Heat Pump Manual

ELECTRIC POWER RESEARCH INSTITUTE

NATIONAL RURAL ELECTRIC COOPERATIVE ASSOCIATION

Heat Pump Manual

EPRI EM-4110-SR

Special Report, August 1985

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Further information on NRECA and the Research Fund is available from NRECA, 1800 Massachusetts Avenue NW, Washington, DC 20036.

Library of Congress Cataloging in Publication Data
Main entry under title:

Heat Pump Manual

Bibliography:
Includes index.

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FOREWORD

The electric heat pump is the most energy efficient home heating and cooling technology today. It is cost-effective, reliable, clean and safe to use, and has received widespread customer acceptance. Nearly one out of every three new homes built today is equipped with an energy-efficient heat pump and, given the growing demand for year-round comfort conditioning, the use of heat pumps is bound to become even more widespread.

This manual is intended to serve as an authoritative and comprehensive guide on heat pump equipment and applications for utility energy management and consumer service personnel, marketing specialists, and corporate planners. The information provided here is general in scope and is not intended to replace manufacturers' technical performance data or installation, operation, and maintenance guidelines for specific products. If the information provided conflicts with a manufacturer's instructions, the manufacturer's instructions should be followed. Where product trade names are used, or technology specific to a manufacturer is discussed, this has been done for clarity of presentation only and does not imply endorsement of these products.

This manual was compiled and edited by Arvo Lannus of the Electric Power Research Institute based on materials provided by Jeffrey Seisler, AnalyTech Management Consulting, Ronald Howell and Harry Sauer, both of the University of Missouri-Rolla, and Mason Somerville, University of Arkansas. James Bose, Oklahoma State University of Stillwater, and Richard Merriam, Arthur D. Little, Inc., reviewed sections of this work. Dorothy Sly of Wm. Nesbit & Associates assisted in the editing and production.

Funding for the compilation and production of this manual was provided by the Electric Power Research Institute (EPRI) and the National Rural Electric Cooperative Association (NRECA).

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GLOSSARY

Design Temperature, Winter: A specific temperature used in calculating the heating load of a building. The winter design temperature is typically the outdoor air temperature that is exceeded 97.5% of the time.

Desuperheater: A device for recovering superheat from the compressor discharge gas of a heat pump or central air conditioner for use in heating or preheating water. Also known as a heat recovery water heater.

DOE: Department of Energy

Energy Efficiency Ratio (EER): A dimensional quantity usually used in specifying cooling performance. The EER is the ratio of cooling provided by the system (in Btu) to the energy consumed by the system (in watthours) under designated operating conditions.

EPA: Environmental Protection Agency

Evaporator: A heat exchanger in which cold, low pressure (liquid) refrigerant is vaporized to absorb heat from the warmer surrounding air or water.

Expansion Device: A device that reduces the pressure of liquid refrigerant entering the evaporator and meters and regulates the flow of refrigerant so that it can properly absorb heat.

Ground-Coupled Heat Pump: A heat pump that uses the earth itself as a heat source and heat sink. It is coupled to the ground by means of a closed-loop heat exchanger (ground coil) installed horizontally or vertically underground.

Heat Exchanger: A device specifically designed to transfer heat between two physically separated fluids of different temperatures.

Heat Pump: A mechanical device used for heating and cooling which operates by pumping heat from a cooler to a warmer location. Heat pumps can draw heat from a number of sources, e.g., air, water, or earth, and are classified as either air-source or water-source units.

Heat Pump Water Heater, Integral: A heat pump built into a water heater.

Heat Pump Water Heater, Remote or Retrofit: A heat pump contained in a separate cabinet and connected to an existing water heater by pipes or hoses.

Heat Sink: The medium — air, water, or earth — which receives heat from a heat pump.

Heat Source: The medium — air, water, or earth — from which heat is extracted by a heat pump.

Heating Seasonal Performance Factor (HSPF): The ratio of total heating provided by a heat pump during the heating season (in Btu) to the total energy consumed by the system (in watthours), taking into account regional weather conditions and supplemental resistance heat.

HVAC: Heating, ventilating, and air conditioning

Hydronic: A heating or cooling distribution system using liquids that are piped throughout the house via radiators or convectors.

Isolation Hangers: Insulated, tubular holders for refrigerant piping used to prevent transmission of vibration noise from pipes to the house.

Life Cycle Costing: A method of analyzing the cost of HVAC systems that considers all the significant costs of ownership, including the time value of money, initial capital investment, energy costs, and maintenance costs over the service life of each system under consideration.

Multizone Heat Pump: A central, split-system air-source heat pump device consisting of an outdoor heat exchanger and compressor unit and multiple (three to five) indoor air handling units, each of which can be independently controlled.

Open-Fluid System: In a ground-coupled heat pump, a heat exchanger system in which the transfer fluid is exposed to atmospheric pressure.

GLOSSARY

Packaged Terminal Heat Pump: A window or through-the-wall mounted air-to-air heat pump unit designed to heat or cool a single room or zone.

Performance Factor: The ratio of useful output capacity of a system to the input required to obtain it. Units of capacity and input need not be consistent.

Refrigerant: A fluid of extremely low boiling point used to transfer heat between the heat source and heat sink. It absorbs heat at low temperature and low pressure and rejects heat at a higher temperature and higher pressure, usually involving changes of state in the fluid (i.e., from liquid to vapor and back).

Seasonal Energy Efficiency Ratio (SEER): A measure of seasonal cooling efficiency under a range of weather conditions assumed to be typical of a location, as well as of performance losses due to cycling under part-load operation.

Simple Payback Method: A method of analyzing the cost of HVAC systems which considers only the time it takes for annual energy and maintenance cost savings to offset an initial difference in cost between two systems.

Single Package Heat Pump: Self-contained heat pump units available as both free-delivery or ductless systems for single rooms, or as larger, central units that can heat or cool an entire home.

Split-System Heat Pump: The most common type of heat pump, this system separates the indoor air handling unit and heat exchanger from the compressor and outdoor heat exchanger.

Suction Line: The tube or pipe that carries the refrigerant vapor from the evaporator to the compressor inlet.

Supplemental Heating: A backup heating system used when a heat pump is operating below the balance point and during defrost. Usually electric resistance heat, but natural gas, LPG, or oil heating systems are also used.

Therm: A quantity of heat equivalent to 100,000 Btu.

Thermostat: An instrument that responds to changes in temperature, and which is used to directly or indirectly control indoor temperature.

Ton of Refrigeration: A measure of cooling delivered by a heat pump (or other air conditioning system) equal to 12,000 Btu per hour.

Unitary Heat Pump: A completely factory assembled heat pump.

Valve, Expansion: A device for regulating the flow of liquid refrigerant to the evaporator. Two types of valves are commonly used: an electronic valve that responds to variation in electric resistance reflecting changes in refrigerant temperature, and a thermostatic valve that uses a metal feeler bulb to sense changes in refrigerant temperature through shifts in fluid pressure.

Valve, Reversing: An electrically-operated valve that allows the heat pump to switch from heating to cooling, or vice versa, by changing the refrigerant's direction of flow.

Water-Source Heat Pump: A heat pump that uses a water-to-refrigerant heat exchanger to extract heat from the heat source.

Water-Source Heat Pump, Closed Loop: Closed-loop systems circulate a heat transfer fluid (such as water, or a water-antifreeze mixture) continuously to extract or reject heat from a ground or water source or sink.

Water-Source Heat Pump, Open Loop: Open-loop systems pump groundwater or surface water from a well, river, or lake through a water-to-refrigerant heat exchanger and return the water to its source, a drainage basin, pond, or storm sewer.

1

Introduction

In This Section: Consumer and societal benefits; utility benefits; heat pump use and growth history

This manual provides technical information on currently available heat pump equipment and systems for home heating and cooling applications. It provides an authoritative summary of available systems and equipment types, their operation and maintenance, and methods of assessing their energy use and economics in comparison to commercial alternatives.

The manual is written for utility energy management and consumer service personnel, marketing specialists, and corporate planners to serve as a comprehensive and up-to-date source of information on heat pump technology for residential users. Most of what is discussed is applicable to small commercial users as well. Applied heat pump systems, such as those installed in large commercial or multi-family residential buildings, are beyond the scope of this work.

Consumer and Societal Benefits

In the last decade, the heat pump has become recognized as an energy-efficient, reliable, and economic means of heating and cooling homes electrically. A broad array of heat pumps of various types is being manufactured and marketed in the United States today. They can meet a variety of heating and cooling needs and are suited to use in the home, in commercial and institutional buildings, and in industry.

The electric heat pump is the only commercially proven heat pump technology currently available. It offers a clean, safe, and highly efficient means of providing heating and cooling through a single machine. Heat pumps are clean because they require no on-site combustion and do not produce polluting byproducts. They are safe because their wiring is simple and because no storage of fuels is necessary. Heat pumps are two or three times as energy efficient as electric furnaces, even though they have attained only 10 to 15% of their theoretical efficiency limit. In contrast, the high-efficiency combustion furnaces in use today have nearly reached their maximum possible efficiency.

Because heat pumps use electricity — most of which is generated from abundant, domestic, primary energy resources such as hydropower, coal, and nuclear energy — their widespread use could potentially lessen reliance on depletable or imported energy resources. As a result, gas and oil supplies could be reserved for uses for which there are no ready alternatives, such as chemical feedstocks and transportation fuel. And, because heat pumps recover and utilize the solar energy present in ambient air (air-source heat pumps) and in the ground (ground-source heat pumps), as well as make low-grade waste heat sources more usable, they are truly an energy-conserving and cost-conserving technology.

Utility Benefits

Heat pumps also offer significant benefits to electric utilities — specifically, a means of managing the growth of their load and energy consumption. For utilities serving areas in warm climates where there is significant seasonal demand for air conditioning, the heat pump offers a means of increased annual kilowatthour usage of otherwise idle capacity and, therefore, a means to improve annual load factors. For utilities in cold climates, where use of fossil fuels for building heating dominates, the heat pump offers an efficient, cost-effective electric heating alternative — one which makes maximum use of available generating capacity.

Heat Pump Use and Growth History

Nearly one out of every three new single-family homes built in the United States today is equipped with an electric heat pump for heating and cooling. In addition, increasing numbers of existing homes are being retrofitted with heat pumps as add-on (bivalent) systems — that is, a heat pump and furnace or boiler combination. Heat pumps are also increasingly being used in multi-family dwellings and commercial buildings (where they provide space conditioning and service-water heating), in industrial processes, and in district heating systems.

The heat pump concept was introduced in the 1800s by British physicist Lord Kelvin (after whom the Kelvin or centigrade scale of absolute temperature is named). Heat pumps themselves, however, were not made commercially available in the United States until the 1950s. Figure 1-1 shows data on industry shipments of unitary (factory assembled) heat pumps between 1952 and 1984.

In their first decade of use, heat pump application in the United States grew slowly, due to reliability problems, many of which stemmed from reliance on existing air conditioner technology. In the 1960s, several leading air conditioner manufacturers made concerted efforts to improve heat pump system design, reliability, and component performance. These refinements, along with better training of dealers and installers, led to significant improvement in consumer acceptance.

In the 1970s, the oil embargo era, consumer confidence in the continued availability of electricity, and interest in energy conservation — coupled with the heat pump's potential to avoid use of interruptible gas and oil supplies — led to rapid growth in heat pump use. By 1978, industry shipments of heat pumps reached a peak of over 570,000 units, including exports. Air-source heat pumps were the dominant configuration for residential use.

In 1979, heat pump shipments declined sharply because of the nationwide construction recession. To combat lagging sales, manufacturers developed methods to improve system efficiency and reliability, and some focused development efforts on systems suited to northern climates. As a result, compressors designed specifically for heat pumps (rather

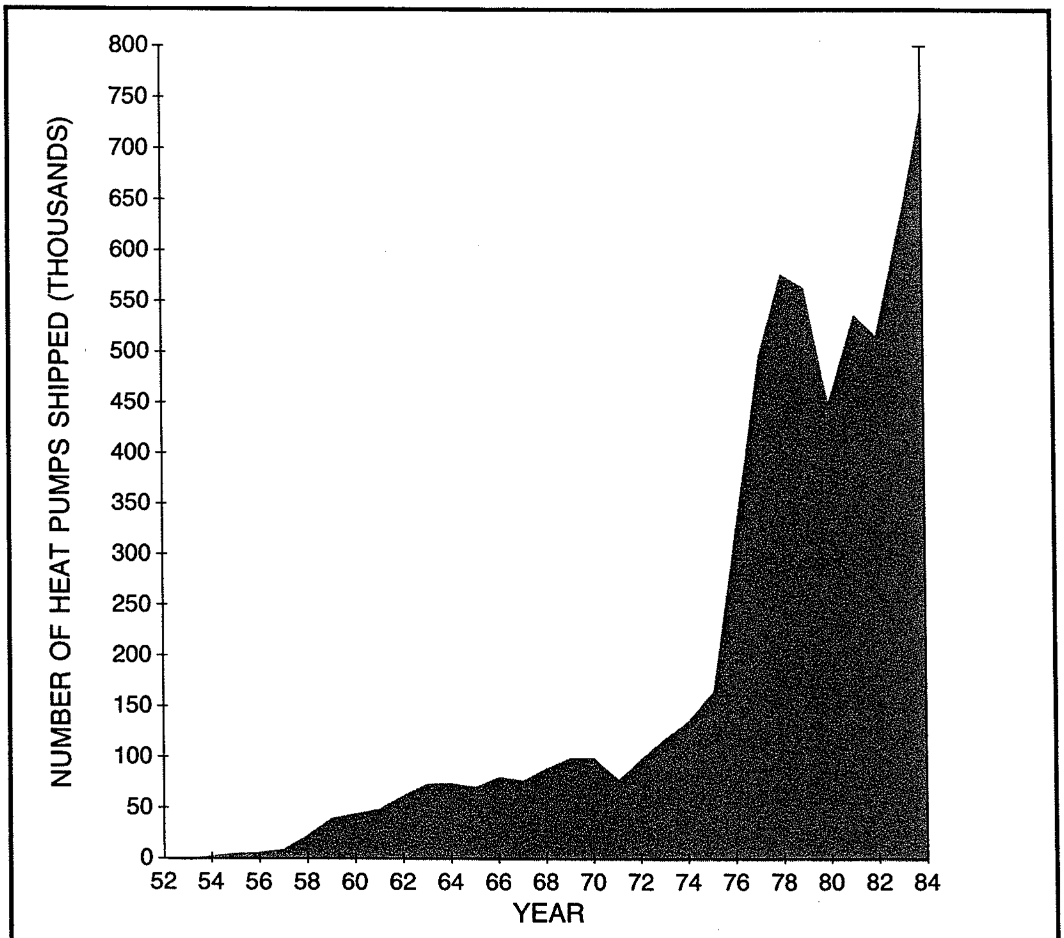


FIGURE 1-1:
Industry Shipments of Unitary Heat Pumps

Source: (13)

than for air conditioners) and multi-capacity (multi-speed, dual compressor, and inverter controlled) machines were introduced. In 1984, 28.5% of the single-family homes constructed in the United States had air-source electric heat pumps, with the greatest number of installations in the southern and western portions of the country. While air-source units remain dominant in the market, groundwater and ground-source systems have also gained popularity. These utilize the moderate temperature of soils and water to further improve system efficiency. With recent emphasis on add-on systems, heat pumps have emerged as a highly efficient heating alternative for northern climates.

