

CHAPTER 48

UNITARY AIR CONDITIONERS AND HEAT PUMPS

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UNITARY air conditioners are factory-made assemblies that normally include an evaporator or cooling coil and a compressor/condenser combination, and possibly provide heating as well. An **air-source unitary heat pump** normally includes an indoor conditioning coil, compressor(s), and an outdoor coil. It must provide heating and possibly cooling as well. A **water-source heat pump** rejects or extracts heat to and from a water loop instead of from ambient air. A unitary air conditioner or heat pump with more than one factory-made assembly (e.g., indoor and outdoor units) is commonly called a **split system**.

Unitary equipment is divided into three general categories: residential, light commercial, and commercial. Residential equipment is single-phase unitary equipment with a cooling capacity of 65,000 Btu/h or less and is designed specifically for residential application. Light commercial equipment is generally three-phase, with cooling capacity up to 135,000 Btu/h, and is designed for small businesses and commercial properties. Commercial unitary equipment has cooling capacity higher than 135,000 Btu/h and is designed for large commercial buildings.

GENERAL DESIGN CONSIDERATIONS

User Requirements

The user primarily needs either space conditioning for occupant comfort or a controlled environment for products or manufacturing processes. Cooling, dehumidification, filtration, and air circulation often meet those needs, although heating, humidification, and ventilation are also required in many applications.

Application Requirements

Unitary equipment is available in many configurations, such as

- **Single-zone, constant-volume**, which consists of one controlled space with one thermostat that controls to maintain a set point.
- **Multizone, constant-volume**, which has several controlled spaces served by one unit that supplies air of different temperatures to different zones as demanded ([Figure 1](#)).
- **Single-zone, variable-volume**, which consists of several controlled spaces served by one unit. Supply air from the unit is at a constant temperature, with air volume to each space varied to satisfy space demands ([Figure 2](#)).
- **Multisplit**, which consists of several controlled spaces, each served by a separate indoor unit. All indoor units are connected to an outdoor condensing unit. When each indoor unit varies its refrigerant flow in response to heating or cooling load demand, the system is called **variable refrigerant flow (VRF)**.

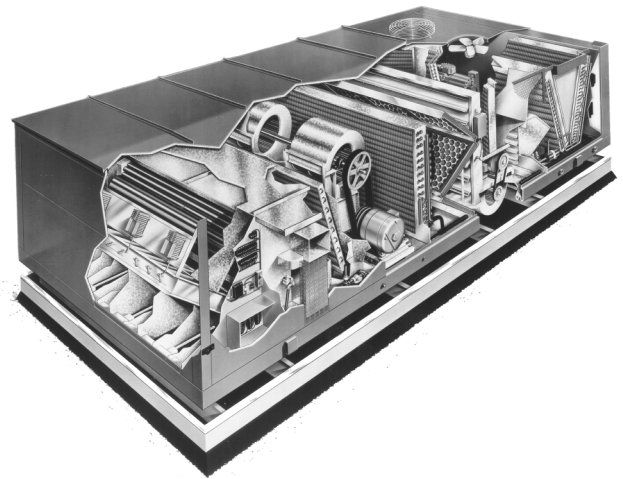


Fig. 1 Typical Rooftop Air-Cooled Single-Package Air Conditioner (Multizone)

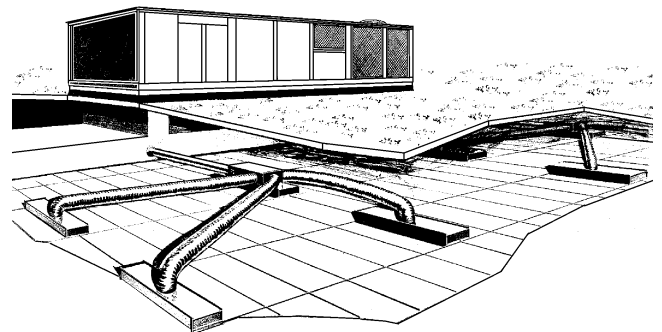


Fig. 2 Single-Package Air Equipment with Variable Air Volume

Factors such as size, shape, and use of the building; availability and cost of energy; building aesthetics (equipment located outdoors); and space available for equipment are considered to determine the type of unitary equipment best suited to a given application. In general, roof-mounted single-package unitary equipment is limited to five or six stories because duct space and available blower power become excessive in taller buildings. Split units are limited by the maximum distance allowed between the indoor and outdoor sections. Indoor, single-zone equipment is generally less expensive to maintain and service than multizone units located outdoors.

The preparation of this chapter is assigned to TC 8.11, Unitary and Room Air Conditioners and Heat Pumps.

The building load and airflow requirements determine equipment capacity, whereas the availability and cost of fuels determine the energy source. Control system requirements must be established, and any unusual operating conditions must be considered early in the planning stage. In some cases, custom-designed equipment may be necessary.

Manufacturers' literature has detailed information about geometry, performance, electrical characteristics, application, and operating limits. The system designer selects suitable equipment with the capacity for the application.

### Installation

Unitary equipment is designed to keep installation costs low. Equipment must be installed properly so that it functions in accordance with the manufacturer's specifications. Interconnecting diagrams for the low-voltage control system should be documented for proper future servicing. Adequate planning is important for installing large, roof-mounted equipment because special rigging equipment is frequently required.

The refrigerant circuit must be clean, dry, and leak-free. An advantage of packaged unitary equipment is that proper installation minimizes the risk of field contamination of the circuit. Care must be taken to properly install split-system interconnecting tubing (e.g., proper cleanliness, brazing, and evacuation to remove moisture and other noncondensables). Some residential split systems have pre-charged line sets and quick-connection couplings, which reduce the risk of field contamination of the refrigerant circuit. Split systems should be charged according to the manufacturer's instructions.

When installing split, multisplit, and VRF systems, lines must be properly routed and sized to ensure good oil return to the compressor. Chapters 2 and 3 of the 2006 *ASHRAE Handbook—Refrigeration* have more details on appropriate refrigerant piping practices.

Unitary equipment must be located to avoid noise and vibration problems. Single-package equipment of over 20 ton capacity should be mounted on concrete pads if vibration control is a concern. Large-capacity equipment should be roof-mounted only after the roof's structural adequacy has been evaluated. If they are located over occupied space, roof-mounted units with return fans that use ceiling space for the return plenum should have a lined return plenum according to the manufacturer's recommendations. Duct silencers should be used where low sound levels are desired. Weight and sound data are available from many manufacturers. Additional installation guidelines include the following:

- In general, install products containing compressors on solid, level surfaces.
- Avoid mounting products containing compressors (such as remote units) on or touching the foundation of a house or building. A separate pad that does not touch the foundation is recommended to reduce any noise and vibration transmission through the slab.
- Do not box in outdoor air-cooled units with fences, walls, overhangs, or bushes. Doing so reduces the air-moving capability of the unit, reducing efficiency.
- For a split-system remote unit, choose an installation site that is close to the indoor part of the system to minimize pressure drop in the connecting refrigerant tubing.
- For VRF units, locate the refrigerant pipes' headers so that the length of refrigerant pipes is minimized.
- Contact the unitary equipment manufacturer or consult installation instructions for further information on installation procedures.

Unitary equipment should be listed or certified by nationally recognized testing laboratories to ensure safe operation and compliance with government and utility regulations. Equipment should also be installed to comply with agency standards' rating and application requirements to ensure that it performs according to industry criteria. Larger and more specialized equipment often does not carry agency

labeling. However, power and control wiring practices should comply with the *National Electrical Code*<sup>®</sup> (NFPA Standard 70). Local codes should be consulted before the installation is designed; local inspectors should be consulted before installation.

### Service

A clear and accurate wiring diagram and well-written service manual are essential to the installer and service personnel. Easy and safe service access must be provided in the equipment for cleaning, lubrication, and periodic maintenance of filters and belts. In addition, access for replacement of major components must be provided and preserved.

Availability of replacement parts aids proper service. Most manufacturers offer warranties covering 1 year of operation after installation. Extended compressor warranties may be standard or optional.

Service personnel must be qualified to repair or replace mechanical and electrical components and to recover and properly recycle or dispose of any refrigerant removed from a system. They must also understand the importance of controlling moisture and other contaminants in the refrigerant circuit; they should know how to clean a hermetic system if it has been opened for service (see Chapter 6 of the 2006 *ASHRAE Handbook—Refrigeration*). Proper service procedures help ensure that the equipment will continue operating efficiently for its expected life.

### Sustainability

Unitary equipment should be properly sized; oversizing should be avoided. Only environmentally friendly refrigerants should be used. Equipment performance should be carefully evaluated at all expected load conditions, and equipment should be selected to achieve the most efficient operation at all expected occupancy conditions.

## TYPES OF UNITARY EQUIPMENT

[Table 1](#) shows the types of unitary air conditioners available, and [Table 2](#) shows the types of unitary heat pumps available. The following variations apply to some types and sizes of unitary equipment.

**Arrangement.** Major unit components for various unitary air conditioners are arranged as shown in [Table 1](#) and for unitary heat pumps as shown in [Table 2](#).

**Heat Rejection.** Unitary air conditioner condensers may be air-cooled, evaporatively cooled, or water-cooled; the letters A, E, or W follow the Air-Conditioning and Refrigeration Institute (ARI) designation.

**Heat Source/Sink.** Unitary heat pump outdoor coils are designated as air-source or water-source by an A or W, following ARI practice. The same coils that act as a heat sink in the cooling mode act as the heat source in the heating mode.

**Unit Exterior.** The unit exterior should be decorative for in-space application, functional for equipment room and ducts, and weatherproofed for outdoors.

**Placement.** Unitary equipment can be mounted on floors, walls, ceilings, roofs, or a pad on the ground.

**Inside Air.** Equipment with fans may have airflow arranged for vertical upflow or downflow, horizontal flow, 90° or 180° turns, or multizone. Indoor coils without fans are intended for forced-air furnaces or blower packages. Variable-volume blowers may be incorporated with some systems.

