiling plate. Top would be insulated in installation.
(b) Radiant panels used to heat and cool at perimeter, cool only at interior.



(a)



(b)

■ **FIGURE 3-29**

(a) Cutaway view of a package terminal air conditioner (PTAC) shows two sections: indoor and outdoor. The two sections should be completely insulated and separated from each other to increase efficiency and decrease noise. The indoor section contains the evaporator coil, fan, and controls. The outdoor section contains the compressor, condenser coil, and fan. A PTAC unit may also be designed to operate on the reverse refrigeration cycle as an air-to-air heat pump.
(b) Exploded view of the PTAC showing all components. From left to right: indoor cabinet, evaporator coil, electric heating coil (optional), separating partition, refrigerant compressor, condenser fan, condenser coil, and outdoor cabinet. (Courtesy: Trane Company, La Crosse, WI.)

however, a heat pump can be a high-maintenance system, since there is a refrigeration system, a heat exchanger, and controls with every unit. Noise from compressors and fans can also be a problem, especially for console units. Ducted concealed units present fewer acoustical problems if supply and return ductwork is designed to attenuate sound.

QUESTIONS

3.1 Describe the basic difference between interior and perimeter space with respect to HVAC loads.

3.2 What principles are used to vary the amount of HVAC service to a space with varying loads?

3.3 What is an HVAC zone, and how might a zone differ from a room?

3.4 Which HVAC delivery systems are best for preventing high humidity in spaces? Why?

3.5 Which HVAC delivery systems are generally avoided because of their high energy usage?

3.6 Name the HVAC delivery systems that are most flexible for adding or rearranging zones. Why are they effective in this respect?

3.7 Which HVAC delivery systems are most energy-efficient? Why?

3.8 Which HVAC delivery systems would be most appropriate in a building in which risk of water damage is a serious concern?

3.9 Which HVAC delivery systems would be most appropriate in a building in which intrusion for maintenance within occupied spaces must be kept at a minimum?

3.10 Of all the HVAC delivery systems discussed in this chapter, which is the most energy-efficient? Why?

3.11 Describe the major difference between electric or pneumatic control and direct digital control.

3.12 When is it appropriate to use two-position control?

3.13 When is it appropriate to use proportional control?

3.14 A hotel developer is deciding whether to use fan coils or PTAC units. How would you counsel him or her on matters of cost and quality?

3.15 You are helping an owner decide on systems for a new office building. For perimeter offices, VAV reheat or VAV with perimeter convectors are used. The contractor will provide either system for the same cost. How would you counsel the owner on matters of cost and quality?

3.16 You are helping an owner decide between VAV terminals and FTU terminals for interior conference rooms in a new office building. How would you counsel the owner on matters of cost and quality?

3.17 Why would you recommend the extra construction cost of a four-pipe fan coil system versus a two-pipe fan coil system?

3.18 How are water-source heat pumps and PTAC units similar? How are they different?

3.19 What is the primary energy advantage of using radiant cooling?