Today there are approximately 40 U.S. manufacturers of heat pump equipment, five of which supply over 90% of the units used in residential buildings. Heat pumps are also being manufactured in Japan (which has begun to export some of its products to the United States), in Europe, and in other parts of the world. In general, the heat pump industry is a highly competitive and capital-intensive one. Standards of performance, comfort, and reliability are being continually improved as new types of systems are developed to offer superior service.

2

Heat Pump Basics

In This Section: Principles of operation; capacity and efficiency; sources and sinks; types of heat pumps

A heat pump is a mechanical device used for heating and cooling. It operates by pumping heat from a cooler to a warmer location. Heat normally flows from a warmer to a cooler region; heat pumps move heat against its normal flow. For example, to heat a home, heat is removed from a cooler outside source — commonly air — and delivered into the home. To cool a home, heat is removed from the cooler indoor air and delivered to the outside.

Removing heat from a cool medium is possible because even when the outside air feels cold, it still contains thermal energy that can be extracted by a heat pump. For example, at 0 °F the air contains almost 90% of the heat it contains at 70 °F. Indeed, some heat remains in the air until the temperature drops to absolute zero (-460 °F).

A heat pump may draw heat from a number of sources, such as air, water, or earth. Similarly, it may release heat to air, water, or earth. The cooler medium from which heat is extracted is called the heat source. The warmer medium receiving the heat is called the heat sink. As will be explained later in this section, heat pumps are typically referred to by their source and sink: e.g., air-to-air or water-to-air heat pumps.

Regardless of the heat pump's type of source or sink, pumping heat against its normal flow requires work, and electricity supplies the needed energy input. Heat pumps use electrical energy efficiently. A conventional air-to-air heat pump, working under typical conditions, delivers about two and a half times as much energy in the form of heat (or removes that much for cooling) as it consumes in electricity.

Principles of Operation

Pumping of heat can be accomplished through a variety of thermodynamic cycles, but virtually all commercially available heat pumps use the vapor-compression cycle called the modified Rankine or, simply, the Rankine cycle. This cycle employs a working fluid, called the refrigerant, which successively undergoes four basic physical processes or changes: compression, condensation, expansion, and evaporation. Therefore, all vapor compression heat pumps have at least four basic working parts: a compressor, two heat exchangers (one of which serves as a condenser and the other as an evaporator), and an expansion device.

2

The refrigerant never leaves the cycle during operation, but is continuously recirculated within the system.

Figures 2-la and 2-lb show the movement of refrigerant through the heat pump cycle during both heating and cooling operations in an air-to-air heat pump. During heating, (Figure 2-la) hot, high-pressure vapor is discharged from the compressor to the heat exchanger located inside the conditioned space. Because the temperature of the refrigerant is above that of the surroundings, heat flows from the hot vapor to the cooler air and, in the process, the vapor condenses. Thus, in the heating operation, the indoor heat exchanger functions as the condenser.

The condensed refrigerant leaving the condenser is a warm liquid under high pressure. It flows into the second heat exchanger, which is located outside the conditioned space, through an expansion device that regulates its flow and expansion to a lower pressure. The expansion process cools the liquid below its surroundings and causes some of the liquid to vaporize. As the cold liquid and vapor mixture contacts warmer air through the surfaces of the second heat exchanger, the liquid boils or evaporates, absorbing heat. The heat exchanger in which this process occurs is called the evaporator. During heating, the outdoor heat exchanger functions as the evaporator. To complete the cycle, warmed refrigerant vapor moves from the evaporator to the compressor where it is compressed again — raising its temperature and pressure to ready it for another pass through the cycle. A changeover switch allows the entire cycle to be reversed to provide indoor cooling. In this case, heat is absorbed from indoor air and rejected to the outside (Figure 2-lb).

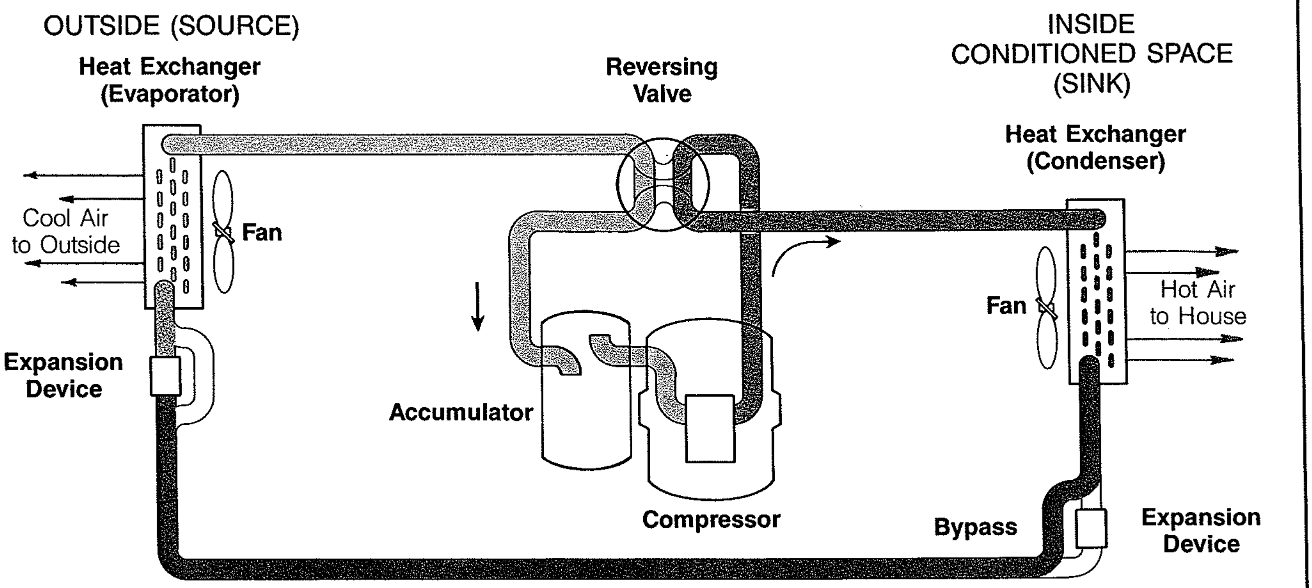
The basic difference between cooling and heating operations lies in which of the two heat exchangers supplies cold vapor to the compressor and which receives hot vapor from it. In the heating mode, the indoor heat exchanger receives the hot vapor, bringing heat to the indoor space. In the cooling mode, the outdoor heat exchanger receives the hot vapor, carrying heat away from the conditioned space to the outdoors. The change in operations is usually accomplished by means of a flow reversing valve, as shown in Figure 2-1. However, other arrangements that do not use a reversing valve have been devised. One such arrangement accomplishes the switchover by means of movable louvers that direct the flow of indoor and outdoor air over the two heat exchangers.

A heat pump can also dehumidify indoor air in the summer, contributing to an overall cooling effect. Dehumidification occurs because the temperature of the evaporator surface is colder than the temperature of the indoor air. In this process, moisture in the air in contact with the cold surface condenses and drips into a condensate pan. In the winter, outdoor air frequently contains sufficient moisture for condensation to occur on the outdoor heat exchanger (the evaporator). Since the temperature of the evaporator surface is usually below the freezing point — except during very mild winter weather — the condensed moisture freezes. The accumulated frost must be periodically removed to avoid reducing the heating capacity of the heat pump. Most heat pumps are equipped with a defrost cycle for this purpose (see Section 3).

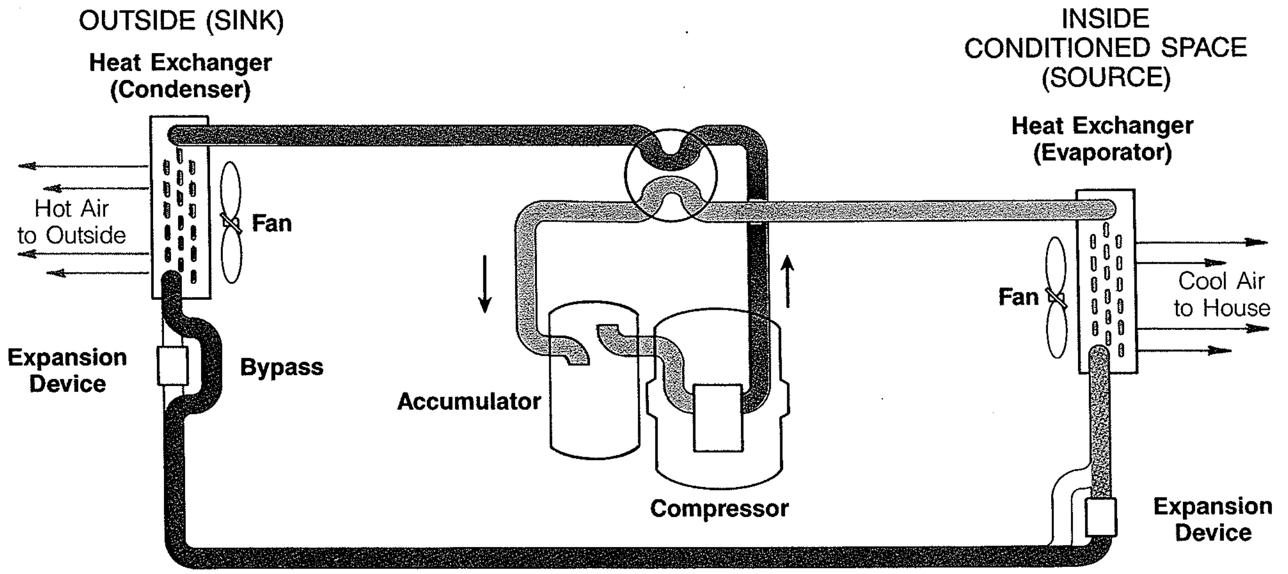
Capacity and Efficiency

The most important performance characteristics of a heat pump are its heating and cooling capacity, and its overall efficiency. Figure 2-2 shows a simplified schematic of the heat pump cycle and a pressure-enthalpy (pressure-energy) diagram describing changes in the state of the most common heat pump working fluid, Refrigerant 22.

2



a) HEATING OPERATION



b) COOLING OPERATION

▨ High Pressure High Temperature Vapor
■ High Pressure Medium Temperature Liquid
▨ Low Pressure Low Temperature Liquid/Vapor
▨ Low Pressure Low Temperature Vapor

FIGURE 2-1 Basic Heat Pump Operation, Air-to-Air Heat Pump: a) Heating and b) Cooling.

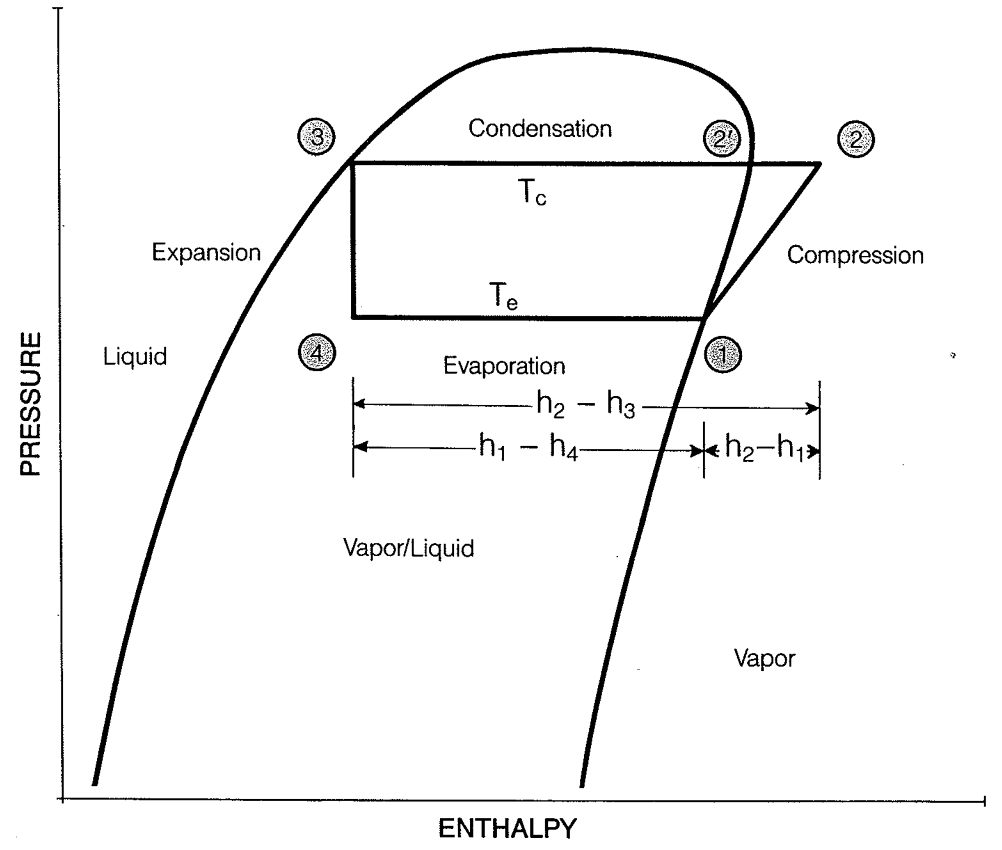


FIGURE 2-2: Heat Pump Cycle on Pressure-Enthalpy Diagram

The compression (1-2), condensation (2-3) (including desuperheating, 2-2'), expansion (3-4), and evaporation (4-1) processes are plotted for an idealized heat pump for which all processes are thermodynamically reversible. Of course, in a real heat pump, some of the energy input is dissipated as heat due to fluid and mechanical friction and expansion without recovery of work. Therefore, the performance of a real installed heat pump is always somewhat less than that of the idealized vapor-compression cycle shown.

The quantities plotted in the diagram are specific properties of the fluid, i.e., enthalpy (energy) per unit mass of refrigerant. Therefore, to calculate the quantity of heat absorbed or rejected, changes in enthalpy are multiplied by the mass rate of refrigerant being circulated. Note also that the fluid temperature during evaporation, T_e, and condensation, T_c, is constant. For heat to be absorbed by the refrigerant in the evaporator, the temperature of the heat source, T_{source}, must be greater than the evaporator temperature

$$T_{source} > T_e \ .$$

The condensation temperature, on the other hand, must be above that of the heat sink

$$T_c > T_{sink}$$

in order for heat to be released to (and absorbed by) the heat sink. For the common air-to-air heat pump in heating mode operation, the heat source temperature is that of ambient air and the heat sink temperature is that of air returning from the conditioned space.

The heating capacity of the heat pump is defined as the product of the mass flow rate of the refrigerant times the heat rejected by the condenser:

$$q_h = w(h_2 - h_3) \qquad (2.1)$$

where:

q_h = heating capacity, Btu/h
w = refrigerant flow rate, lb/h
$h_2 - h_3$ = condenser heat rejection, Btu/lb .

The work input to the compressor is

$$W = w(h_2 - h_1) \qquad (2.2)$$

where:

W = work input to compressor, Btu/h
w = refrigerant flow rate, lb/h
$h_2 - h_1$ = specific work of compression, Btu/lb .

The cooling capacity is, similarly, the product of the mass flow rate of the refrigerant times the heat absorbed by the evaporator (this is also called the refrigeration effect):

$$q_c = w(h_1 - h_4) \qquad (2.3)$$

where:

q_c = cooling capacity, Btu/h
w = refrigerant flow rate, lb/h
$h_1 - h_4$ = evaporator heat absorption (refrigeration effect), Btu/lb .