**Location.** Unitary equipment intended for indoor use may be placed in the conditioned space with plenums or furred-in ducts or concealed in closets, attics, crawlspaces, basements, garages, utility rooms, or equipment rooms. Wall-mounted equipment may be attached to or built into a wall or transom. Outdoor equipment may be mounted on roofs or concrete pads on the ground. Installations must conform with local codes.

**Table 1 ARI Standard 210/240 Classification of Unitary Air Conditioners**

System Designation	ARI Type*	Heat Rejection	Arrangement	
Single package	SP-A	Air	Fan	Comp
	SP-E	Evap Cond	Evap	Cond
	SP-W	Water		
Refrigeration chassis	RCH-A	Air		Comp
	RCH-E	Evap Cond	Evap	Cond
	RCH-W	Water		
Year-round single package	SPY-A	Air	Fan	
	SPY-E	Evap Cond	Heat	Comp
	SPY-W	Water	Evap	Cond
Remote condenser	RC-A	Air	Fan	
	RC-E	Evap Cond	Evap	Cond
	RC-W	Water	Comp	
Year-round remote condenser	RCY-A	Air	Fan	
	RCY-E	Evap Cond	Evap	Cond
	RCY-W	Water	Heat	
			Comp	
Condensing unit, coil alone	RCU-A-C	Air	Evap	Cond
	RCU-E-C	Evap Cond		Comp
	RCU-W-C	Water		
Condensing unit, coil and blower	RCU-A-CB	Air	Fan	Cond
	RCU-E-CB	Evap Cond	Evap	Comp
	RCU-W-CB	Air		
Year-round condensing unit, coil and blower	RCUY-A-CB	Air	Fan	
	RCUY-E-CB	Evap Cond	Evap	Cond
	RCUY-W-CB	Water	Heat	
			Comp	

\*Adding a suffix of “-O” to any of these classifications indicates equipment not intended for use with field-installed duct systems.

**Table 2 ARI Standard 210/240 Classification of Air-Source Unitary Heat Pumps**

Designation	ARI Type*		Arrangement				
	Heating and Cooling	Heating Only					
Single package	HSP-A	HOSP-A	Fan		Comp		
			Indoor Coil		Outdoor Coil		
Remote outdoor coil	HRC-A-CB	HORC-A-CB	Fan				
			Indoor Coil		Outdoor Coil		
			Comp				
Remote outdoor coil with no indoor fan	HRC-A-C	HORC-A-C	Indoor Coil		Outdoor Coil		
			Comp				
Split system	HRCU-A-CB	HORCU-A-CB	Fan		Comp		
			Indoor Coil		Outdoor Coil		
Split system, no indoor fan	HRCU-A-C	HORCU-A-C			Comp		
			Indoor Coil		Outdoor Coil		
Through-the-wall heat pump	TTW-HSP-A	TTW-HOSP-A	Fan	Comp	or	Fan	Comp
	TTW-HRCU-A-C	TTW-HORCU-A-C	Indoor Coil	Outdoor Coil		Indoor Coil	Outdoor Coil
	TTW-HRCU-A-CB	TTW-HORCU-A-CB					
Space-constrained products	SCP-HSP-A	SCP-HOSP-A	Fan	Comp	or	Fan	Comp
	SCP-HRCU-A-C	SCP-HORCU-A-C	Indoor Coil	Outdoor Coil		Indoor Coil	Outdoor Coil
	SCP-HRCU-A-CB	SCP-HORCU-A-CB					
Small-duct, high-velocity system	SDHV-HSP-A	SDHV-HOSP-A	Fan	Comp	or	Fan	Comp
	SDHV-HRCU-A-C	SDHV-HORCU-A-C	Indoor Coil	Outdoor Coil		Indoor Coil	Outdoor Coil
	SDHV-HRCU-A-CB	SDHV-HORCU-A-CB					

\*A suffix of “-O” following any of these classifications indicates equipment not intended for use with field-installed duct systems.

**Heat.** Unitary systems may incorporate gas-fired, oil-fired, electric, hot-water coil, or steam coil heating sections. In unitary heat pumps, these heating sections supplement the heating capability.

**Ventilation Air.** Outside air dampers may be built into equipment to provide outside air for cooling or ventilation.

**Refrigerant Flow.** Unitary equipment can use either constant or variable refrigerant flow.

**Desuperheaters.** Desuperheaters may be applied to unitary air conditioners and heat pumps. These devices recover heat from the compressor discharge gas and use it to heat domestic hot water. The desuperheater usually consists of a pump, heat exchanger, and controls, and can produce about 5 to 6 gph of heated water per ton of air conditioning (heating water from 60 to 130°F). Because desuperheaters improve cooling performance and reduce the degrading effect of cycling during heating, they are best applied where cooling requirements are high and where a significant number of heating hours occur above the building's balance point (Counts 1985). Although properly applied desuperheaters can improve cooling efficiency, they can also reduce space-heating capacity. This causes the unit to run longer, which reduces system cycling above the balance point.

**Ductwork.** Unitary equipment is usually designed with fan capability for ductwork, although some units may be designed to discharge directly into the conditioned space.

**Accessories.** Consult the manufacturer of any unitary equipment before installing any accessories or equipment not specifically approved by the manufacturer. These installations may not only void the warranty, but also could cause the unitary equipment to function improperly or create fire or explosion hazards.

### Combined Space-Conditioning/Water-Heating Systems

Unitary systems are available that provide both space conditioning and potable-water heating. These systems are typically heat pumps, but some are available for cooling only. One type of combined system includes a full-condensing water-heating heat exchanger integrated into the refrigerant circuit of the space-conditioning system. Full-condensing system heat exchangers are larger than desuperheaters; they are generally sized to take the full condensing output of the compressor. Thus, they have much greater water-heating capacity. They also have controls that allow them to heat water year-round, either independently or coincidentally with space heating or space cooling. In spring and fall, the system is typically operated only to heat water.

Another type of combined system incorporates a separate, ancillary **heat pump water heater (HPWH)**. The evaporator of this heater typically uses the return air (or liquid) stream of the space-conditioning system as a heat source. The HPWH thus cools the return stream during both space heating and cooling. In spring and fall, the space-conditioning blower (or pump) operates when water heating is needed.

As with desuperheaters, simultaneous space and water heating reduces the output for space heating. This lower output is partially compensated for by reduced cycling of the space-heating system above the balance point.

Combined systems can provide end users with significant energy savings, and electric utilities with a significant reduction in demand. The overall performance of these systems is affected by the refrigerant charge and piping, water piping, and control logic and wiring. It is important, therefore, that the manufacturer's recommendations be closely followed. One special requirement is to locate water-containing section(s) in areas not normally subjected to freezing temperatures.

### Typical Unitary Equipment

Figures 1 to 6 show various types and installations of single-package equipment. Figure 7 shows a typical installation of a split-system, air-cooled condensing unit with indoor coil (the most widely used

unitary cooling system). Figures 8 and 9 show split-system condensing units with coils and blower-coil units. Figure 8 also shows ductless blower-coil units, discharging air directly into the space. Ductless indoor units can be wall mounted, under ceiling mounted, or ceiling cassette. See Chapter 7 for information on engine-driven heat pumps and air conditioners.

Many special light commercial and commercial unitary installations include a single-package air conditioner for use with variable air volume systems, as shown in Figure 2. These units are often equipped with a factory-installed system for controlling air volume in response to supply duct pressure (such as dampers or variable-speed drives).

Another example of a specialized unit is the **multizone unit** shown in Figure 1. The manufacturer usually provides all controls, including zone dampers. The air path in these units is designed so that supply air may flow through a hot deck containing a means of heating or through a cold deck, which usually contains a direct-expansion evaporator coil.

To make multizone units more efficient, a control is commonly provided that locks out cooling by refrigeration when the heating unit is in operation and vice versa. Another variation to improve efficiency is the three-deck multizone. This unit has a hot deck, a