COEFFICIENT OF PERFORMANCE

The measure of heat pump efficiency at any given set of operating conditions is called its coefficient of performance (COP). The coefficient of performance is defined as the ratio of the heating or cooling capacity (i.e., the useful output) to the work input. For heating, the coefficient of performance is:

$$COP_h = \frac{q_h}{W} = \frac{h_2 - h_3}{h_2 - h_1} \ . \qquad (2.4)$$

For cooling, the coefficient of performance is:

$$COP_c = \frac{q_c}{W} = \frac{h_1 - h_4}{h_2 - h_1} \ . \qquad (2.5)$$

When the heat pump is in heating operation, the condenser temperature is essentially fixed because it must be kept above the desired room air temperature. The evaporator temperature, however, may vary depending on the temperature of the heat source. If air is the heat source, the evaporator temperature must drop as the ambient air gets colder. This increases the work of the compressor and reduces both the heat absorbed per unit mass of refrigerant and (because the density of the refrigerant and the pumping efficiency of the compressor both decrease) the refrigerant's mass circulation rate. As a result, both the capacity and the coefficient of performance of the heat pump drop.

When the heat pump is in cooling operation, it is the evaporator temperature that is fixed by the indoor air temperature setting. When it is hot outside, the temperature of the condenser must rise in order to be able to reject heat to the outdoor air. Again this increases the work of the compressor and diminishes pumping efficiency and the refrigeration effect. As a result, the capacity and coefficient of performance of the heat pump decrease.

A heat pump is most efficient when there is a small temperature difference between the source and sink, and least efficient when these temperatures are at their seasonal extremes. In maintaining a desired indoor temperature year around, what matters is not the steady state, but the seasonal efficiency — that is, the seasonal average coefficient of performance. This measure is affected by the steady-state COP, by power consumed by fans and other auxiliary equipment, and by power lost to motor inefficiency, cycling, and other aspects of heat pump operation.

SEASONAL EFFICIENCY

The seasonal efficiency of a heat pump depends on a variety of factors, among them: weather conditions, the building's requirement for heating and cooling, and how well the heat pump's capacity matches the building's heating and cooling load. In colder climates with at least three or four months of sub-freezing temperatures, a source of supplemental heat is necessary to maintain the desired indoor temperature. This might be either electric resistance heat (usually built into the heat pump system) or backup fossil fuel heating.

During the heating season, heat pump performance is affected by decreases in the heat source temperature, as shown in Figure 2-3. As the outside temperature decreases, the heat pump must work harder to extract heat, and its capacity and efficiency drop. Once the balance point is reached — the temperature at which the heating capacity of the heat pump equals the building heating load — supplementary heat is required. The balance point varies with different heat pump models and sizes, but is between about 15 and 35 °F for common air-to-air systems. Dual-capacity compressors (either a multi-speed compressor or two compressors for different seasonal demands) can reduce the need for backup heating. Frost buildup on the outside heat exchanger coil can impair heat pump performance during the winter; it is removed through the automatic defrost cycle.

During the cooling season, heat pump performance is affected by increases in the heat sink temperature (Figure 2-3). As the outside temperature increases, both the cooling capacity of the heat pump and its performance decrease. When the heat pump's cooling capacity no longer meets the building's cooling requirement, the indoor temperature will rise somewhat.

Appropriate sizing of a heat pump, i.e., matching its capacity to the heating and cooling needs of a building in a particular climate, also affects performance. Heat pump sizing is discussed in Section 7 and specific measures of heat pump performance, such as coefficient of performance, energy efficiency ratio, and seasonal performance factors, are further defined and discussed in Section 6.

Sources and Sinks

The efficiency of a heat pump greatly depends on the difference between the temperature of the heat source and the temperature of the heat sink. That is, the heating efficiency of an air-source heat pump, set to maintain a relatively constant indoor air temperature, decreases as the outside temperature decreases. This is because more energy must be expended to pump heat against a higher temperature difference. Similarly, the cooling efficiency of a heat pump decreases as the outside temperature increases, because more energy is expended to reject heat to a higher temperature sink.

In most parts of the United States there is considerable annual temperature variation in outdoor air. This suggests that heat pumps using heat sources and sinks that experience smaller annual temperature variations (e.g., groundwater, river or lake water, or the ground itself) may be more energy efficient. Indeed, heat pump equipment capable of utilizing

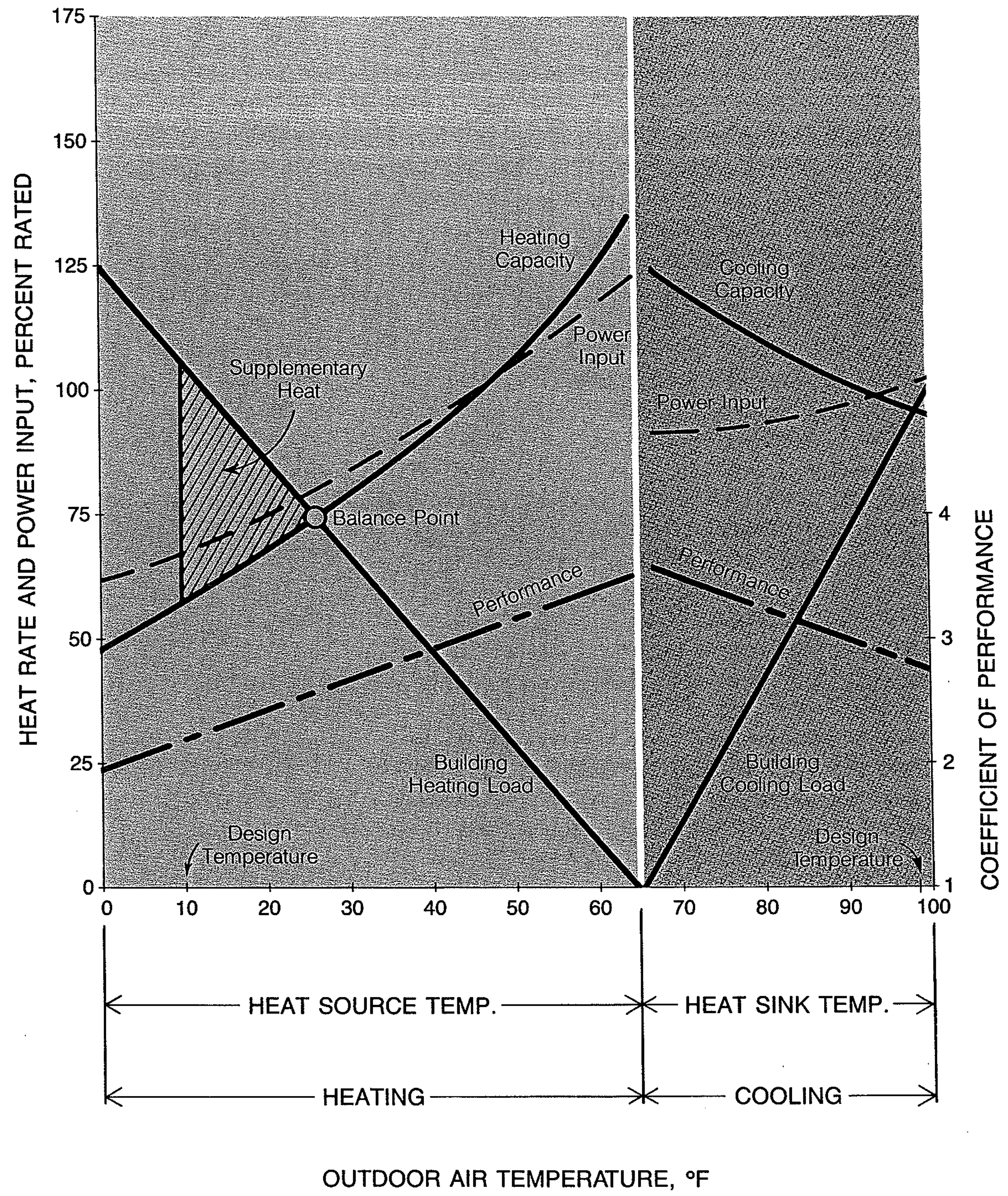


FIGURE 2-3: Heating and Cooling Performance Characteristics of a Typical Air-Source Heat Pump

Source: ASHRAE (14)

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TABLE 2-1: Heat Pump Sources and Sinks

Source: Modified from ASHRAE (15)

		AIR	GROUND-WATER	SURFACE WATER	CITY WATER	WASTE WATER	GROUND	SOLAR
SUITABILITY	HEAT SOURCE	Good but capacity and performance decline at colder temperatures	Excellent	Excellent — large water bodies or high flow rates required	Excellent	Poor to good — varies with location	Good if wet, else poor	Fair
	HEAT SINK	Good	Excellent	Excellent in large water bodies or high flow rates	Excellent	Fair — varies with location	Fair to good if wet, else poor	Poor, usually unacceptable
AVAILABILITY	LOCATION	Excellent, universal	Varies	Varies	Subject to regulation	Varies	Universal	Universal
	TIME	Excellent, continuous	Usually continuous, check local conditions	Varies by location	Excellent if allowed	Continuous	Excellent, continuous	Intermittent
COST	INSTALLED	Low	High (low if new wells not required)	Varies based on distance to water body	Low	Moderate to high	High (varies with soil conditions)	Very high
	OPERATION & MAINTENANCE	Low	Low	Low	Low unless charged for water use	Moderate	Low	Moderate
TEMPERATURE	LEVEL	Variable	Constant, favorable	Usually satisfactory	Usually satisfactory	Satisfactory	Usually good	Varies — favorable to unavailable
	VARIATION	Extreme in many locations	Usually slight	Depends on location; less than air	Usually slight	Usually slight	Low	Extreme
ADAPTABILITY TO STD EQUIPMENT	USAGE	Excellent, standard products	Favorable, particularly if new wells not required	Favorable, particularly with fresh water	Favorable	Poor	Favorable	Poor
	LIMITATIONS	Supplemental heat and defrosting usually required	Water disposal may limit; well permits may be required; corrosion, fouling, and scaling are potential problems	Some water bodies are regulated and use may not be allowed; corrosion potential problems	May not be allowed in some locations, water disposal may limit; corrosion and scaling are potential problems	Fouling, scaling, and corrosion are potential problems, requires careful design	Ground coupling expensive; technology in use but still being developed	Supplemental source or storage required

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these sources and sinks is commercially available.

Table 2-1 summarizes the common media that can be used as sources or sinks for heat pumps. The relative investment cost, availability, and use limitations are summarized in general terms. Although water- or ground-source heat pumps are generally more efficient than the common air-source systems, investment costs tend to be higher as well. These costs may offset some of the performance gain.

Types of Heat Pumps

A wide array of residential heat pumps is available, and these systems are adaptable to most homes. Heat pumps can provide all of a home's heating and cooling needs. In a retrofit situation, they can be installed around an existing heating system so that the old system becomes a supplemental heater for very cold weather. Heat pumps and solar energy systems also can be combined, and waste heat from heat pump systems can be used to provide a home's water heating needs. Heat pumps solely for domestic water heating are also available (see Section 11).

In addition to being referred to by their source and sink, heat pumps are also classified by the method used for energy distribution throughout the home. For example, an air-to-air heat pump uses air as the heat source and heat sink and supplies heating and cooling via a central forced air distribution system. An air-to-water heat pump (sometimes called an air-source hydronic heat pump) uses air as the heat source, water as the heat sink, and circulates hot water through radiators or fin-and-tube type baseboard convectors to distribute heat indoors. A water-source heat pump, on the other hand, uses water as the source and can be installed with an air or water heat sink and distribution system within the home; hence the terms water-to-air and water-to-water heat pump.

Heat pumps are also classified by design. Single package heat pumps contain all their components in one box. Smaller-capacity single package heat pumps are used to heat and cool single rooms or small zones of a home or apartment. Larger-capacity single package heat pumps can provide central heating and cooling to an entire home. Split systems, heat pumps designed as two or three modular pieces, are more commonly used to heat an entire home. These generally use a central forced air distribution system, but some small split systems can also provide room or zone heating alone. Both packaged and split-system heat pumps are manufactured as unitary (factory assembled) products.

3

Heat Pump Components

In This Section: Compressor; heat exchangers; expansion devices; refrigerant and piping; supplemental electric resistance heater; controls; other components

Manufacturers may employ different approaches in the design of heat pump systems and components. However, all heat pumps contain the following basic parts: a compressor, two heat exchangers (one of which functions as a condenser and the other as an evaporator), and an expansion device. Depending on the type and make of the heat pump, a supplemental electric heater and other components may be added. These may aid in system control and protection, and in the movement of air or water over the heat exchangers.

The heat pump components are connected by piping that circulates refrigerant throughout the system. Figure 3-1 shows a typical air-to-air heat pump with most of the principal components labeled. Although experience has shown that certain design approaches may be more successful in particular applications than others, consumers should be advised to compare the performance ratings for each variety of heat pump to evaluate overall efficiency and performance.

Compressor

The compressor is the central component of the heat pump system. It pressurizes the refrigerant and causes it to flow through the rest of the system. Figure 3-2a shows a reciprocating compressor, the type most commonly used in residential heat pumps. It has one or more pistons that move back and forth in cylinders, similar to the pistons in a car engine. Unlike a car engine, however, these pistons are driven by an electric motor contained in the same pressure shell as the compressor. The piston's downstroke creates suction and draws gaseous refrigerant into the cylinder. When the piston moves upward it pressurizes the refrigerant, thereby increasing its temperature. The high-pressure refrigerant vapor is then forced out of the cylinder into the heat pump piping system.

A rotary compressor (Figure 3-2b) may be used to perform the same functions as the reciprocating compressor. A rotary compressor has either an eccentric rolling piston and a stationary vane between the low- and the high-pressure side, or rotating sliding vanes. Both increase refrigerant pressure by squeezing the gas with each rotation of the piston in the compressor cylinder.