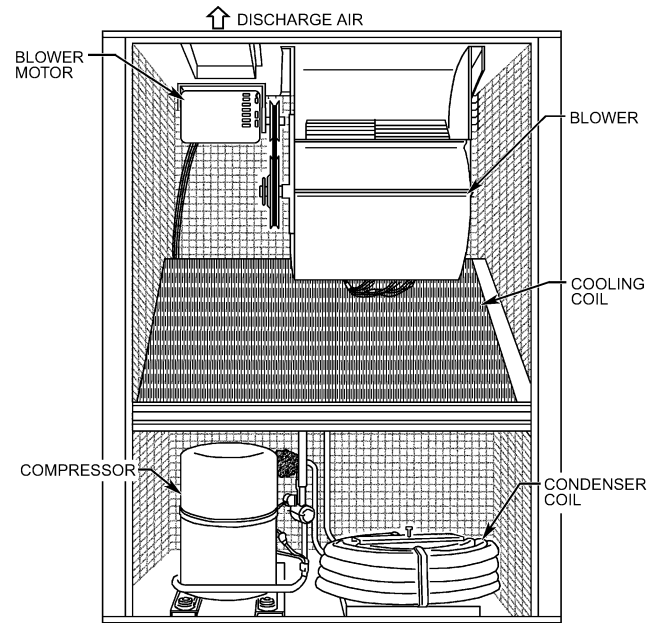


Fig. 3 Water-Cooled Single-Package Air Conditioner

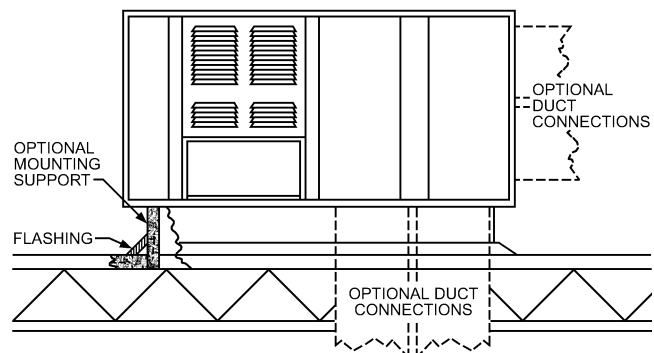
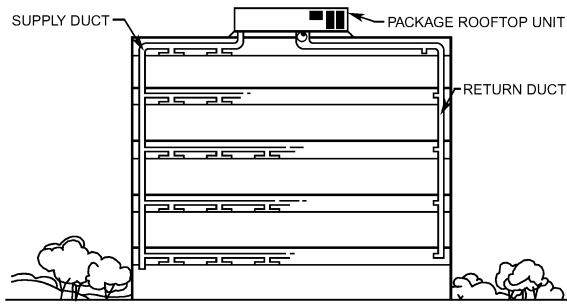
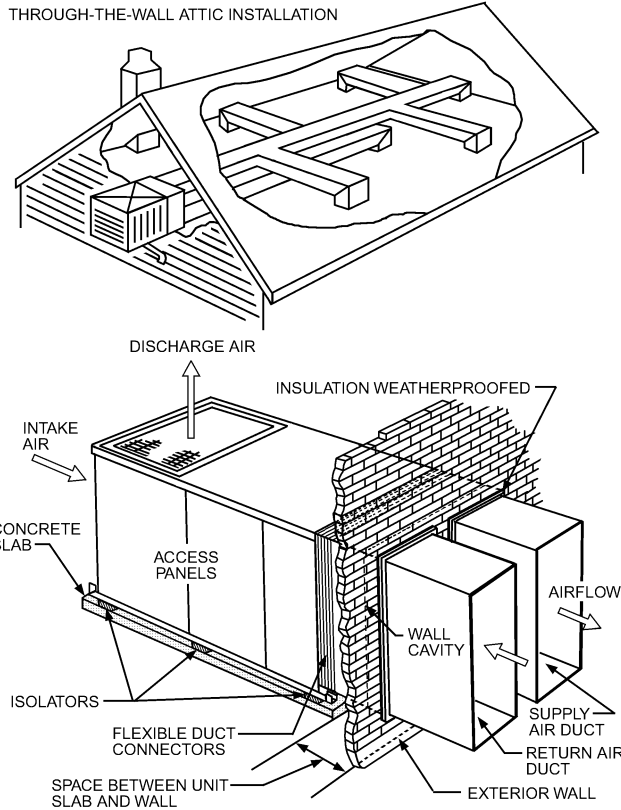


Fig. 4 Rooftop Installation of Air-Cooled Single-Package Unit



**Fig. 5 Multistory Rooftop Installation of Single-Package Unit**



**Fig. 6 Through-the-Wall Installation of Air-Cooled Single-Package Unit**

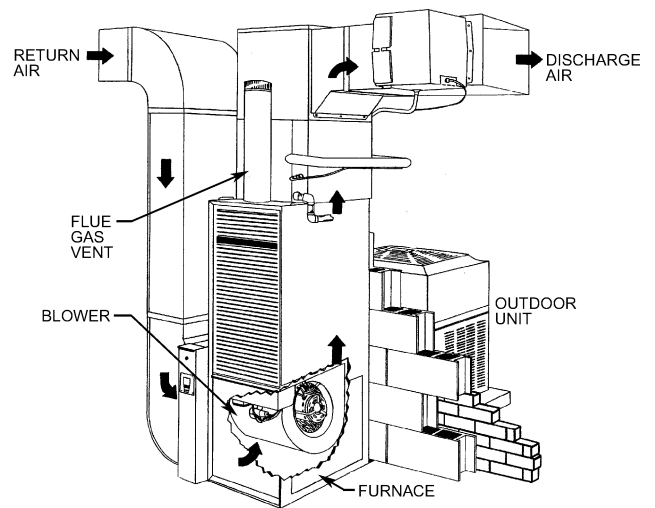
cold deck, and a neutral deck carrying return air. Hot and/or cold deck air mixes only with air in the neutral deck.

**EQUIPMENT AND SYSTEM STANDARDS**

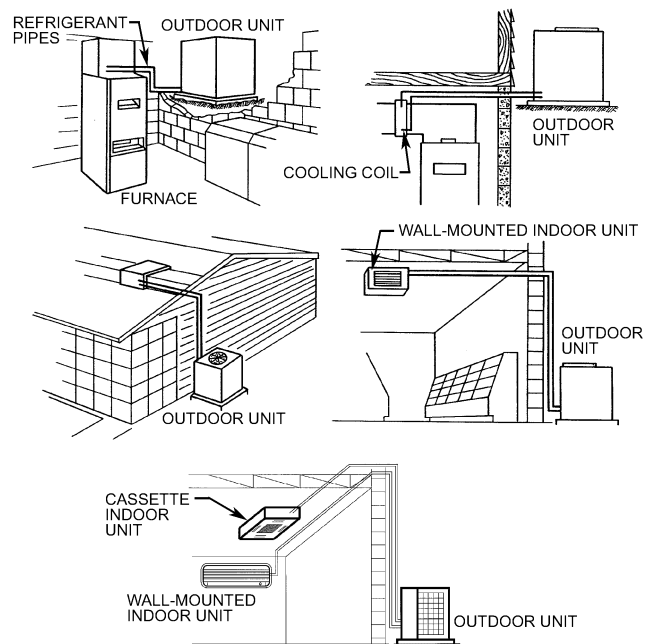
**Energy Conservation and Efficiency**

In the United States, the Energy Policy and Conservation Act (Public Law 95-163) requires the Federal Trade Commission (FTC) to prescribe an energy label for many major appliances, including unitary air conditioners and heat pumps. The National Appliance Energy Conservation Act (NAECA) (Public Law 100-12) provides minimum efficiency standards for major appliances, including unitary air conditioners and heat pumps.

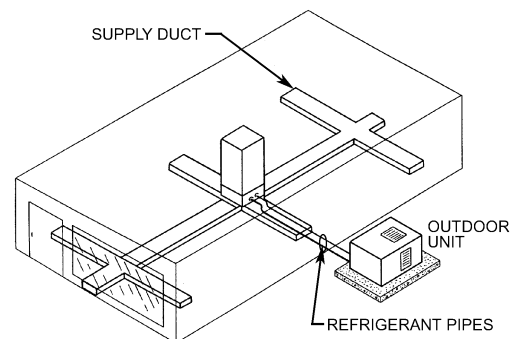
The U.S. Department of Energy (DOE) testing and rating procedure is documented in Appendix M to Subpart 430 of Section 10 of the *Code of Federal Regulations*, Uniform Test Method for Measuring the Energy Consumption of Central Air Conditioners. This testing procedure provides a seasonal measure of operating efficiency



**Fig. 7 Residential Installation of Split-System Air-Cooled Condensing Unit with Coil and Upflow Furnace**



**Fig. 8 Outdoor Installations of Split-System Air-Cooled Condensing Units with Coil and Upflow Furnace or with Indoor Blower-Coils**



**Fig. 9 Outdoor Installation of Split-System Air-Cooled Condensing Unit with Indoor Coil and Downflow Furnace**

for residential unitary equipment. The **seasonal energy efficiency ratio (SEER)** is the ratio of total seasonal cooling output measured in Btu to total seasonal watt-hours of input energy. This efficiency value is developed in the laboratory by conducting tests at various indoor and outdoor conditions, including a measure of performance under cyclic operation.

Seasonal heating mode efficiencies of heat pumps are similarly expressed as the ratio of total heating output to total seasonal input energy. This is expressed as a **heating seasonal performance factor (HSPF)**. In the laboratory, HSPF is determined from test results at different conditions, including a measure of cyclic performance. The calculated HSPF depends not only on the measured equipment performance, but also on climatic conditions and heating load relative to the equipment capacity.

For HSPF rating purposes, the DOE divided the United States into six climatic regions and defined a range of maximum and minimum design loads, producing about 30 different HSPF ratings for a given piece of equipment. The DOE established Region 4 (moderate northern climate) and minimum design load as the typical climatic region and building design load to be used for comparative certified performance ratings.

SEER, HSPF, and operating costs vary appreciably with equipment design and size and from manufacturer to manufacturer. SEER and HSPF values, size ranges, and unit operating costs for DOE-covered unitary air conditioners certified by ARI are published semi-annually in the ARI *Unitary Directory of Certified Product Performance*.

In the United States, the Energy Policy Act of 1992 requires unitary equipment with cooling capacities from 65,000 to 240,000 Btu/h to meet the minimum efficiency levels prescribed by ASHRAE *Standard* 90.1.

### ARI Certification Programs

ARI certification programs for unitary equipment include the following:

- Unitary air conditioners (water-, air-, and evaporatively cooled) under 65,000 Btu/h
- Air-source unitary heat pumps under 65,000 Btu/h
- Unitary large equipment at or above 65,000 Btu/h

Information on specific programs is available at [http://www.ari.org/Content/CertificationPrograms\\_19.aspx](http://www.ari.org/Content/CertificationPrograms_19.aspx). Smaller equipment is rated according to ARI *Standard* 210/240 and ARI *Standard* 37. Large equipment is rated according to ARI *Standard* 340/360 and 365. Sound ratings are discussed in ARI *Standard* 270, and sound application in ARI *Standard* 275.

### Safety Standards and Installation Codes

Approval agencies list unitary air conditioners complying with a standard such as CSA *Standard* C22.2 No. 236/Underwriters Laboratories (UL) *Standard* 1995. Other UL standards may also apply. An evaluation of the product determines that its design complies with the construction requirements specified in the standard and that the equipment can be installed in accordance with the applicable requirements of the *National Electrical Code*<sup>®</sup>; ASHRAE *Standard* 15; NFPA *Standard* 90A; and NFPA *Standard* 90B.

Tests confirm that the equipment and all components operate within their recognized ratings, including electrical, temperature, and pressure, when the equipment is energized at rated voltage and operated at specified environmental conditions. Stipulated abnormal conditions are also imposed under which the product must perform in a safe manner. The evaluation covers all operational features (such as electric space heating) that may be used in the product.

Products complying with the applicable requirements may bear the agency listing mark. An approval agency program includes auditing continued production at the manufacturer's factory.

## AIR CONDITIONERS

Unitary air conditioners consist of factory-matched refrigerant circuit components that are applied in the field to fulfill the user's requirements. The manufacturer often incorporates a heating function compatible with the cooling system and a control system that requires minimal field wiring.

Products are available to meet the objectives of nearly any system. Many different heating sections (gas- or oil-fired, electric, or condenser reheat), air filters, and heat pumps, which are a specialized form of unitary product, are available. Such matched equipment, selected with compatible accessory items, requires little field design or field installation work.

### Refrigerant Circuit Design

Chapters 22, 37, and 38 describe coil, compressor, and condenser designs. Chapters 2, 5, 6, and 7 of the 2006 ASHRAE *Handbook—Refrigeration* cover refrigerant circuit piping selection, chemistry, cleanliness, and lubrication. Proper coil circuiting is essential for adequate oil return to the compressor. Crankcase heaters are usually incorporated to prevent refrigerant migration to the compressor crankcase during shutdown. Oil pressure switches and pumpdown or pumpout controls are used when additional assurance of reliability is economical and/or required.

**Safety Controls.** High-pressure and high-temperature limiting devices, internal pressure bypasses, current-limiting devices, and devices that limit compressor torque prevent excessive mechanical and electrical stresses. Low-pressure or temperature cutout controllers may be used to protect against loss of charge, coil freeze-up, or loss of evaporator airflow. Because suction pressures drop momentarily during start-up, circuits with a low-pressure cutout controller may require a time-delay relay to bypass it momentarily to prevent nuisance tripping.

**Flow Control Devices.** Refrigerant flow is most commonly controlled either by a fixed metering device, such as a short-tube restrictor or capillary tube, or by thermostatic expansion valves. Capillaries and short-tube restrictors are simple, reliable, and economical, and can be sized for peak performance at rating conditions. The evaporator may be overfled at high condensing temperatures and underfled at low condensing temperatures because of changing pressure differential across the fixed metering device. Under these conditions, a less-than-optimum cooling capacity usually results. However, the degree of loss varies with condenser design, system volume, and total refrigerant charge. The amount of unit charge is critical, and a capillary-controlled evaporator must be matched to the specific condensing unit.

Properly sized thermostatic expansion valves provide constant superheat and good control over a range of operating conditions. Superheat is adjusted to ensure that only superheated gas returns to the compressor, usually with 7 to 14°F superheat at the compressor inlet at normal rating conditions. This superheat setting may be higher at a lower outdoor ambient temperature (cooling tower water temperature for water-cooled products) or indoor wet-bulb temperature. Compressor loading can be limited with vapor-charged thermostatic expansion valves. Low-discharge-pressure (low ambient) operation decreases pressure drop across valves and capillaries so that full flow is not maintained. Decreased capacity, low coil temperatures, and freeze-up can result unless low ambient condensing-pressure control is provided.

Properly designed unitary equipment allows only a minimum amount of liquid refrigerant to return through the suction line to the compressor during non-steady-state operation. Normally, the heat absorbed in the evaporator vaporizes all the refrigerant and adds a few degrees of superheat. However, any conditions that increase refrigerant flow beyond the heat transfer capabilities of the evaporator can cause liquid carryover into the compressor return line. This increase may be caused by a poorly positioned thermal element of

an expansion valve or by an increase in the condensing pressure of a capillary system, which may be caused by fouled condenser surfaces, excessive refrigerant charge, reduced flow of condenser air or water, or the higher temperature of the condenser cooling medium. Heat transfer at the evaporator may be reduced by dirty surfaces, low-temperature air entering the evaporator, or reduced airflow caused by a blockage in the air system.

**Piping.** Transient flow conditions are a special concern. During *off* periods, refrigerant migrates and condenses in the coldest part of the system. In an air conditioner in a cooled space, this area is typically the evaporator. When the compressor starts, the liquid tends to return to the compressor in slugs. The severity of **slugging** is affected by temperature differences, *off* time, component positions, and traps formed in suction lines. Various methods such as suction-line accumulators, specially designed compressors, the refrigerant pumpdown cycle, nonbleed port thermostatic expansion valves, liquid-line solenoid valves, or limited refrigerant charge are used to avoid equipment problems associated with excessive liquid return. Chapter 2 of the 2006 *ASHRAE Handbook—Refrigeration* has further information on refrigerant piping.

Strainers and filter-driers minimize the risk of foreign material restricting capillary tubes and expansion valves (e.g., small quantities of solder, flux, and varnish). Overheated and oxidized oil may dissolve in warm refrigerant and deposit at lower temperatures in capillary tubes, expansion valves, and evaporators. Filter-driers are highly desirable, particularly for split-system units, to remove any moisture introduced during installation or servicing. Moisture contamination can cause oil breakdown, motor insulation failure, and freezing or other restrictions at the expansion device.

**Capacity Control.** Buildings with high internal heat loads require cooling even at low outdoor temperatures. The capacity of air-cooled condensers can be controlled by changing airflow or flooding tubes with refrigerant. Airflow can be changed by using dampers, adjusting fan speed, or stopping some of the fan motors in a multifan system.

In cool weather, air conditioners operate for short periods only. If the weather is also damp, high humidity levels with wide variances may occur. Properly designed capacity-controlled units operate for longer periods, which may improve humidity control and comfort. In any case, cooling equipment should not be oversized.

Units with two or more separate refrigerant circuits allow independent operation of the individual systems, which reduces capacity while better matching changing load conditions. Larger, single-compressor systems may offer capacity reduction through cylinder-unloading compressors, variable-speed or multispeed compressors, multiple compressors, or hot-gas bypass controls. At full-load operation, efficiency is unimpaired. However, reduced-capacity operation may increase or decrease system efficiency, depending on the capacity-reduction method used.

Variable-speed, multispeed, and staged multiple compressors can improve efficiency at part-load operation. Cylinder unloading can increase or decrease system performance, depending on the particular method used. Multispeed and variable-speed compressors, multiple compressors, and cylinder unloading generally produce higher comfort levels through lower cycling and better matching of capacity to load. Hot-gas bypass does not reduce capacity efficiently, although it generally provides a wider range of capacity reduction. Units with capacity-reduction compressors usually have capacity-controlled evaporators; otherwise evaporator coil temperatures may be too high to provide dehumidification. Capacity-controlled evaporators are usually split, with at least one of the expansion valves controlled by a solenoid valve. Evaporator capacity is reduced by closing the solenoid valve. Compressor capacity-reduction controls or hot-gas bypass system then provides maximum dehumidification, while the evaporator coil temperature is maintained above freezing to avoid coil frosting. Chapter 2 of the 2006 *ASHRAE Handbook—Refrigeration* has details on hot-gas bypass.

## Air-Handling Systems

High airflow, low-static-pressure performance, simplicity, economics, and compact arrangement are characteristics that make propeller fans particularly suitable for nonducted air-cooled condensers. Small-diameter fans are direct-driven by four-, six-, or eight-pole motors. Low starting-torque requirements allow use of single-phase shaded pole and permanent split-capacitor (PSC) fan motors and simplify speed control for low-outdoor-temperature operation. Many larger units use multiple fans and three-phase motors. Larger-diameter fans are belt-driven at a lower rpm to maintain low tip speeds and quiet operation.

Centrifugal blowers meet the higher static-pressure requirements of ducted air-cooled condensers, forced-air furnaces, and evaporators. Indoor airflow must be adjusted to suit duct systems and plenums while providing the required airflow to the coil. Some small blowers are direct-driven with multispeed motors. In ductless indoor units, such as wall-mounted, under-ceiling-mounted, and ceiling cassette units, aluminum or fire-retardant plastic centrifugal fans are used. Large blowers are always belt-driven and may have variable-pitch motor pulleys or a variable-frequency drive (VFD) for airflow adjustment. Vibration isolation reduces the amount of noise transmitted by bearings, motors, and blowers into cabinets. (See [Chapter 20](#) for details of fan design and [Chapters 18](#) and [19](#) for information on air distribution systems.)

Disposable fiberglass filters are popular because they are available in standard sizes at low cost. Cleanable filters can offer economic advantages, especially when cabinet dimensions are not compatible with common sizes. Charcoal filters can help remove volatile organic compounds (VOCs) or microparticles. Electronic or other high-efficiency air cleaners are used when a high degree of cleaning is desired. Larger equipment frequently is provided with automatic roll filters or high-efficiency bag filters. (See [Chapter 28](#) for additional details about filters.)

Many units have a way to introduce outside air for economizer cooling and/ or ventilation; rooftop units are particularly adaptable for receiving outside air. Air-to-air heat exchangers can be used to reduce energy losses from ventilation. Ductless units are provided with either a factory-mounted or a field-installed outside air kit. Some units have automatically controlled dampers to allow cooling by outside air, which increases system efficiency.

## Electrical Design

Electrical controls for unitary equipment are selected and tested to perform their individual and interrelated functions properly and safely over the entire range of operating conditions. Internal line-break thermal protectors provide overcurrent protection for most single-phase motors, smaller three-phase motors, and hermetic compressor motors. These rapidly responding temperature sensors, embedded in motor windings, can provide precise locked rotor and running overload protection.

Branch-circuit, short-circuit, and ground-fault protection is commonly provided by fused disconnect switches. Time-delay fuses allow selection of fuse ratings closer to running currents and thus provide backup motor overload protection, as well as short-circuit and ground-fault protection. Circuit breakers may be used in lieu of fuses where allowed by codes.

Some larger compressor motors have dual windings and contactors for step starting. A brief delay when energizing contactors reduces the magnitude of inrush current.

Using 24 V (NEC Class 2) control circuitry is common for room thermostats and interconnecting wiring between split systems. It offers advantages in temperature control, safety, and ease of installation. Electronic, communicating microprocessor thermostats and control systems are common.

Motor-speed controls are used to vary evaporator airflow of direct-drive fans, air-cooled condenser airflow for low-outdoor-temperature operation, and compressor speed to match load

demand. Multitap motors and autotransformers provide one or more speed steps. Solid-state speed control circuits provide a continuously variable speed range. However, motor bearings, windings, overload protection, and motor suspension must be suitable for operation over the full speed range.