3

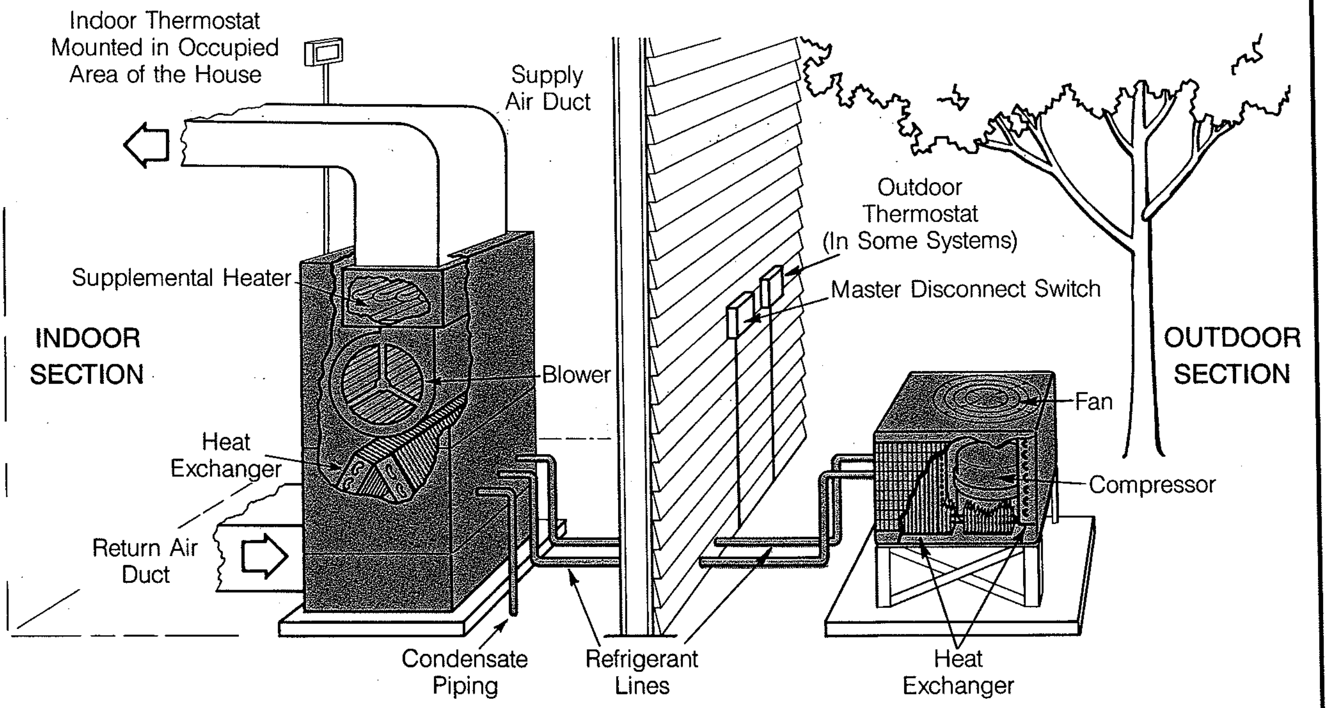


FIGURE 3-1: Basic Components of a Heat Pump System (Air-to-Air, Split-System Shown)

Heat Exchangers

A heat exchanger is a device for transferring heat between two physically separated fluids of different temperatures. All heat pump systems have at least two heat exchangers (usually called coils), one of which acts as a condenser and one of which acts as an evaporator. When hot, pressurized (gaseous) refrigerant is circulated in the heat exchanger, heat is transferred from the refrigerant to the cooler surrounding air or water. In this process, the refrigerant vapor condenses into liquid and the heat exchanger functions as a condenser. Conversely, if the refrigerant inside the heat exchanger is colder than the surrounding air or water, the refrigerant will absorb heat from the air or water. Because the cold refrigerant is at a low pressure, it vaporizes or boils as it gains heat. In this case, the heat exchanger functions as an evaporator. The roles of the heat exchangers are reversed when the heat pump is switched from the heating to the cooling (air conditioning) mode.

In a split-system type of residential heat pump, such as the air-to-air system shown in Figure 3-1, one heat exchanger is located outside the home and the other inside. In package

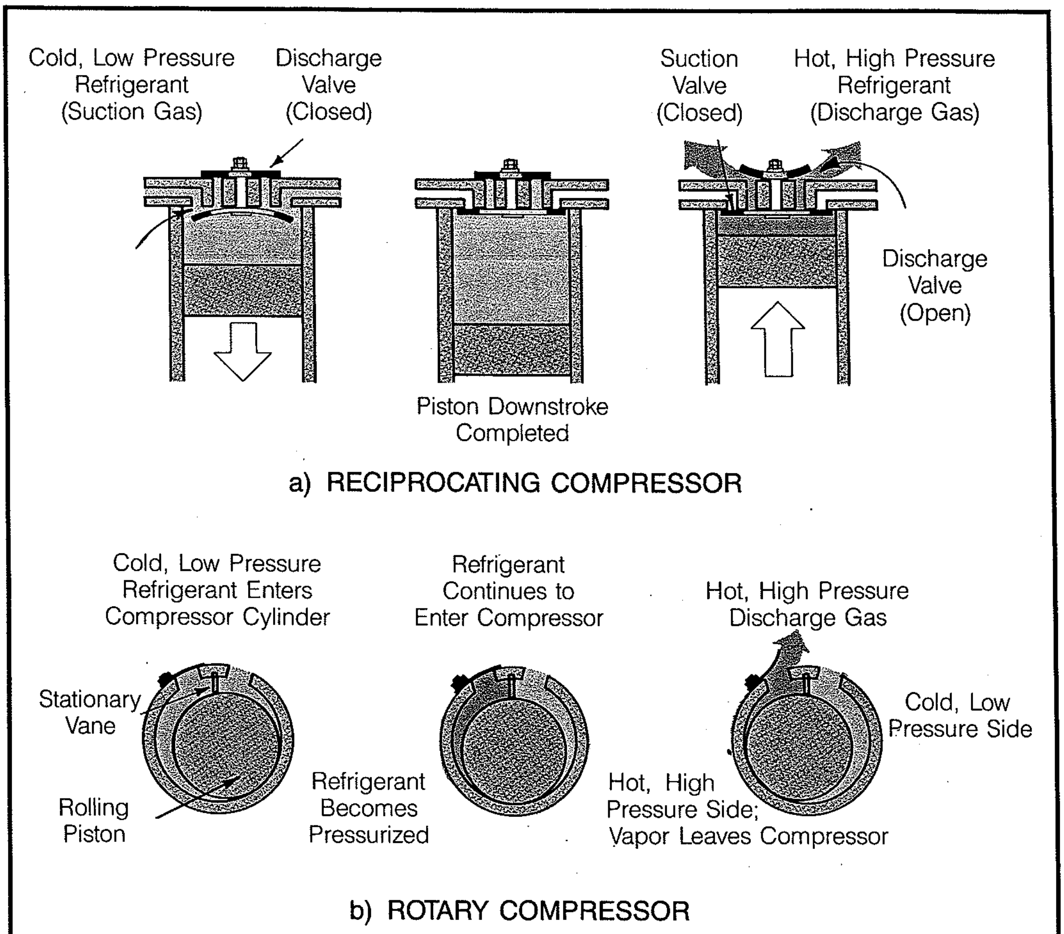


FIGURE 3-2: Reciprocating and Rotary Compressors

systems, both heat exchangers are located in the same unit outside the home. Heat pump heat exchangers are usually of the fin-and-tube design. That is, refrigerant piping snakes horizontally back and forth inside a casing of thin, closely knit aluminum fins, spines, or spikes. This arrangement increases the area available for heat transfer.

Water-source heat pumps differ from the more common air-source systems in that one of the heat exchangers is a water-to-refrigerant type rather than air-to-refrigerant type. Water-to-refrigerant heat exchangers are usually designed as concentric tubes or shell-and-tube devices. The concentric tube heat exchanger consists of a refrigerant pipe and a water pipe coiled together in a helical shape like a common spring. The refrigerant pipe is usually wound in the inner part of the coil. This configuration allows for heat transfer between the refrigerant and water. The shell-and-tube heat exchanger is a hollow metal cylindrical container filled with refrigerant with water piping running through its shell. In both types of water-to-refrigerant heat exchangers the water and refrigerant do not mix.

Expansion Devices

An expansion device reduces the pressure of the liquid refrigerant entering the evaporator and meters and regulates the flow of refrigerant so that it can properly absorb heat. As the refrigerant passes through the expansion device its pressure decreases, due to friction and acceleration, and its temperature drops. When this cold, low-pressure refrigerant contacts air or water it absorbs heat and changes into a gas. The two basic types of expansion devices are a fixed bore, fixed length capillary tube, and a variable opening expansion valve.

The capillary tube device is a long, small bore tube (0.5 to 2 millimeters) that acts to constrict the refrigerant line. A single capillary tube may be used for both heating and cooling operation, but performance is improved if separate tubes are used. In this case, a smaller capillary is used for heating than is used for cooling, since the density of the refrigerant is lower in the heating mode.

The variable opening expansion valve mechanically adjusts the flow rate and pressure of the refrigerant. A thermostatic expansion valve uses a metal feeler bulb located on the refrigerant line leaving the evaporator. It senses changes in the refrigerant temperature as a change in fluid pressure in the bulb and valve, and the refrigerant flow is adjusted mechanically. An electronic expansion valve opens and closes electromechanically. It responds to changes in electric resistance that reflect changes in the temperature of the refrigerant.

Refrigerant and Piping

The heat pump working fluid, the refrigerant, is a liquid with an extremely low boiling point. This low boiling point allows the fluid to vaporize and absorb heat from air at 0 °F or lower. The fluid's function is to transfer heat between the heat pump source and sink. As the refrigerant absorbs heat at reduced pressure at the source, it changes from liquid to vapor. Conversely, when it gives up its heat at high pressure at the sink, it changes from vapor to liquid.

Refrigerant 22 (R 22) is the fluid most commonly used for heat pumps and air conditioners in residences and small commercial buildings. R 12, R 500, and R 502 are also used for heat pumps and heat pump water heaters. All of these liquids are nontoxic and nonflammable.

Special refrigeration-grade piping able to withstand variations in pressure and temperature is used for refrigerant lines. To ensure good performance and prevent potential compressor damage, this piping must be sized and installed according to the manufacturer's recommendations. Precharged piping with quick-connect fittings is normally used in residential systems.

Supplemental Electric Resistance Heater

It is generally impractical and uneconomic to size a heat pump for the maximum heating load that might be encountered when the temperature drops to its lowest value. For example, some heat pump models are not operated at extremely low outdoor temperatures, because the resulting high compression ratios can strain the compressor. Consequently, supplemental heating is recommended to provide additional capacity and for backup during emergency shutdown. Most air-source heat pumps have electric resistance heating elements, sometimes called strip heaters, for supplemental heat when outside temperatures are very low or when the heat pump is defrosting. Strip heaters usually come in stages of five to eight kW each. Built-in controls in many models allow the supplemental resistance heat to be energized in sequenced stages to provide greater flexibility and efficiency. Strip heaters are not required if the heat pump is added on to an existing furnace or on some water-source systems.

Controls

Heat pump controls consist of operational controls and system protection devices. Operational controls, usually one or more thermostats, govern the operational mode and comfort delivered by the system. Protection devices are used to protect the motor and compressor against stressful operating conditions.

THERMOSTATS

Thermostats control the operation of the heat pump system to maintain the desired comfort condition indoors, even though outdoor temperature conditions — and, therefore, the heating or cooling load on the heat pump — may vary. Typically, a two-stage thermostat is used for heating and a one-stage thermostat is used for cooling. During heating, one stage of the room thermostat controls the compressor and fan operation. When supplemental heat is needed, the second stage activates. For cooling, only the one stage controlling the operation of the compressor and fan is used. The outdoor thermostat, a separate control from the room thermostat and included in only some systems, permits additional stages of supplementary heat to be turned on during low outdoor temperatures. Use of the outdoor thermostat limits the use of resistance heat, thus avoiding excessive electrical demand, particularly if the indoor thermostat is turned up suddenly.

Many indoor thermostats are equipped with an emergency heat switch that makes it possible to bypass the thermostat and turn on the supplemental heater in case of compressor or general system failure. Some thermostats have a small light that comes on to remind the homeowner that the compressor is off and that the less efficient supplemental resistance heater is on. Excessive use of resistance heat, particularly at temperatures above the balance point, may indicate a problem in the system and a need for servicing.

Some manufacturers make three- and four-stage thermostats for more precise control of the heat pump's operation at different outdoor temperatures. In this case, one stage operates the reversing valve (see pg. 20), the second operates the compressor during cooling, the third operates the compressor during heating, and the fourth stage energizes the supplemental heater.

If a heat pump has an outdoor thermostat to control supplementary heat, night setback is feasible. However, when no outdoor thermostat is provided, setback of the conventional two-stage thermostat is not recommended. Setback without an outdoor thermostat allows supplementary heat to come on when the indoor thermostat is set up suddenly (as it might be in the morning), thus reducing any savings obtained by setback. Availability and operation of night setback varies by heat pump manufacturer. Owners' manuals will generally provide this information.

Thermostats of water-source heat pumps may be put on setback as long as the heat pumps are sized for enough capacity to provide "quick recovery" or instantaneous heating. Manufacturers and dealers, or the heat pump owners' manual, can provide information about thermostat operation for these systems as well.

PRESSURE LIMIT CONTROLS

Low-pressure and high-pressure limit controls are generally used to protect the compressor when suction pressure drops too low, or when the discharge or "head" pressure is too high. Both direct pressure-sensing or temperature-sensing control devices can be used. Not all heat pumps have high- or low-pressure controls; some use other means to detect improper operation.

REVERSING VALVE

The reversing valve allows the heat pump to switch from heating to cooling or from cooling to heating by changing the refrigerant's direction of flow in the system. This valve is electrically operated and located on the discharge side of the compressor. In the heating mode, the reversing valve allows hot, pressurized refrigerant to be discharged to the indoor heat exchanger (where it condenses and releases its heat to the conditioned space) while the cold, low-pressure refrigerant is discharged to the outdoor heat exchanger. In the cooling mode, and for defrost operation, the reversing valve directs the hot, pressurized refrigerant to the outside heat exchanger and the cold, low-pressure refrigerant to the indoor heat exchanger (where it evaporates and absorbs heat from the indoor air).

DEFROST CONTROLS

During the winter or heating season, humidity in the air may cause frost to accumulate on the outdoor heat exchanger coil, much as frost occurs in a kitchen freezer. It is not unusual for a heat pump to defrost 400 or more times a year, each defrost cycle lasting two to five minutes. When humidity is less than about 60%, relatively little frost will form on the outside coil, even when the temperature is below 20°F. During the defrost cycle in most heat pumps, the reversing valve switches the system to the cooling cycle so that hot refrigerant enters the outdoor heat exchanger and melts the frost. The outdoor fan does not operate and supplemental resistance heat is used to satisfy indoor heating need. The use of supplemental heat can reduce a heat pump's overall efficiency by 3 to 10%, depending upon the length of its operation.

Primarily two types of defrost controls are used in heat pumps: demand-defrost, and time-temperature defrost. Demand-defrost controls activate the defrost cycle whenever frost buildup is detected by a temperature, pressure, air flow, or other type of sensor in the outdoor heat exchanger. Time-temperature defrost is initiated by a clock and is terminated after a preset interval or when a temperature sensor indicates that the frost has been removed. Demand-defrost generally is more efficient but may add to the cost and complexity of the control system.

Water- and ground-source heat pumps do not require defrosting because they are not exposed to outdoor humidity. However, these systems employ temperature or low flow-rate sensors to prevent the possibility of water freezing in the evaporator.

Other Components

Depending on the type and make of the heat pump system, an accumulator, fans and blowers, and a water pump may be added to improve system reliability and to aid in the movement of air or water over the heat exchangers.

ACCUMULATOR

The accumulator is a buffer and storage device located in the refrigerant suction line between the evaporator and the compressor. The accumulator acts as a storage vessel for the refrigerant and helps prevent it from flooding or surging into the compressor. Floodback may occur when the heat pump cycle is reversed, such as during defrost, or when air-source outdoor compressors are subject to low ambient temperatures. An accumulator improves system reliability by preventing damage to the valves and by reducing strain on the compressor. Accumulators are available in a variety of designs but all perform essentially the same function.

FANS AND BLOWERS

Fans and blowers are used to move air across the heat exchangers. A propeller-type fan is used to draw air through the outdoor heat exchanger coils. Indoors, a centrifugal blower is used to force air through the heat exchanger. Heat from the indoor fan motor adds to the system's heating capacity in winter, but detracts from its cooling capacity in summer. In calculating heat pump efficiency, electrical input to indoor and outdoor fans and blowers must be considered along with heating and cooling capacity.

PUMPS

Pumps are generally required to provide water circulation in water-source heat pumps. Centrifugal pumps, powered by electric motors of about one horsepower, are usually required. Deep wells require larger-capacity pumps, while smaller-capacity pumps can remove water from single or multiple shallow wells. Water pressure or "static head," the length of the pipe run between the water source and the heat pump, and the water flow rate determine power requirements for pumping. These factors must be considered in calculating the overall energy consumption of a water-source heat pump system.