In addition to speed control, solid-state circuits can provide reliable temperature control, motor protection, and expansion valve refrigerant control. Complete temperature-control systems are frequently included with the unit. Features such as automatic night setback, economizer control sequence, and zone demand control of multizone equipment contribute to improved comfort and energy savings. Chapter 46 of the 2007 *ASHRAE Handbook—HVAC Applications* has additional information on control systems.

### Mechanical Design

Cabinet height is important for rooftop and ceiling-suspended units. Size limitations of truck bodies, freight cars, doorways, elevators, and various rigging practices must be considered in large-unit design. In addition, structural strength of both the unit and the crate must be adequate for handling, warehouse stacking, shipping, and rigging.

Additionally, (1) cabinet insulation must prevent excessive sweating in high-humidity ambient conditions, (2) insulated surfaces exposed to moving air should withstand air erosion, (3) air leakage around panels and at cabinet joints should be minimized, (4) cabinet and coils should be provided with a corrosion-resistant coating in highly corrosive environments, and (5) cabinet insulation must be adequate to reduce energy transfer losses from the circulating airstream.

Also, cooling-coil air velocities must be low enough to ensure that condensate is not blown off the coil. The drain pan must be sized to contain the condensate, must be protected from high-velocity air, and should be properly sloped to drain condensate to minimize standing water. Service access must be provided for installation and repair. Versatility of application, such as multiple fan discharge directions and the ability to install piping from either side of the unit, is another consideration. Weatherproofing requires careful attention and testing.

### Accessories

Using standard cataloged accessories, the designer can often incorporate unitary products in special applications. Typical examples (see [Figures 4, 6, 7, and 8](#)) are plenum coil housings, return air filter grilles, and diffuser-return grilles for single-outlet units. Air duct kits offered for rooftop units (see [Figure 4](#)) allow concentric or side-by-side ducting, as well as horizontal or vertical connections. Mounting curbs are available to facilitate unit support and roof flashing. Accessories for ductless split units include wireless or wired thermostats, motorized air sweep flow louvers that automatically change airflow directions, and wind baffle kits for condensing-unit operation during high winds. Other accessories include high-static-pressure fan drives, controls for low-outdoor-temperature operation, and duct damper kits for control of outside air intakes and exhausts.

### Heating

It is important to install cooling coils downstream of furnaces so that condensation does not form inside the combustion and flue passages. Upstream cooling-coil placement is permissible when the furnace has been approved for this type of application and designed to prevent corrosion. Burners, pilot flames, and controls must be protected from the condensate.

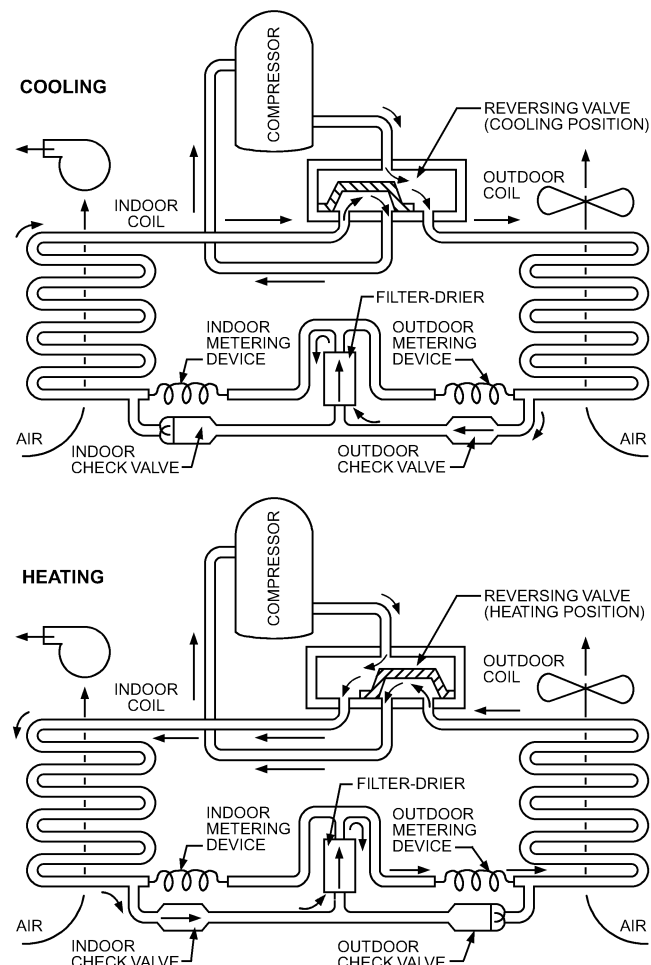
[Chapter 26](#) describes hot-water and steam coils used in unitary equipment, as well as the prevention of coil freezing from ventilation air in cold weather. [Chapters 27, 30, and 32](#) discuss forced-air and oil- and gas-fired furnaces commonly used with, or included as part of, year-round equipment.

### AIR-SOURCE HEAT PUMPS

Capacities of unitary air-source heat pumps range from about 1.5 to 30 tons, although there is no specific limitation. This equipment is used in residential, commercial, and industrial applications. Multiunit and multisplit systems installations are particularly advantageous because they permit zoning, which allows heating or cooling in each zone on demand. Application factors unique to unitary heat pumps include the following:

- The unitary heat pump normally fulfills a dual function: heating and cooling; therefore, only a single piece of equipment is required for year-round comfort. Some regions, especially central and northern Europe and parts of North America, have little need for cooling. Some manufacturers offer heating-only heat pumps for these areas and for special applications.
- A single energy source can supply both heating and cooling requirements.
- Heat output can be as much as two to four times that of the purchased energy input.
- Vents and/or chimneys may be eliminated, thus reducing building costs.

In an air-source heat pump ([Figure 10](#)), the outdoor coil rejects heat to outside air in cooling mode and extracts heat from outside air in heating mode. Most residential applications consist of an indoor fan and coil unit, either vertical or horizontal, and an outdoor fan-coil unit. The compressor is usually in the outdoor unit. Electric



**Fig. 10 Schematic Typical of Air-to-Air Heat Pump System**

heaters are commonly included in the indoor unit to provide heat during defrost cycles and during periods of high heating demand that cannot be satisfied by the heat pump alone.

**Add-On Heat Pumps**

An air-source heat pump can be added to new or existing gas- or oil-fired furnaces. This unit, typically called an add-on, dual-fuel, or hybrid heat pump, normally operates as a conventional heat pump. During extremely cold weather, the refrigerant circuit is turned off and the furnace provides the required space heating. These add-on heat pumps share the air distribution system with the warm-air furnace. The indoor coil may be either parallel to or in series with the furnace. However, the furnace should never be upstream of the indoor coil if both systems are operated together.

Special controls are available that prevent simultaneous operation of the heat pump and furnace in this configuration. This operation raises the refrigerant condensing temperature, which could cause compressor failure. In applications where the heat pump and furnace operate simultaneously, the following conditions must be met: (1) the furnace and heat pump indoor coil must be arranged in parallel, or (2) the furnace combustion and flue passages must be designed to avoid condensation-induced corrosion during cooling operation.

**Selection**

Figure 11 shows performance characteristics of a single-speed, air-source heat pump, along with heating and cooling loads for a typical building. Heat pump heating capacity decreases as ambient temperature decreases. This characteristic is opposite to the trend of the building load. The outdoor temperature at which heat pump capacity equals the building load is called the **balance point**. When outdoor temperature is below the balance point, supplemental heat (usually electric resistance) must be added to make up the difference, as shown by the shaded area. The coefficient of performance (COP) shown in Figure 11 is for the refrigerant circuit only and does not include supplemental heat effects below the balance point.

In selecting the proper size heat pump, the building cooling load is calculated using standard practice. The heating balance point may be lowered by improving the structure’s thermal performance or by

choosing a heat pump larger than the cooling load requires. Excessive oversizing of cooling capacity causes excessive cycling, which results in uncomfortable temperature and humidity levels during cooling.

Using variable-speed, multispeed, or multiple compressors and variable-speed fans can improve matching of both heating and cooling loads over an extended range. This equipment can reduce cycling losses and improve comfort levels.

Building codes must be consulted before specifying indoor units that use plastic components where the proposed installation is in a return air plenum, because many codes require all materials exposed to airflow to be noncombustible or of limited combustibility, with a maximum smoke-developed index of 50.

**Refrigerant Circuit and Components**

In cold climates, heat pump yearly operating hours are often up to five times those of a cooling-only unit. In addition, heating extends over a greater range of operating conditions at higher-stress conditions, so the design must be thoroughly analyzed to ensure maximum reliability. Improved components and protective devices increase reliability, but the equipment designer must select components that are approved for the specific application.

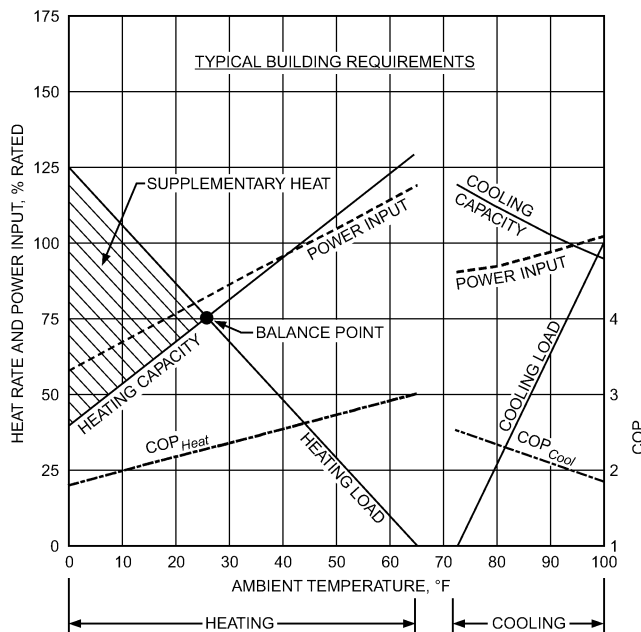
For a reliable and efficient heat pump system, the following factors must be considered: (1) outdoor coil circuitry, (2) defrost and water drainage, (3) refrigerant flow controls, (4) refrigerant charge management, and (5) compressor selection.

**Outdoor Coil Circuitry.** When the heat pump is used for heating, the outdoor coil operates as an evaporator. The refrigerant in the coil is less dense than when the coil operates as a condenser. To avoid excessive pressure drop during heating, circuitry usually compromises between optimum performance as an evaporator and as a condenser.

**Defrost and Water Drainage.** During colder outdoor temperatures, usually below 40 to 50°F, and high relative humidities (above 50%), the outdoor coil operates below the frost point of the outside air. Frost that builds up on the coil surface is usually removed by **reverse-cycle defrost**. In this method, refrigerant flow in the system is reversed, and hot gas from the compressor flows through the outdoor coil, melting the frost. A typical defrost takes 4 to 10 min. The outdoor fan is normally off during defrost. Because defrost is a transient process, capacity, power, and refrigerant pressures and temperatures in different parts of the system change throughout the defrost period (Miller 1989; O’Neal et al. 1989a).

Heat pump performance during defrost can be enhanced in several ways. Defrost times and water removal can be improved by ensuring that adequate refrigerant is routed to the lower refrigerant circuits in the outdoor coil. Properly sizing the defrost expansion device is critical for reducing defrost times and energy use (O’Neal et al. 1989b). If the expansion device is too small, suction pressure can be below atmospheric, defrost times become long, and energy use is high. If the expansion device is too large, the compressor can be flooded with liquid refrigerant. During conventional reverse-cycle defrost, there is a significant pressure spike at defrost termination. Starting the outdoor fan 30 to 45 s before defrost termination can minimize the spike (Anand et al. 1989). In cold climates, the cabinet should be installed above grade to provide good drainage during defrost and to minimize snow and ice build-up around the cabinet. During prolonged periods of severe weather, it may be necessary to clear ice and snow from around the unit.

Several methods are used to determine the need to defrost. One common, simple, and reliable control method is to initiate defrost at predetermined time intervals (usually 90 min). Demand-type systems detect a need for defrosting by measuring changes in air pressure drop across the outdoor coil or changes in temperature difference between the outdoor coil and outside air. Microprocessors are used to control this function, as well as numerous other func-



**Fig. 11 Operating Characteristics of Single-Stage Unmodulated Heat Pump**

tions (Mueller and Bonne 1980). Demand defrost control is preferred because it requires less energy than other defrost methods.

**Refrigerant Flow Controls.** Separate refrigerant flow controls are usually used for indoor and outdoor coils. Because refrigerant flow reverses direction between heating and cooling modes, a check valve bypasses in the appropriate direction around each expansion device. Capillaries, fixed orifices, thermostatic expansion valves, or electronically controlled expansion valves may be used; however, capillaries and fixed orifices require that greater care be taken to prevent excessive flooding of refrigerant into the compressor. A check valve is not needed when an orifice expansion device or biflow expansion valve is used. The reversing valve is the critical additional component required to make a heat pump air-conditioning system.

**Refrigerant Charge Management.** Extra care is required to control compressor flooding and refrigerant storage in the system during both heating and cooling. The mass flow of refrigerant during cooling is greater than during heating. Consequently, the amount of refrigerant stored may be greater in heating mode than in cooling, depending on the relative internal volumes of the indoor and outdoor coils. Usually, the internal volume of indoor coils ranges from 110 to 70% of the outdoor coil volume. The relative volumes can be adjusted so the coils not only transfer heat but also manage the charge.

When capillaries or fixed orifices are used, the refrigerant may be stored in an accumulator in the suction line or in receivers that can remove the refrigerant charge from circulation when compressor floodback is imminent. Thermostatic expansion valves reduce the flooding problem, but storage may be required in the condenser. Using accumulators and/or receivers is particularly important in split systems.

To maintain performance reliability, the amount of refrigerant in the system must be checked and adjusted in accordance with the manufacturer's recommendations, particularly when charging a heat pump. Manufacturer recommendations for accumulator installation must be followed so that good oil return is ensured.

**Compressor Selection.** Compressors are selected on the basis of performance, reliability, and probable applications of the unit. In good design practice, equipment manufacturers often consult with compressor manufacturers during both design and application phases of the unitary equipment to verify proper application of the compressor. Compressors in a heat pump operate over a wide range of suction and discharge pressures; thus, their design parameters (e.g., refrigerant discharge temperatures, pressure ratios, clearance volume, motor-overload protection) require special consideration. In all operating conditions, compressors should be protected against loss of lubrication, liquid floodback, and high discharge temperatures.

### System Control and Installation

Installation should follow the manufacturer's instructions. Because supply air from a heat pump is usually at a lower temperature (typically 90 to 100°F) than that from most heating systems, ducts and supply registers should control air velocity and throw to minimize the perception of cool drafts.

Low-voltage heating/cooling thermostats control heat pump operation. Ductless split units are usually controlled by wireless thermostats. Models that switch automatically from heating to cooling operation and manual-selection models are available. Usually, heating is controlled in two stages. The first stage controls heat pump operation, and the second stage controls supplementary heat. When the heat pump cannot satisfy the first stage's call for heat, supplementary heat is added by the second-stage control. The amount of supplementary heat is often controlled by an outdoor thermostat that allows additional stages of heat to be turned on only when required by the colder outdoor temperature.

Microprocessor technology has led to night setback modes and intelligent recovery schemes for morning warm-up on heat pump

systems (see Chapter 46 of the 2007 *ASHRAE Handbook—HVAC Applications*).

### WATER-SOURCE HEAT PUMPS

A water-source heat pump (WSHP) is a single-package reverse-cycle heat pump that uses water as the heat source for heating and as the heat sink for cooling. The water supply may be a recirculating closed loop, a well, a lake, or a stream. Water for closed-loop heat pumps is usually circulated at 2 to 3 gpm per ton of cooling capacity. A **groundwater heat pump (GWHP)** can operate with considerably less water flow. The main components of a WSHP refrigeration system are a compressor, refrigerant-to-water heat exchanger, refrigerant-to-air heat exchanger, refrigerant expansion devices, and refrigerant-reversing valve. [Figure 12](#) shows a schematic of a typical WSHP system.

Designs of packaged WSHPs range from horizontal units located primarily above the ceiling or on the roof, to vertical units usually located in basements or equipment rooms, to console units located in the conditioned space. [Figures 13](#) and [14](#) illustrate typical designs.

### Systems

WSHPs are used in a variety of systems, such as

- Water-loop heat pump systems ([Figure 15A](#))
- Groundwater heat pump systems ([Figure 15B](#))
- Closed-loop surface-water heat pump systems ([Figure 15C](#))
- Surface-water heat pump systems ([Figure 15D](#))
- Ground-coupled heat pump systems ([Figure 15E](#))