4

Air-Source Heat Pump Systems

In This Section: Classification of equipment and systems; air-to-air heat pumps; air-to-water heat pumps; add-on heat pumps; new developments

The majority of heat pumps manufactured and installed in the United States are residential-use air-source heat pumps. Air is universally available and, even at wintertime temperature extremes, contains solar heat recoverable by a heat pump. The ready availability of air and the wide selection of air-source heat pump equipment being manufactured give unrivaled flexibility to heat pump applications in new and existing buildings. At present, there are about 50 manufacturers of air-source heat pumps making residential units ranging in capacity from 1/2 to 6 tons (6000 to 72,000 Btu/hour). Larger capacity heat pumps, for commercial applications, are also manufactured.

Classification of Equipment and Systems

Air-source heat pumps may be classified as air-to-air or air-to-water systems, depending on the heat sink or heat distribution system within the home. Air-to-air systems can heat individual rooms or zones directly or deliver heat to the entire home through central forced-air supply ducts. Air-to-water heat pumps (hydronic heat pumps) are designed for buildings with a hot water distribution system. In recent years, smaller air-to-water units have been developed specifically for domestic water heating (see Section 11).

Residential air-source heat pumps are generally unitary (completely factory assembled), and come in one or more equipment modules or "packages." Single package or self-contained heat pumps are available both as free-delivery or ductless systems for single rooms (similar to a window or through-the-wall room air conditioner), or as larger, central units that provide heating and cooling for the entire home through an air- or water-distribution system. Split-system heat pumps come in two or more separate assemblies that are connected by refrigerant piping when installed. One newly developed air-to-air system uses multiple indoor units to provide heating and cooling to up to five separate, individually controlled rooms or zones — avoiding the use of central forced-air ducts entirely.

4

Air-to-Air Heat Pumps

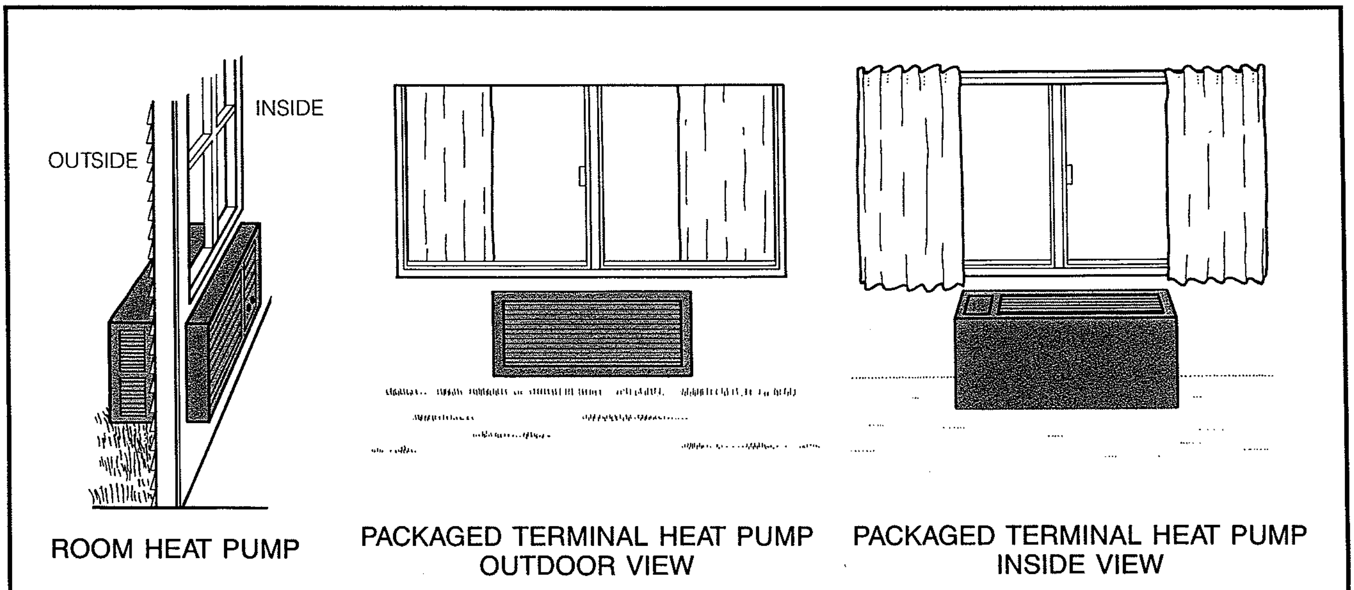
Air-to-air heat pumps are the most common type of heat pump system. As the name implies, these systems use air as the heat distribution medium and typically provide both heating and cooling in one unit — since the operating cycle can be easily reversed by interchanging the function of the heat exchangers.

ROOM AND PACKAGED TERMINAL HEAT PUMPS

Room and packaged terminal heat pumps, shown in Figure 4-1, are window or through-the-wall mounted units designed to heat and cool a single room or zone. A room heat pump (sometimes called a reverse-cycle room air conditioner) is a consumer appliance that may be installed by the homeowner or by the service crew of an appliance store. A packaged terminal heat pump is generally a contractor-installed product marketed to hotels, motels, offices, hospitals, and nursing homes where the individual zone control is an important asset.

Both room and packaged terminal heat pumps are suitable for providing heating and cooling to add-on rooms or areas newly converted to living space (e.g., an attic or garage). Often, a newly converted living space will require air conditioning, but hooking the space up to the existing HVAC system may be difficult or may overload the system. In this case, a through-the-wall or window-type heat pump unit may provide the best solution. These self-contained units employ free air delivery, whereby air is drawn in at the bottom of the unit and blown out the front or the top. No air ducts are necessary, although when it is desirable to serve two adjoining rooms or zones, a duct-type extension can be fit to the outlet air register of the packaged terminal unit.

Air-source heat pump manufacturers make room heat pumps in capacities ranging from 5000 to 20,000 Btu/hour in heating and 6000 to 24,000 Btu/hour in cooling. Both 115-volt and 230-volt systems are available. The 115-volt units that plug into a standard household outlet do not come with supplemental resistance heat and, therefore, are suitable for installa-



ROOM HEAT PUMP

PACKAGED TERMINAL HEAT PUMP OUTDOOR VIEW

PACKAGED TERMINAL HEAT PUMP INSIDE VIEW

FIGURE 4-1: Room and Packaged Terminal Heat Pumps tion in moderate climates only, where the outdoor temperature does not fall below 35 °F. For lower temperature applications, resistance heating elements are available on 115-volt units on dedicated branch circuits, and for 230-volt units. Room heat pumps typically defrost by cycle reversal, but units without resistance heating elements have no means of providing heat during this interval.

Packaged terminal heat pumps are manufactured in capacities ranging from 6000 to 15,000 Btu/hour for heating and 6000 to 15,000 Btu/hour for cooling. Only 230-volt and 265-volt units are currently available. These units switch to electric resistance heat below the balance point temperature (the temperature at which the heating requirement exceeds the heating capacity of the heat pump) and use the "natural defrost" method, one which works only if the outdoor temperature is above freezing. In this case, the heat pump compressor is stopped and the outdoor heat exchanger is allowed to defrost in contact with the warmer outdoor air. Below 32 °F, the heat pump compressor does not operate. Under these circumstances, heat is provided by electric resistance only.

CENTRAL SINGLE-PACKAGE HEAT PUMPS

Central single-package heat pumps can provide heating and cooling to the entire home. These units are usually located outside the home with supply and return air ducts entering the home through the exterior wall nearest the heat pump, as shown in Figure 4-2. Roof-mounted and eave-mounted units are also available. As an alternative to a ducted supply system, the space above a furred, lowered hallway ceiling can serve as a supply air plenum, with registers leading directly into rooms on either side of the hall. Louvered doors and the hallway itself constitute the return air conduit.

Central single-package heat pumps are suited to use in manufactured or small, single-story, site-built homes with a slab or crawl space type foundation. Small commercial buildings with single or multiple roof-mounted or ground-mounted units are also common. Central single-package heat pumps are usually available with 18,000 to 120,000 Btu/hour heating and cooling capacity.

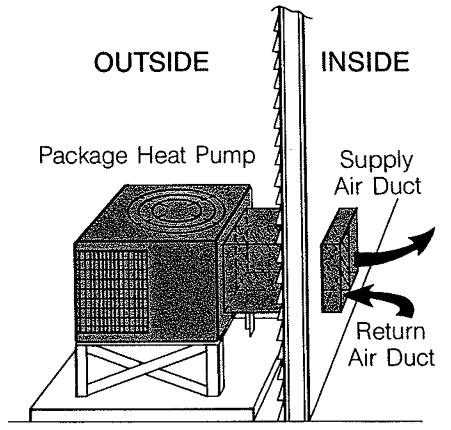
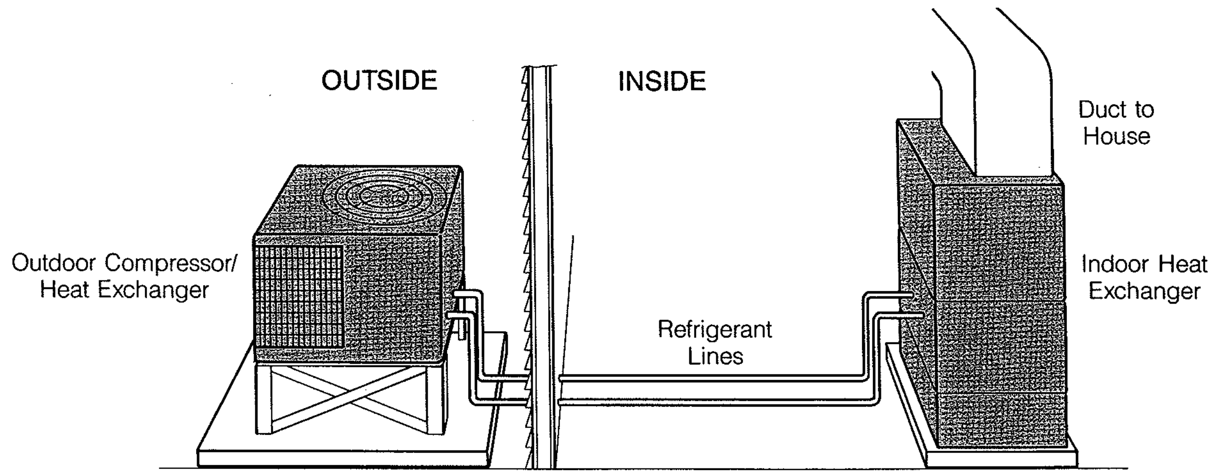


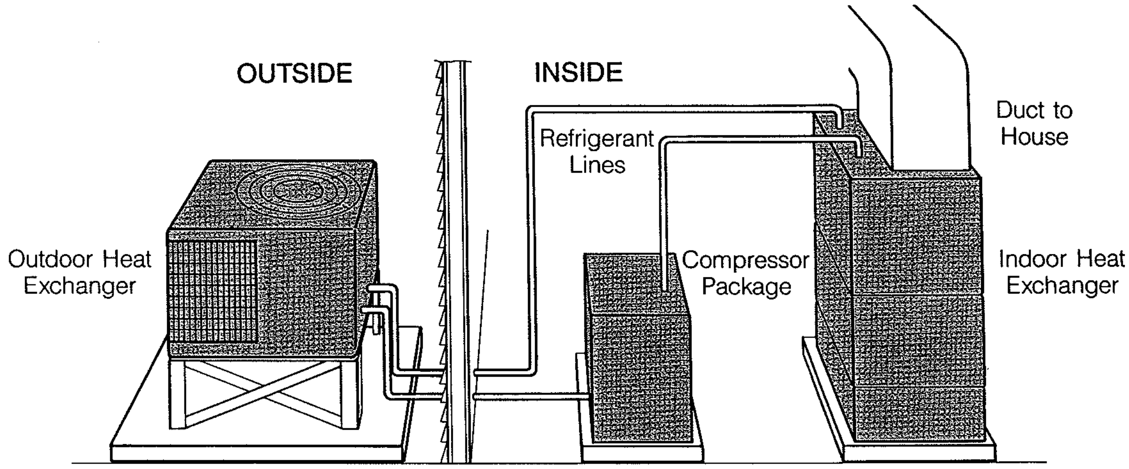
FIGURE 4-2: Central Single-Package Heat Pump

CENTRAL SPLIT-SYSTEM HEAT PUMPS

Of all heat pump systems, the air-to-air, split-system type is the most common. In split systems, the indoor air handling unit (i.e., the blower and heat exchanger) is separate from the compressor and the outdoor heat exchanger. This allows considerable flexibility in locating these units. For example, the indoor air handlers can be installed in the basement, the crawl space, the utility room or closet, or the attic. Split-system heat pumps may be two-piece (dual-split) or three-piece (triple-split), as shown in Figure 4-3. In the dual-split system, the compressor is part of the outdoor unit and, because of the compressor's motor noise, is usually located away from bedroom windows and other living space.



TWO PIECE HEAT PUMP (DUAL-SPLIT)



THREE PIECE HEAT PUMP (TRIPLE-SPLIT)

FIGURE 4-3: Split-System Heat Pumps

The three-piece system, manufactured specifically for use in northern climates, has a heat exchanger unit located outdoors, and a compressor unit and an air handling unit located indoors (e.g., in the garage). Locating the compressor indoors provides it a more moderate environment and enhances system performance, longevity, and ease of maintenance. A three-piece arrangement in which the compressor unit is located in the garage or basement is ideal because the compressor is removed from the living space and yet kept indoors.

Split-system heat pumps are suitable for installation in both new and existing homes, provided the latter have air ducts of sufficient size to accommodate the approximately 400 cubic feet of air distributed per minute, per ton, in a central air conditioning system. Residential split-system heat pumps are now controlled by a single central thermostat. In the future, control of individual rooms or zones may be accomplished through dampers in supply ducts, but this technology is still in development.

Split-system heat pumps are manufactured with 12,000 to 60,000 Btu/hour nominal heating and cooling capacity for residential installation. Larger, commercial units are also available. Because of the market dominance of these systems for both residential and commercial uses, a variety of compressors, heat exchangers, and thermostatic controls are available, as are accessory components such as desuperheaters for water heating or preheating. Supplemental heating is typically supplied through electric resistance heaters installed in the air handler, but a combustion furnace may be used as well.

MULTIZONE HEAT PUMP

The multizone heat pump is a central split-system device consisting of an outdoor heat exchanger and compressor unit and multiple (three to five) indoor air handling units. These units come as console and wall-mounted types and are connected to the outdoor unit by refrigerant piping, as shown in Figure 4-4. The indoor units can be independently controlled to allow different temperatures in each room, enabling residents to save energy by heating only occupied areas. The compressor and outdoor heat exchanger unit currently available is designed to supply refrigerant to as many as five rooms. While these currently marketed systems do not allow heating of one zone with simultaneous cooling of another, units in one or more zones may be turned off while other zones are heated or cooled. The use of refrigerant piping rather than ducts makes the multizone heat pump especially attractive for retrofit in older homes where installing ductwork would be too expensive, difficult, or otherwise undesirable.