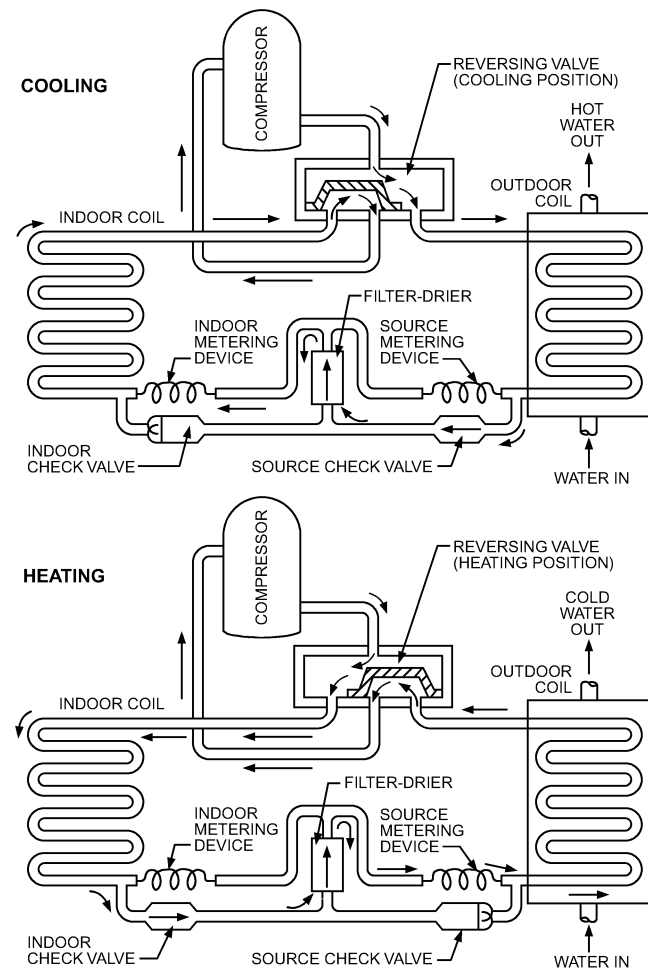


Fig. 12 Schematic of Typical Water-Source Heat Pump System

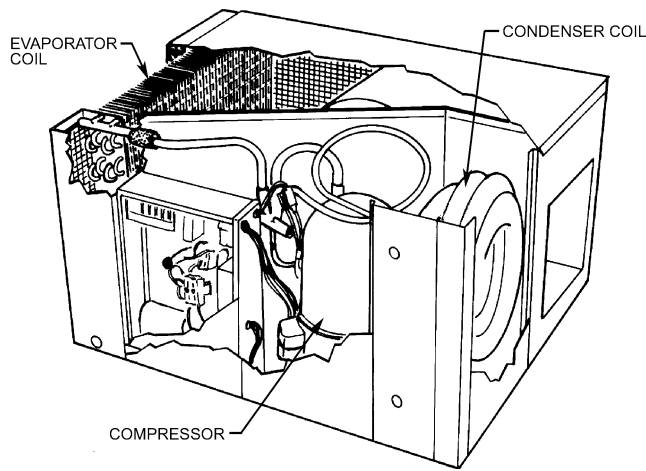


Fig. 13 Typical Horizontal Water-Source Heat Pump

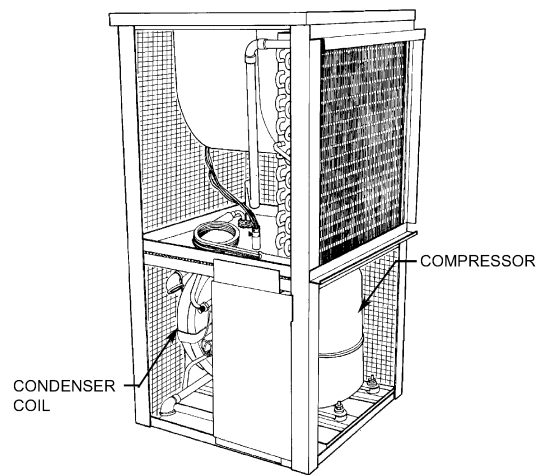
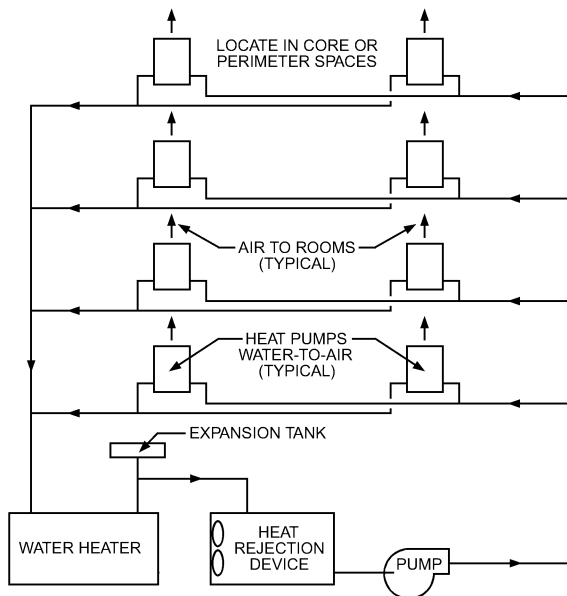
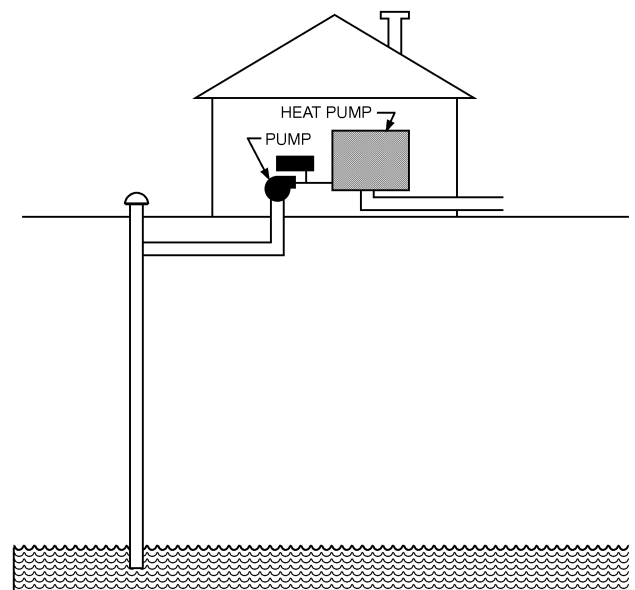


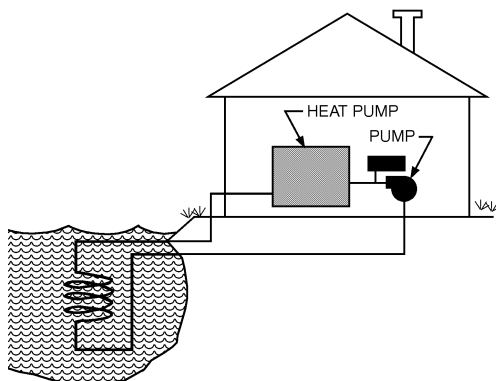
Fig. 14 Typical Vertical Water-Source Heat Pump



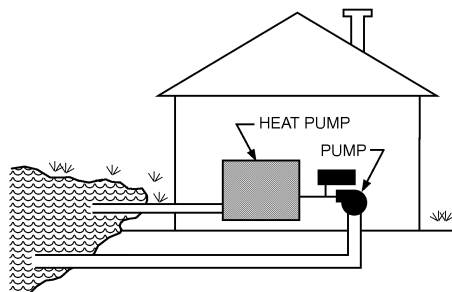
A. WATER-LOOP HEAT PUMP SYSTEM



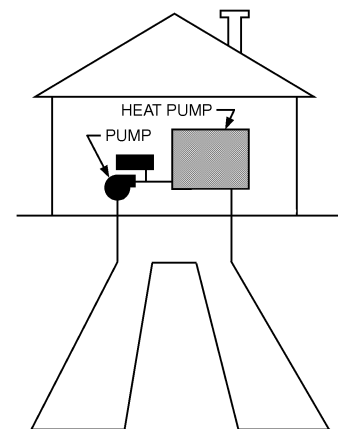
B. GROUNDWATER HEAT PUMP SYSTEM



C. CLOSED-LOOP SURFACE-WATER HEAT PUMP SYSTEM



D. SURFACE-WATER HEAT PUMP SYSTEM



E. GROUND-COUPLED HEAT PUMP SYSTEM

Fig. 15 Water-Source Heat Pump Systems

A **water-loop heat pump (WLHP)** uses a circulating water loop as the heat source and heat sink. When loop water temperature exceeds a certain level during cooling, a cooling tower dissipates heat from the water loop into the atmosphere. When loop water temperature drops below a prescribed level during heating, heat is added to the circulating loop water, usually with a boiler. In multiple-unit installations, some heat pumps may operate in cooling mode while others operate in heating, and controls are needed to keep loop water temperature within the prescribed limits. [Chapter 8](#) has more information on water-loop heat pumps.

A **groundwater heat pump (GWHP)** passes groundwater from a nearby well through the heat pump's water-to-refrigerant heat exchanger, where it is warmed or cooled, depending on the operating mode. It is then discharged to a drain, stream, or lake, or is returned to the ground through a reinjection well.

Many state and local jurisdictions have ordinances about use and discharge of groundwater. Because aquifers, the water table, and groundwater availability vary from region to region, these regulations cover a wide spectrum.

A **surface-water heat pump (SWHP)** uses water from a nearby lake, stream, or canal. After passing through the heat pump heat exchanger, it is returned to the source or a drain several degrees warmer or cooler, depending on the operating mode of the heat pump. **Closed-loop** surface water heat pumps use a closed water or brine loop that includes pipes or tubing submerged in the surface water (river, lake, or large pond) that serves as the heat exchanger. The adequacy of the total thermal capacity of the body of water must be considered.

A **ground-coupled heat pump (GCHP)** system uses the earth as a heat source and sink. Usually, plastic piping is installed in either a shallow horizontal or deep vertical array to form the heat exchanger. The massive thermal capacity of the earth provides a temperature-stabilizing effect on the circulating loop water or brine. Installing this type of system requires detailed knowledge of the climate; site; soil temperature, moisture content, and thermal characteristics; and performance, design, and installation of water-to-earth heat exchangers. Additional information on GCHP systems is presented in Chapter 32 of the 2007 *ASHRAE Handbook—HVAC Applications*.

**Entering Water Temperatures.** These various water sources provide a wide range of entering water temperatures to WSHPs. Entering water temperatures vary not only by water source, but also by climate and time of year. Because of the wide range of entering water or brine temperatures encountered, it is not feasible to design a universal packaged product that can handle the full range of possibilities effectively. Therefore, WSHPs are rated for performance at a number of standard rating conditions.

### Performance Certification Programs

ARI certifies water-to-air and brine-to-air heat pumps rated below 135,000 Btu/h. Certification is based on ISO *Standard* 13256-1. For details, go to [http://www.ari.org/Content/WatertoAirandBrinetoAirHeatPumps\\_102.aspx](http://www.ari.org/Content/WatertoAirandBrinetoAirHeatPumps_102.aspx).

### Equipment Design

Water-source heat pumps are designed to match differing levels of entering water temperatures by optimizing the relative sizing of the indoor refrigerant-to-air heat exchanger and refrigerant-to-water heat exchangers and by matching expansion devices to refrigerant flow rates.

**Compressors.** WSHPs usually have single-speed compressors, although some high-efficiency models use multispeed compressors. Higher-capacity equipment may use multiple compressors. Compressors may be reciprocating, rotary, or scroll. Single-phase units are available at voltages of 115, 208, 230, and 265. All larger equipment is for three-phase power supplies with voltages of 208, 230, 460, or 575. Compressors usually have electromechanical protective devices.

**Table 3 Space Requirements for Typical Packaged Water-Source Heat Pumps**

Water-to-Air Heat Pump	Length × Width × Height, ft	Weight, lb
1.5 ton vertical unit	2.0 × 2.0 × 3.0	180
3 ton vertical unit	2.5 × 2.5 × 4.0	250
3 ton horizontal unit	3.5 × 2.0 × 2.0	250
5 ton vertical unit	3.0 × 2.5 × 4.0	330
11 ton vertical unit	3.5 × 3.0 × 6.0	720
26 ton vertical unit	3.5 × 5.0 × 6.0	1550

Note: See manufacturers' specification sheets for actual values.

**Inside Air System.** Console WSHP models are designed for free delivery of conditioned air. Other models have ducting capability. Smaller WSHPs have multispeed, direct-drive centrifugal blower wheel fan systems. Large-capacity equipment has belt-drive systems. All units have provisions for fiberglass, metal, or plastic foam air filters.

**Inside Air Heat Exchanger.** The indoor air heat exchanger of WSHP units is a conventional plate-fin coil of copper tubes and aluminum fins. The coil tubing is circuited so that it can function effectively as an evaporator with refrigerant flow in one direction and as a condenser when refrigerant flow is reversed.

**Refrigerant-to-Water Heat Exchanger.** The heat exchanger, which couples the heat pump to source/sink water, is tube-in-tube, tube-in-shell, or brazed-plate. It must function in either condensing or evaporating mode, so special attention is given to refrigerant-side circuitry. Heat exchanger construction is usually of copper and steel, and the source/sink water is exposed only to the copper portions. Cupronickel options to replace the copper are usually available for use with brackish or corrosive water. Brazed-plate heat exchangers are usually constructed of stainless steel, which reduces the need for special materials.

**Refrigerant Expansion Devices.** WSHPs rated in accordance with ARI *Standard* 320 operate over a narrow range of entering water temperatures, so most use simple capillaries as expansion devices. Units rated according to ARI *Standard* 325 or 330 usually use thermostatic expansion valves for improved performance over a broader range of inlet fluid temperatures.

**Refrigerant-Reversing Valve.** The refrigerant-reversing valves in WSHPs are identical to those used in air-source heat pumps.

**Condensate Disposal.** Condensate, which forms on the indoor coil when cooling, is collected and conveyed to a drain system.

**Controls.** Console WSHP units have built-in operating mode selector and thermostatic controls. Ducted units use low-voltage remote heat/cool thermostats.

**Size.** Typical space requirements and weights of WSHPs are presented in [Table 3](#).

**Special Features.** Some WSHPs include the following:

*Desuperheater.* Uses discharge gas in a special water/refrigerant heat exchanger to heat water for a building.

*Capacity modulation.* Multiple compressors, multispeed compressors, or hot-gas bypass may be used.

*Variable air volume (VAV).* Reduces fan energy usage and requires some form of capacity modulation.

*Automatic water valve.* Closes off water flow through the unit when the compressor is off and permits variable water volume in the loop, which reduces pumping energy.

*Outside-air economizer.* Cools directly with outside air to reduce or eliminate the need for mechanical refrigeration during mild or cold weather when outside humidity levels and air quality are appropriate.

*Water-side economizer.* Cools with loop water to reduce or eliminate the need for mechanical refrigeration during cold weather; requires a hydronic coil in the indoor air circuit that is valved into

the circulating loop when loop temperatures are relatively low and cooling is required.

*Electric heaters.* Used in WLHP systems that do not have a boiler as a source for loop heating.

### VARIABLE-REFRIGERANT-FLOW HEAT PUMPS

A variable-refrigerant-flow (VRF) system typically consists of a condensing section housing compressor(s) and condenser heat exchanger interconnected by a single set of refrigerant piping to multiple indoor direct-expansion (DX) evaporator fan-coil units. Thirty or more DX fan coil units can be connected to a single condensing section, depending on system design, and with capacity ranging from 0.5 to 8 tons.

The DX fan coils are constant air volume, but use variable refrigerant flow through an electronic expansion valve. The electronic expansion valve reacts to several temperature-sensing devices such as return air, inlet and outlet refrigerant temperatures, or suction pressure. The electronic expansion valve modulates to maintain the desired set point.

### Application

VRF systems are most commonly air-to-air, but are also available in a water-source (water-to-refrigerant) configuration. They can be configured for simultaneous heating and cooling operation (some indoor fan coil units operating in heating and some in cooling, depending on requirements of each building zone).

Indoor units are typically direct-expansion evaporators using individual electronic expansion devices and dedicated microprocessor controls for individual control. Each indoor unit can be controlled by individual thermostat. The outdoor unit may connect several indoor evaporator units with capacities 130% or more than the outdoor condensing unit capacity.

### Categories

VRF equipment is divided into three general categories: residential, light commercial, and applied. Residential equipment is single-phase unitary equipment with a cooling capacity of 65,000 Btu/h or less. Light commercial equipment is generally three-phase, with cooling capacity greater than 65,000 Btu/h, and is designed for small businesses and commercial properties. Applied equipment has cooling capacity higher than 135,000 Btu/h and is designed for large commercial buildings.

### Refrigerant Circuit and Components

VRF heat pump systems use a two-pipe (liquid and suction gas) system; simultaneous heat and cool systems use the same system, as well as a gas flow device that determines the proper routing of refrigerant gas to a particular indoor unit.

VRF systems use a sophisticated refrigerant circuit that monitors mass flow, oil flow, and balance to ensure optimum performance. This is accomplished in unison with variable-speed compressors and condenser fan motors. Both of these components adjust their frequency in reaction to changing mass flow conditions and refrigerant operating pressures and temperatures. A dedicated microprocessor continuously monitors and controls these key components to ensure proper refrigerant is delivered to each indoor unit in cooling or heating.

### Heating and Defrost Operation

In heating mode, VRF systems typically must defrost like any mechanical heat pump, using reverse cycle valves to temporarily operate the outdoor coil in cooling mode. Oil return and balance with the refrigerant circuit is managed by the microprocessor to ensure that any oil entrained in the low side of the system is brought back to the high side by increasing the refrigerant velocity using a

high-frequency operation performed automatically based on hours of operation.

### REFERENCES

- Anand, N.K., J.S. Schliesing, D.L. O'Neal, and K.T. Peterson. 1989. Effects of outdoor coil fan pre-start on pressure transients during the reverse cycle defrost of a heat pump. *ASHRAE Transactions* 95(2).
- ARI. 2006. Performance rating of unitary air-conditioning and air-source heat pump equipment. ANSI/ARI *Standard* 210/240-2006. Air-Conditioning and Refrigeration Institute, Arlington, VA.
- ARI. 1995. Sound rating of outdoor unitary equipment. *Standard* 270-95. Air-Conditioning and Refrigeration Institute, Arlington, VA.
- ARI. 1997. Application of sound rating levels of outdoor unitary equipment. *Standard* 275-97. Air-Conditioning and Refrigeration Institute, Arlington, VA.
- ARI. 1998. Water-source heat pumps. *Standard* 320-98. Air-Conditioning and Refrigeration Institute, Arlington, VA.
- ARI. 1998. Ground water-source heat pumps. *Standard* 325-98. Air-Conditioning and Refrigeration Institute, Arlington, VA.
- ARI. 1998. Ground source closed-loop heat pumps. *Standard* 330-98. Air-Conditioning and Refrigeration Institute, Arlington, VA.
- ARI. 2007. Commercial and industrial unitary air-conditioning and heat pump equipment. *Standard* 340/360-2007. Air-Conditioning and Refrigeration Institute, Arlington, VA.
- ARI. 2002. Commercial and industrial unitary air-conditioning condensing units. ANSI/ARI *Standard* 365-2002. Air-Conditioning and Refrigeration Institute, Arlington, VA.
- ARI. Semiannual. *Unitary directory of certified product performance*. Air-Conditioning and Refrigeration Institute, Arlington, VA. Available at <http://www.aridirectory.org/ari/unitary.html>.
- ASHRAE. 2004. Safety code for mechanical refrigeration. ANSI/ASHRAE *Standard* 15-2004.
- ASHRAE. 2005. Methods of testing for rating electrically driven unitary air-conditioning and heat pump equipment. ANSI/ASHRAE *Standard* 37-2005.
- ASHRAE. 2004. Energy standard for buildings except low-rise residential buildings. *Standard* 90.1-2004.
- Counts, D. 1985. Performance of heat pump/desuperheater water heating systems. *ASHRAE Transactions* 91(2B):1473-1487.
- CSA. 2005. Heating and cooling equipment. *Standard* C22.2 No. 236-05. Canadian Standards Association International, Toronto.
- DOE. Annual. Uniform test method for measuring the energy consumption of central air conditioners. 10CFR430, Appendix M. *Code of Federal Regulations*, U.S. Department of Energy, Washington, D.C.
- ISO. 1998. Water-source heat pumps—Testing and rating for performance—Part 1: Water-to-air and brine-to-air heat pumps. *Standard* 13256-1. International Organization for Standardization, Geneva.
- Miller, W.A. 1989. Laboratory study of the dynamic losses of a single speed, split system air-to-air heat pump having tube and plate fin heat exchangers. ORNL/CON-253. Oak Ridge National Laboratory, Oak Ridge, TN.
- Mueller, D. and U. Bonne. 1980. Heat pump controls: Microelectronic technology. *ASHRAE Journal* 22(9).
- NFPA. 2008. *National electrical code*<sup>®</sup>. ANSI/NFPA *Standard* 70. National Fire Protection Association, Quincy, MA.
- NFPA. 2002. Installation of air-conditioning and ventilating systems. ANSI/NFPA *Standard* 90A. National Fire Protection Association, Quincy, MA.
- NFPA. 2006. Installation of warm air heating and air-conditioning systems. ANSI/NFPA *Standard* 90B. National Fire Protection Association, Quincy, MA.
- O'Neal, D.L., N.K. Anand, K.T. Peterson, and S. Schliesing. 1989a. Determination of the transient response characteristics of the air-source heat pump during the reverse cycle defrost. *Final Report*, ASHRAE Research Project TRP-479.
- O'Neal, D.L., N.K. Anand, K.T. Peterson, and S. Schliesing. 1989b. Refrigeration system dynamics during the reverse cycle defrost. *ASHRAE Transactions* 95(2).
- UL. 2005. Heating and cooling equipment. *Standard* 1995-05. Underwriters Laboratories, Northbrook, IL.

**BIBLIOGRAPHY**

- ANSI. 2002. Acoustics—Determination of sound power levels of noise sources using sound pressure—Precision methods for reverberation rooms. ANSI *Standard* S12.51-2002 (ISO 3741:1999 NAIS Standard). American National Standards Institute, New York.
- ARI. Semiannual. *Applied directory of certified product performance*. Air-Conditioning and Refrigeration Institute, Arlington, VA. Available at <http://www.aridirectory.org/ari/applied.html>.
- CSA. 2005. Performance of direct-expansion ground-source heat pumps. CAN/CSA *Standard* C748-94 (R2005). Canadian Standards Association International, Toronto.

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