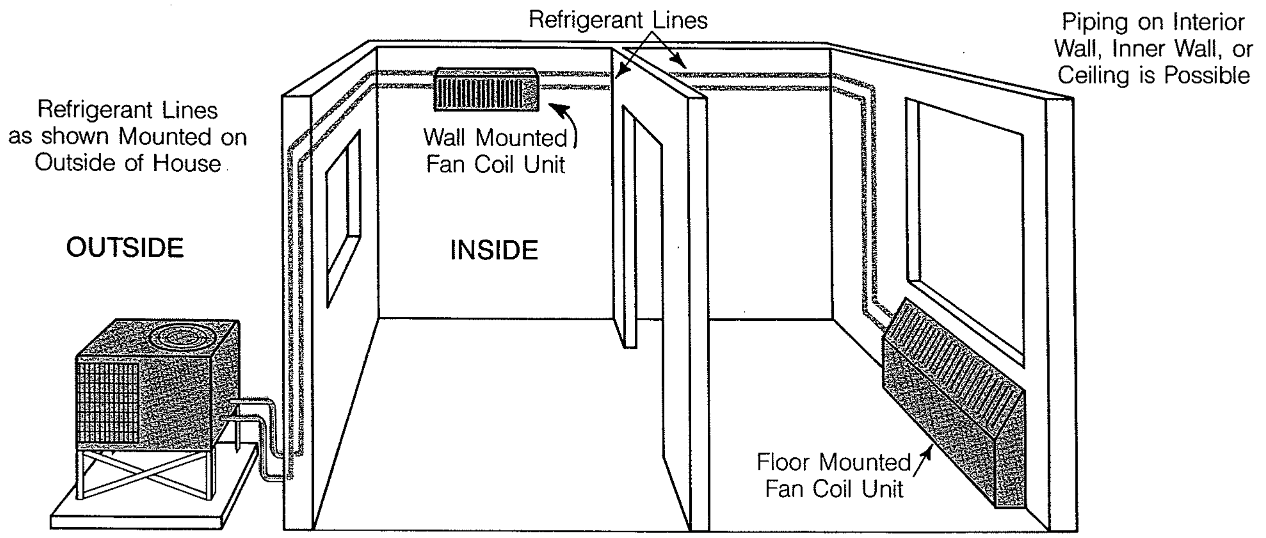


FIGURE 4-4: Multizone Heat Pump

4

Air-to-Water Heat Pumps

Air-to-water (hydronic) heat pumps are used for both space heating and domestic water heating. Space heating air-to-water heat pumps distribute heat through a central hydronic system using radiators or convectors. These systems absorb heat from outside air but use a refrigerant-to-water heat exchanger and hot water piping to deliver heat to the home. More prevalent in Europe than in the United States, these systems are usually retrofitted into homes that have hot water heating systems and where an existing boiler can provide supplemental heat.

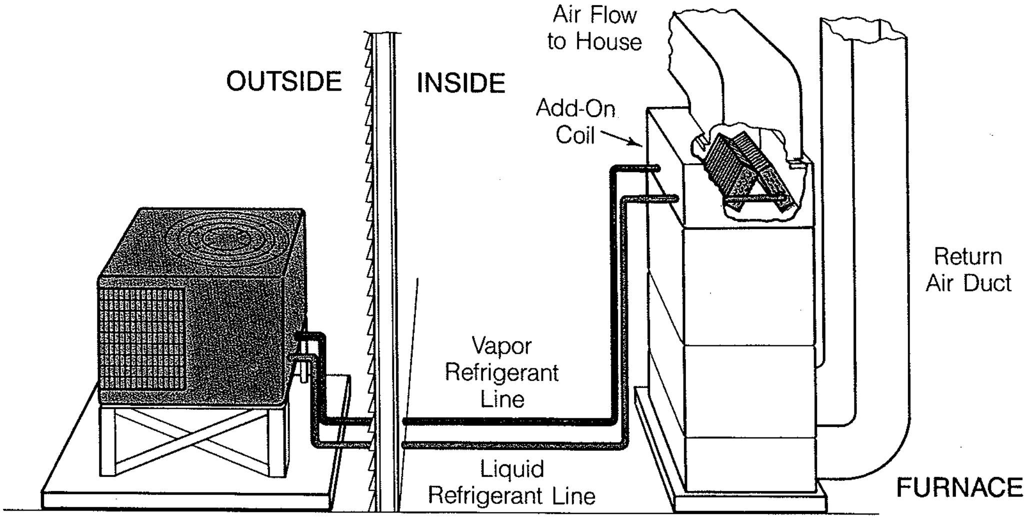
Hydronic heat pumps generally provide heat but not cooling. Although they could be used to deliver chilled water for cooling, moisture condensation and disposal problems make this impractical. Therefore, room air conditioners are frequently a better solution for the retrofit situation where cooling is needed. If necessary, an air-to-water heat pump can be used with a forced-air distribution system (by putting the water coil into the duct). In most cases, however, it is preferable to install a standard air-to-air heat pump.

Add-On Heat Pumps

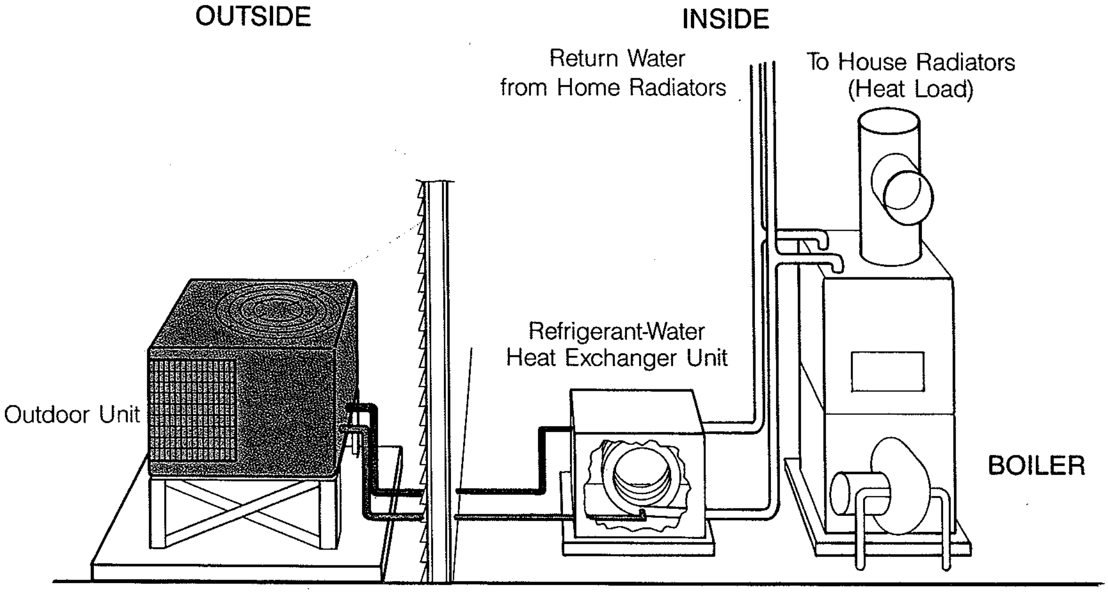
Add-on heat pumps are those used in combination with an existing warm air furnace or boiler, as shown in Figure 4-5. If the furnace or boiler is a combustion type — using natural gas, fuel oil, or liquefied petroleum gas (LPG) — the add-on heat pump is called a bivalent or dual-fuel system. If the furnace is electric, the add-on heat pump is basically identical to a resistance heat-supplemented unit and is monovalent. If the furnace air handler can accommodate an air conditioner coil it is generally possible to add on a heat pump coil for electric heating and cooling.

A less common add-on configuration is the add-on hydronic system which combines a heat pump and a hot water boiler. In this case, the heat pump does not provide cooling, but rather provides heat during periods of moderate outdoor temperatures. At colder temperatures, when the heat pump alone cannot meet the heating requirements of the home, the furnace or boiler turns on and the heat pump turns off. The furnace also operates when the heat pump is defrosting. Thus, the advantage of the add-on arrangement is that each heating system operates when it is most efficient: the heat pump when the temperature is moderate, the furnace when the temperature is low and the heating load high.

Generally, add-on heat pumps are suitable for cold climates with high heating demand, particularly where the price of electricity is relatively low compared to that of fossil fuels. In warmer climates, add-on heat pumps might be considered by homeowners who are planning to install or replace a central air conditioning system. Although the initial cost of an add-on system is more than that of a conventional heat pump or furnace and air conditioner combination, the add-on system allows displacement of fossil fuels and provides a hedge against disproportionate increases in the price of fuel or fuel supply curtailments. From the perspective of an electric utility, add-on systems with fossil fuel backup are especially attractive because they do not impose high peak demands on the utility system, as resistance-supplemental systems do in cold weather. Add-on heat pumps are also particularly amenable to utility load control either by direct or local methods.



AIR-TO-AIR ADD-ON HEAT PUMP SYSTEM WITH FURNACE



AIR-TO-WATER ADD-ON HEAT PUMP SYSTEM WITH BOILER

▨ High Pressure Medium Temperature Liquid ■ High Pressure High Temperature Vapor

FIGURE 4-5: Add-On Heat Pump Systems

4

New Developments

Electric heat pumps have reached only 10 to 15% of their maximum theoretical efficiency and research on these systems is proceeding. In addition, rising energy costs and perception of a market demand for more efficient heating and cooling systems have increased the rate of product evolution and spurred introduction of new concepts. One of the new systems, the multizone heat pump, developed in Japan, has already entered the United States marketplace. Others, such as variable speed heat pumps, unitary bivalent systems, and heat pumps with integrated water heating and thermal storage, may enter the market soon. These and other concepts will be described here briefly. Most of these new concepts are applicable to water-source as well as air-source heat pumps.

VARIABLE SPEED HEAT PUMPS

A variable speed drive allows a heat pump to continuously vary the compressor pumping rate according to the heating and cooling load. This eliminates the need for — and the inherent inefficiencies of — cycling the compressor on and off (at all but very low loads). A rectifier-inverter system converts 60 hertz current to frequencies as low as 15 to 30 hertz, and as high as 90 hertz, and allows the motor speed to be varied over a 6:1 or 3:1 range.

Variable speed heat pumps, properly sized to the building load, could potentially reduce or altogether eliminate the need for supplemental resistance heat. In addition, the comfort delivery, reliability, and electrical demand characteristics of the variable speed heat pump are improved because of the more sustained operation and lack of on-and-off cycling.

Variable speed heat pumps have been developed in both the United States and Japan, but so far have enjoyed market acceptance in Japan only. High inverter costs have impeded market acceptance of these systems in the United States, but as inverter costs decrease and energy costs increase, that picture could change. While there are other means of providing capacity modulation in heat pumps — some of which have been commercially introduced — a truly "thermal-load-following" heat pump represents an efficiency ideal, if not an economic one.

NONAZEOTROPIC REFRIGERANT MIXTURES

Nonazeotropic refrigerant mixtures are mixtures that contain a more and a less volatile refrigerant, and which do not boil at a constant vapor and liquid composition. Because the mass flow rate of a refrigerant diminishes at high source-sink temperature differences (such as are encountered in cold weather), vaporizing greater amounts of the more volatile refrigerant would enhance the mass flow and the heat-carrying capacity of the fluid, and improve efficiency as well. Nonazeotropic refrigerant mixture systems are being actively investigated both in this country and abroad.

UNITARY BIVALENT HEAT PUMP

Unitary bivalent heat pumps represent an improvement to the add-on heat pump concept. One such system, designed in Canada, was recently introduced in the United States. This system employs a conventional heat pump design, but adds a burner unit under the outdoor heat exchanger. When the air temperature becomes too low for efficient heat pump operation, the burner fires to heat the air entering the outdoor heat exchanger, thereby increasing the capacity and the efficiency of the system. Locating the combustor in the outdoor unit eliminates the need for a furnace and chimney and a potential source of air infiltration.

If successfully developed, unitary bivalent heat pumps may make dual-fuel heating systems more competitive in the new home market because the consumer will have to buy just one instead of two heating systems.

GAS-FIRED HEAT PUMPS

Gas-fired heat pumps have been under investigation for many years. They fall into two basic categories: absorption cycle systems and engine-driven systems. In theory, gas-fired heat pumps can attain higher efficiencies in heating operation than can combustion furnaces. This is because gas-fired heat pumps are not constrained by the thermodynamic efficiency limit of 100% — which combustion furnaces are now approaching — but can absorb heat from ambient heat sources, as do electric heat pumps. In a gas-fired unit, heat from the flue gas of the generator of an absorption system, or from the exhaust and jacket cooling water of an engine-driven system, is recoverable and may be used to supplement the pumped heat. Conversely, the waste heat generated on site by a gas-fired heat pump is a disadvantage in the cooling mode. The waste heat of fuel combustion for electricity generation in a thermal generating plant is rejected at the plant site and is not available for electric heat pump augmentation.

In addition to the absorption cycle machine, natural gas-fired spark-ignition engines, Stirling engines, and organic Rankine turbines are being tested as drivers for vapor compression and Stirling (refrigeration cycle) heat pumps. Because of unresolved difficulties with these systems, gas-fired heat pumps are not expected to become commercially available in the near future.

5

Water-Source Heat Pump Systems

In This Section: Classification of equipment and systems; groundwater heat pump systems; surface water heat pump systems; ground-coupled heat pumps; solar-assisted heat pumps

Water-source heat pumps function much like air-source units in that they can provide both heating and cooling, heating only, or water heating only; use either forced-air or water (hydronic) heat distribution systems; and are suitable for both new homes or retrofit applications. A water-source heat pump uses a water-to-refrigerant heat exchanger to extract heat from a heat source. In residential settings, the source can be groundwater, river or lake water, city water, stored solar energy, or the ground itself. In large commercial buildings, heat generated in the building interior by lights, office machinery, and the occupants themselves may be recovered for perimeter heating or water heating, constituting a closed-loop system. In fact, the majority of the water-source heat pumps currently manufactured are for closed-loop applications in commercial buildings. This discussion, however, is confined to residential applications where the heat source is generally external to the building.

In principle, water-source heat pumps have an efficiency advantage over air-source systems because of heat source temperature constancy: the annual range of variation in groundwater or surface water temperatures in most parts of the country is much less than the variation in air temperature. Groundwater temperatures range from about 42 °F to about 77 °F within the continental United States. The temperature of most rivers and lakes (except very shallow ones in cold regions), too, stays above freezing. Unlike air-source heat pumps that must use supplementary heat when the outside air temperature drops below the balance point, a decrease in air temperature has no effect on the performance of water-source heat pumps that have been sized for heating. Even during extended periods of subfreezing weather, these water-source heat pumps will continue to perform efficiently because the source and sink temperatures will remain relatively constant (assuming proper installation of water pipes below the frost line or below the freezing depth of the lake or pond water source).

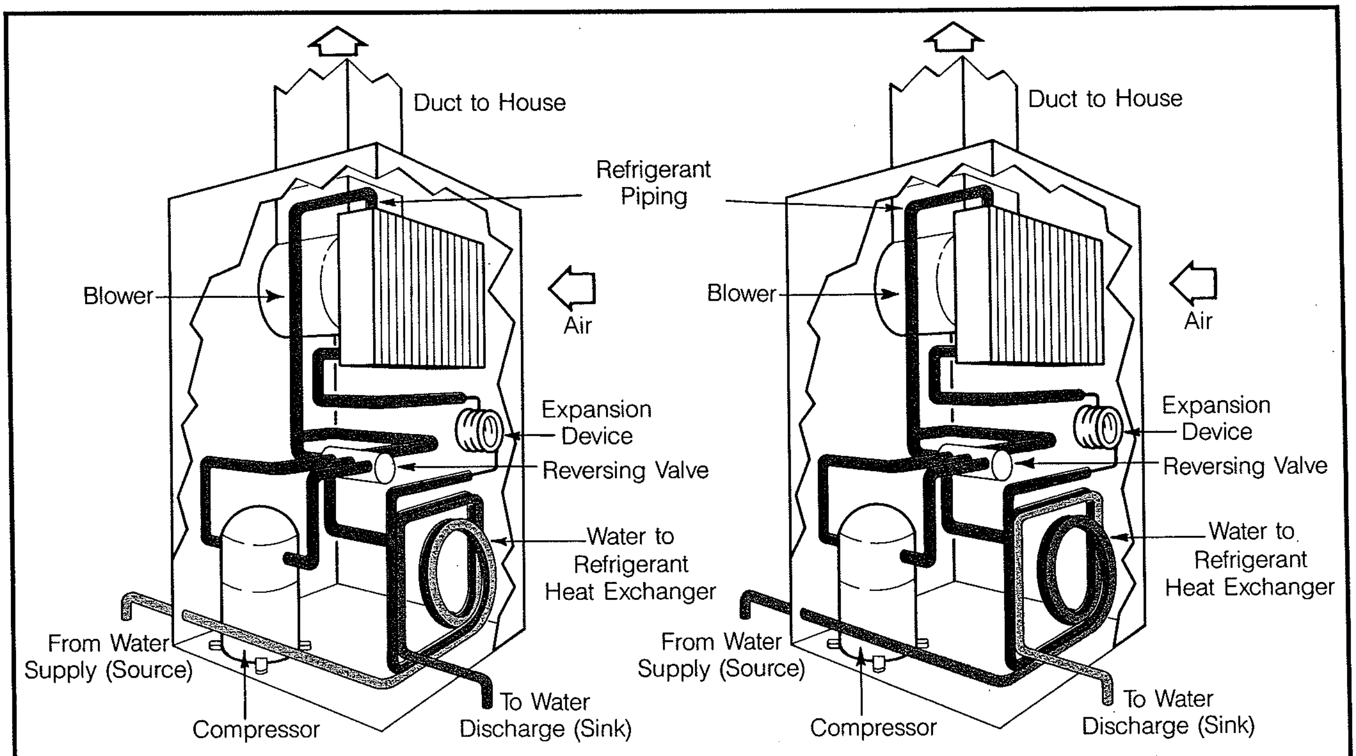
5

Classification of Equipment and Systems

In describing water-source heat pumps, it is important to distinguish between the equipment and the system in which the equipment is applied. Water-source heat pump equipment is either of the water-to-air or water-to-water type and is available in single-package units or split systems that can be designed to accommodate a wide range of building types and heat sources. About 16 manufacturers make water-source heat pump equipment. A schematic diagram of a water-to-air heat pump is shown in Figure 5-1.

A water-source heat pump system can be either open-loop or closed-loop. Open-loop systems use groundwater or surface water directly: water is pumped from the well, river, or lake through the water-to-refrigerant heat exchanger and, eventually, either returned to the source or pumped to a drainage basin, pond, or storm sewer. Closed-loop systems continuously circulate a heat transfer fluid, such as water or a water-antifreeze mixture, to extract heat from the ground or surface water source (and reject heat thereto).

Water-source heat pump systems are most often classified according to the heat source utilized. Although a uniform nomenclature for water-source heat pump systems has not yet been adopted by the industry, for purposes of this manual they are divided into groundwater systems, surface water systems, and ground-coupled systems. The principal difference among these systems is the method employed for source-to-refrigerant heat exchange.



HEATING OPERATION

COOLING OPERATION

FIGURE 5-1: Water-to-Air Heat Pump

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Choosing between an open-loop or closed-loop system often depends upon water availability. An open-loop system may be used where an adequate and steady supply of water exists and where water disposal does not present a problem. A closed-loop system is better if there is a problem with water availability, quality, or disposal.

Groundwater Heat Pump Systems

Groundwater is available in most parts of the United States and many homes in rural areas have wells that tap into groundwater. Figure 5-2 is a map of average groundwater temperatures in the contiguous United States, showing that even in typically cold regions such as Bismark, North Dakota (where air temperatures can drop below -30 °F for a few days each year), the groundwater temperature remains relatively moderate.

SUPPLY CONSIDERATIONS

A number of states now regulate the withdrawal, use, and disposal of groundwater. Local authorities, usually the county or state well-permitting agency or the geological survey, should be consulted to determine the current, local regulations. Also, information on the quality of groundwater in the area, the depth of the water table, and the expected well flow rates should be

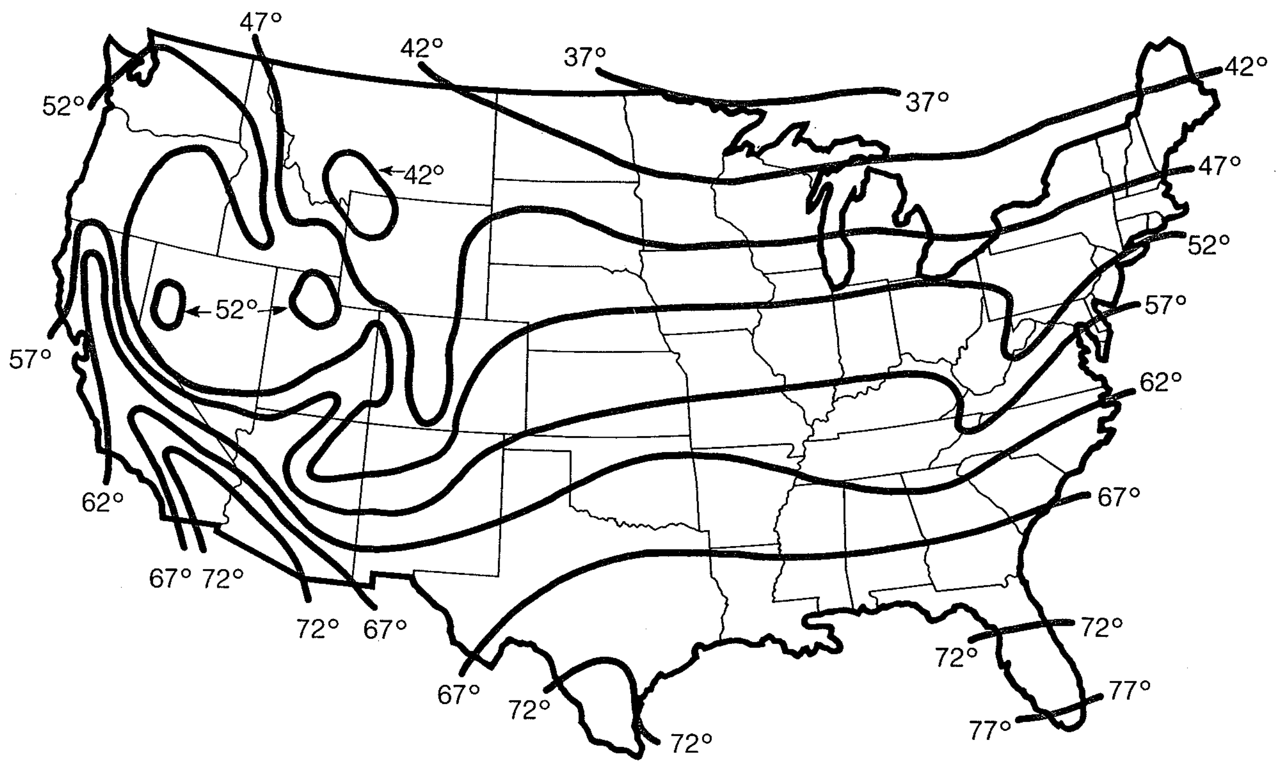


FIGURE 5-2: Mean Groundwater Temperatures in Shallow (30 to 60 feet) Wells in the United States

Source: (16)

obtained. This information may be available from well logs of nearby wells, the state geological survey, reputable well drillers, or the state water commission. If information is unavailable, a test well should be drilled.

Water quality analyses can be performed by commercial laboratories and, in some states, by the state health department or geological survey. Hardness, acidity, and similar characteristics should be determined, as mineral deposits can accumulate in the water-to-refrigerant heat exchanger and can eventually block the heat exchanger completely. Test results should be compared with manufacturers' specifications to ensure that the water will not corrode or foul the water-to-refrigerant heat exchanger.

Water from existing wells can be used to supply the heat pump, provided flow rate and water quality are acceptable. Wells with marginal water flows require an oversized water tank as buffer storage for the heat pump. Alternatively, an existing supply well could be converted to a recharging well and a new supply well drilled.

If a new well must be drilled, it should be deep enough to fall below the lowest expected water table. Data on the 50- or 100-year water table should be used to determine the level. In sections of the country where overdraft is occurring, however, these data cannot be used. For these areas, a well's useful life may be estimated by multiplying the total water table depression rate, in feet per year, by the number of years the well is required to last. The product of this calculation is the depth to which the well should be drilled below the lowest experienced water level for the local water table. Of course, drilling to this depth does not guarantee that water will be available, as the water table could be depleted more rapidly than projected. The local water commission, geological survey, or reputable well drillers should be able to provide current or historical water table depression rates.

All groundwater wells, whether deep or shallow, should be cased to protect them from caving in and to allow access to equipment installed in the well. Wells drilled in stable rock formations, however, usually do not require casing.

TYPES OF GROUNDWATER HEAT PUMP SYSTEMS

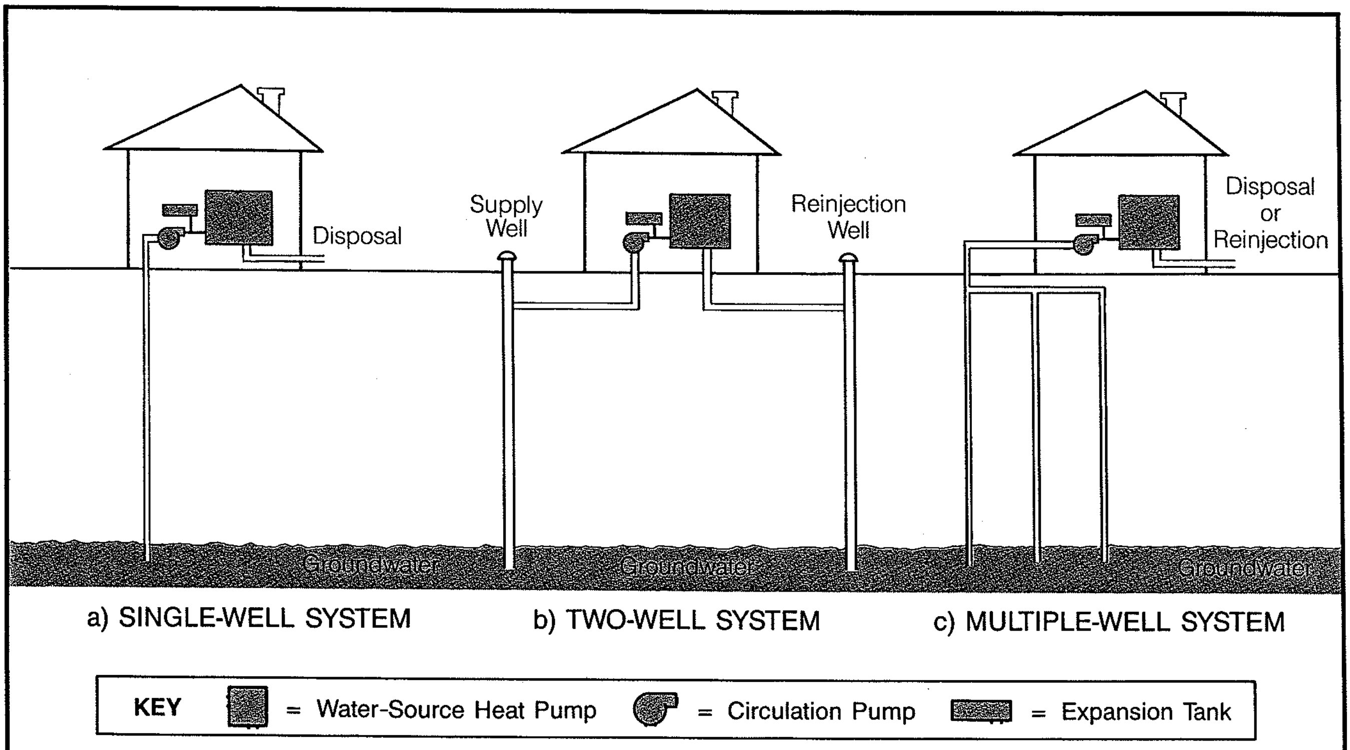
As described previously, groundwater heat pump systems are of the open-loop type: water is withdrawn from a well, flows through the heat exchanger of the heat pump, where it exchanges heat with the refrigerant, and is then disposed of by reinjection or discharged into a specially prepared disposal pond, storm sewer, or stream. As shown in Fig. 5-3, groundwater heat pump systems may be classified into single-well, two-well, and multiple-well systems.

Single-Well System. A single-well system (Figure 5-3a) consists of a supply well connected to the water-source heat pump. A well pump and a surge (expansion) tank are usually required. The single-well system is usually the least expensive to install because it requires only one well and minimal piping. The disadvantage of this type of system is that water withdrawn from the supply well must be disposed of elsewhere. The cost of disposal depends on the location of the well, the legal restrictions, if any, imposed on the method of discharge, the distance of the discharge site from the supply well, and quality of the discharge water. In some jurisdictions it is illegal to extract water and return it to the same aquifer; other jurisdictions require reinjection.

Two-Well System. A two-well system consists of a supply well and a reinjection well (Figure 5-3b). The two-well system may make a groundwater heat pump installation possible where other methods of discharge are not allowed or pose a problem. The major disadvantages of a two-well system are well cost (usually the most significant cost of the entire installation) and the tendency of reinjection wells to clog.

The horizontal distance between supply and reinjection wells depends on the water withdrawal rate and the flow rate of the water in the aquifer itself. In an active aquifer (i.e., one in which water moves at a rate greater than 1000 feet per year), two wells may be placed reasonably close to one another, that is, 10 to 30 feet apart. If the aquifer is sluggish (water flow of 10 feet per year or less), the wells should be placed 100 feet or more apart to avoid using reinjected water. Some installers recommend reversing the supply and discharge wells periodically, particularly if the aquifer is sluggish or inactive. Information about aquifer activity may be obtained from a hydrologist or the state geological survey.

Multiple-Well System. Multiple shallow wells may be used for supply and reinjection if the groundwater table is at shallow depths (Figure 5-3c). Several shallow wells are typically less expensive and easier to drill and complete than a single deep well of equivalent casing length. Furthermore, less power is required to pump a given amount of water from a shallow well than from a deep well. Spacing of the wells can be close — about 10 to 30 feet apart for a four or five well system — but this varies by application. Multiple-well systems are often used for larger residential or commercial applications and require careful design of the well field and pipe manifolds to balance withdrawal rates.



a) SINGLE-WELL SYSTEM

b) TWO-WELL SYSTEM

c) MULTIPLE-WELL SYSTEM

FIGURE 5-3: Types of Groundwater Heat Pump Systems

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Surface Water Heat Pump Systems

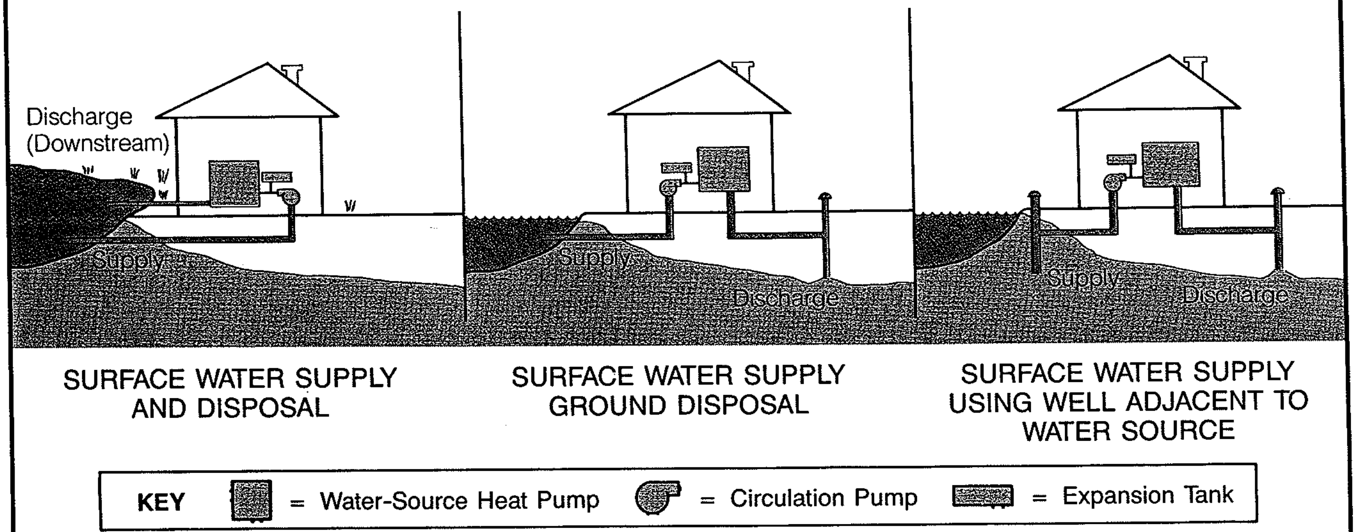
Surface waters — rivers, lakes, or even small ponds — may be used as heat sources for water-source heat pump systems if they are located close enough to the intended installation. This generally requires that the homeowner's property contain or abut a river, lake, or other body of water, and that the homeowner have rights to the water supply. The distance from the water source also has obvious implications as to the cost of the water supply pipe and the pumping power required.

SUPPLY CONSIDERATIONS

Surface water is exposed to the air and is, therefore, affected by air temperature and solar radiation to a greater extent than is groundwater. Surface water sources that freeze in the winter are unsuitable for heat pumps. In northern sections of the country that experience extended periods of subfreezing temperatures (e.g., upper Michigan, North Dakota) it is not uncommon for small, shallow lakes (up to as much as 20 or 30 feet deep) to freeze completely.

Ocean or brackish water can be used as a heat source only if special, corrosion-resistant materials are used in the refrigerant-to-water heat exchanger. Such heat exchangers are likely to be quite expensive.

Several methods of utilizing a surface water source are illustrated in Figure 5-4. The simplest is to lay a supply pipe in the water. Water can be discharged into the same body of water through a return pipe. With a properly designed drain-down system, it may be possible to install pipes on the land surface. However, this is not a satisfactory procedure if the ground freezes. In cold climates, pipes to surface water should be buried below the frost line and should enter the surface water below the maximum depth at which ice usually forms. Pipe insulation and protection may be required



SURFACE WATER SUPPLY AND DISPOSAL

SURFACE WATER SUPPLY GROUND DISPOSAL

SURFACE WATER SUPPLY USING WELL ADJACENT TO WATER SOURCE

FIGURE 5-4: Surface Water Heat Pump Systems to prevent exposed pipes from freezing.

Another approach is to use a shallow supply well adjacent to the water source. The well must be several feet below the frost line to ensure that water will remain in it throughout the year. A discharge well should be constructed a sufficient distance (at least 30 feet) away from the intake pipe in order to avoid recirculation. If the water source is a river or creek, the discharge should be located downstream of the intake. Coupling arrangements require standard plumbing, including air bleed valves and check valves (presuming the system is not drain-down).

Surface disposal of water is strictly regulated. The U.S. Environmental Protection Agency (EPA) has the primary federal responsibility for ensuring surface and groundwater quality. Regional governments, counties, cities, and some states also regulate surface waters, and these regulations vary widely. Most codes stipulate that surface waters supplying drinking water may not accept discharges from users of that water. Less restrictive regulations govern discharge into surface waters not intended for potable use. Local code information can be obtained from regional water works associations, the state geological survey, the city water department, or the state water resources office.

Ground-Coupled Heat Pumps

Ground-coupled heat pumps use the earth itself as a heat source and heat sink. The heat pump is coupled to the earth by means of a closed-loop heat exchanger. This heat exchanger, or ground coil, is usually either synthetic or copper piping and may be installed horizontally or vertically in the ground. Other configurations, using tanks and plates, are under investigation.

The ground-coupled heat pump circulates water from the heat pump through the ground coil to absorb or reject heat. Apart from the heat exchanger configuration, ground-coupled heat pumps function similarly to open-loop water-source heat pumps. The closed-loop configuration eliminates the need for the great quantities of water demanded by open-loop water-source heat pumps. Also, water disposal is not required, thereby avoiding the need for a reinjection well. Ground-coupled heat pumps may be economic for a wide range of homes, especially those with adequate space to install horizontal heat exchanger piping. Vertical heat exchanger systems can be a realistic economic option for homes with small yards.

TYPES OF GROUND-COUPLED HEAT PUMPS

At present, all ground-coupled heat pumps use commercially available water-to-air equipment. Two basic configurations are used: the pressurized or closed-fluid system, and the atmospheric or open-fluid system. (This is not to be confused with the fact that a ground-coupled system is a closed-loop system, which means that the heat exchanger fluid recirculates within the heat pump and does not leave the system.) In what is termed an atmospheric system, the transfer fluid is exposed to atmospheric pressure; thus, atmospheric systems typically require larger pumps to accommodate pressure head differences. Pressurized systems, whose transfer fluids are not exposed to atmospheric pressure, require smaller circulation pumps and, as a result, have lower operating costs. Pumping power may account for 10 to 12% of total electrical consumption in an atmospheric system, and 4 to 5% in a pressurized system. Consequently, the performance of the atmospheric system will be somewhat lower than that of the pressurized system. (Atmospheric or pressurized classification may be applied to all water-source heat pump systems. See Figure 10-3, pg. 95.)

An infinite number of ground-coupled heat exchanger designs are possible, but the most common are horizontal serpentine, vertical U-tube, and vertical U-tube in multiple shallow wells. Heat exchangers are installed either horizontally or in a vertical well hole, and typically are constructed on-site.

HEAT EXCHANGER WORKING FLUIDS AND MATERIALS

Several types of fluids are commonly used in these heat exchangers: plain water; a mixture of water and ethylene glycol, propylene glycol, or calcium chloride; and refrigerant. The choice of heat exchanger transfer fluid controls the behavior of the system and affects the design and choice of heat exchanger materials. Design also depends on existing soil conditions, the local costs of constructing a ground-coupled heat exchanger, and variation in soil water content.

Water. Water is the least expensive of all the heat exchanger fluids and is a proven working fluid. However, the water circulation system must have antifreeze control mechanisms to ensure that the evaporator shell does not freeze and that the heat pump will operate during extended periods of subfreezing temperatures when heat demand is highest. Freeze protection can be provided by strip heaters, by running the circulation pump continuously (an emergency measure), or by installing suction pressure controls on the heat pump.

Antifreeze-Water Mixture. Antifreeze-water mixtures help prevent pipes from bursting in the ground-coupled heat exchanger or in the heat pump's refrigerant-to-water exchanger. The freezing point of the antifreeze mixture should be 20 °F less than the lowest anticipated operating temperature. For example, if the heat pump suction temperature is 10 °F or above, the antifreeze mixture should be set at -10 °F.

Ethylene glycol is permanent antifreeze similar to commercially available automotive antifreeze. It contains corrosion inhibitors and can be used as a working fluid. It is highly toxic and local or state codes may not allow its use. Propylene glycol is less toxic than ethylene glycol, but becomes viscous at lower operating temperatures. Calcium chloride is more frequently used than glycol mixtures because it is nontoxic and requires less power to pump. Methanol-water mixtures should not be used because extended exposure to such a liquid and/or its fumes in an enclosed space (such as a cellar) could be fatal. Because of the potential health hazards of methanol-water mixtures, many states prohibit their use in residential applications.

Refrigerant. Although designs have been devised in which the heat pump's refrigerant is pumped through a direct refrigerant expansion (DX) coil buried in the ground, heat pump manufacturers do not recommend using this technique. A main consideration is cost, due to two factors: necessary custom design of the heat exchanger, and use of copper as the coil material. The heat exchanger must be custom-designed by a refrigeration engineer to ensure that the oil return rate to the compressor is adequate and occurs under all operating conditions. Copper's durability makes it the only heat exchanger material that can be used. Horizontal burial is preferred if a DX coil is used because of oil return problems. The advantage of using the heat pump refrigerant as the heat exchanger working fluid is that it eliminates the temperature drop that typically occurs between the refrigerant and the heat exchanger fluid. The performance of the DX ground-coupled heat pump may be 20% higher than that of systems using other heat exchanger fluids.

Materials. The materials most commonly used in ground-coupled heat exchangers are copper, high density polyethylene (PE), and polybutylene (PB). Of these materials, copper has the best thermal characteristics and is readily available, but is the most expensive and may be subject to corrosion. Plastic pipes cost less and are easier to install than copper ones. High density PE is very popular; however, PB pipes are more flexible and so are more easily installed. It is sometimes difficult to obtain fittings for these pipes, so installers using this material must plan in advance.

Polyvinylchloride (PVC) has also been used in many installations but has proven problematic. PVC is more brittle than either PE or PB and its heat exchange characteristics are not as good. Because PVC is brittle and tends to expand and contract with seasonal changes in the heating and cooling modes, it can develop breaks and leaks that require expensive replacement.

Typically, plastic piping is connected by chemical bonding or by a fusion joining process. Chemical bonding is used strictly for PVC and is not suitable for PE or PB pipe. Fusion joining is a thermal process in which the PE or PB pipe or couplings are heated and the pieces are forced together. Another method used to join PE and PB pipe is called socket fusing. This method uses a connector coupling which is heat-fused to both pipes. A third method suitable for PB pipe uses brass insert barbed fittings and all-stainless band clamps and screws. Beware, however, of substitution of non-stainless screws on band clamps marked "all-stainless." High-density polyethylene pipe cannot be joined with band clamps.

DESIGN OPTIONS: PRESSURIZED SYSTEMS

Pressurized systems may be designed to use a deep vertical hole, multiple shallow holes, or horizontal ground-coil systems.

Deep Vertical Hole. This design, which results in minimum disturbance to the surface earth, uses a borehole drilled vertically into the earth, typically to a depth of 100 to 300 feet. A U-tube shaped heat exchanger, commonly made of 3/4- to two-inch diameter PB or PE pipe, may be installed in the hole, or a concentric tube of four-inches diameter or more may be used. The ground-coupled heat exchanger is usually constructed on-site. To prevent cave-in, the heat exchanger should be installed as soon as the borehole is completed. This design can be used only in settings where the earth is stable and where boreholes remain open long enough for heat exchanger installation.

If the earth is not stable and cave-in occurs during or shortly after drilling, then the hole will have to be cased and backfilled with sand or earth after the heat exchanger is installed. It is better if the hole is not cased, however, because direct contact between the heat exchanger piping and the earth improves the rate of heat transfer to the heat exchanger. If the hole has water in it, the heat exchanger pipe must be filled with water during installation, otherwise the buoyancy force upon the pipe will prevent installation. Insertion of the heat exchanger into a cased or uncased hole may present a challenge to inexperienced installers and so should be done by an experienced professional.

It is essential that the heat exchanger be pressure-tested for leaks prior to installation. This test should be performed at twice the operational pressure expected for the system — typically 40 psi or more. Once a heat exchanger has been installed in a hole, it generally cannot be extracted for repair.

A 150- to 200-foot deep hole per ton of capacity has been found adequate to support a five-ton heat pump in most applications, particularly if the soil around the pipe is wet. If no water is found in the drilling operation, then some capability for wetting the soil around the heat exchanger should be provided

Periodic wetting ensures that the system will operate at a uniformly high capacity and tends to maximize performance. A suction pressure gauge can be installed and used by the homeowner to determine when to wet the well; city water with a manual shut-off valve can be used for this purpose.

Multiple Shallow Holes. Multiple shallow holes can be used with the U-tube heat exchanger configuration described above. Multiple shallow heat exchangers, which use antifreeze or water, have several advantages. For example, they are easier and often cheaper to install because smaller machinery can be used to drill the shallow boreholes, which are about 30 to 70 feet deep.

Multiple wells typically are closed, reverse-return systems (their transfer fluids are not exposed to atmospheric pressure) and often are plumbed in parallel. A reverse-return system ensures that the pressure loss between the discharge side and the suction side of the water pump is equal in each branch, and that the flow of water through the heat exchanger is uniform in all its branches. This tends to maximize heat exchanger performance and also allows a single well to be isolated for repair without shutting down the entire system.

Multiple-well parallel systems also may be easily expanded to accommodate increased loads. Surface wetting of the holes is likely to be more effective with multiple shallow boreholes than with one deep borehole. However, shallow holes can be more expensive in some areas, can require more land area, and can be less effective if the water table is deep.

Horizontal Ground Coil. In areas where vertical boreholes cannot be used, it may be preferable to install a horizontal heat exchanger coil (if adequate surface area is available). All horizontal coils are closed systems using water or antifreeze as the working fluid. As a rule-of-thumb, each typically requires a surface area equal to twice the conditioned floor area of the building, with runs of copper, PE, or PB pipe usually located two to four feet apart. Although it is slightly more expensive to construct, a reverse-return piping system should be used to ensure uniform flow through all portions of the heat exchanger. Leaks that may develop in a single pipe then can be easily isolated.

Horizontal ground coils may be installed above or below the frost line if an appropriate heat exchanger fluid is utilized. In regions where the frost line exceeds six feet, installation can be expensive — unless the coil is installed above the frost line.

Wetting a horizontal coil system to ensure a continued, uniform heat exchange rate with the earth is more difficult than wetting the vertical borehole designs. Horizontal systems have been successfully coupled to septic drain fields and have maintained high performance in both winter and summer operation.

DESIGN OPTIONS: ATMOSPHERIC SYSTEMS

Atmospheric systems are used only in vertical borehole designs. They require a cased well and a water storage tank. In some systems, water is withdrawn from the well and stored in an insulated tank that is buried near or installed inside the house. Water is withdrawn from the tank as needed.

The atmospheric system has several advantages. First, homeowners can put their own water supply into the tank, rather than rely on some external water source. The atmospheric system can also provide watering capability to ensure that the earth around the well is wet. If the water in the well around the heat exchanger becomes too hot, as it might during summer operation, then the heated water can be removed and replaced with cold water, thus improving the system's operating performance.

Experimental systems with casings using

either concentric or U-tube heat exchangers have been built. In these designs, the water stored within the casing — in the space between the casing and U-tube heat exchanger — may be frozen and then melted by the earth cyclically. These designs can accommodate shallow or deep wells, but multiple shallow wells appear to be more reliable and less costly to install. Increased interest in this concept is likely in heating-dominated climatic regions because of the stress being placed on surface and groundwater sources, and because the heat transfer area required between the earth and the system is significantly decreased (about 25 to 75 %), reducing the initial system cost.

Several examples of ground-coupled heat pump designs are shown in Figure 5-5.

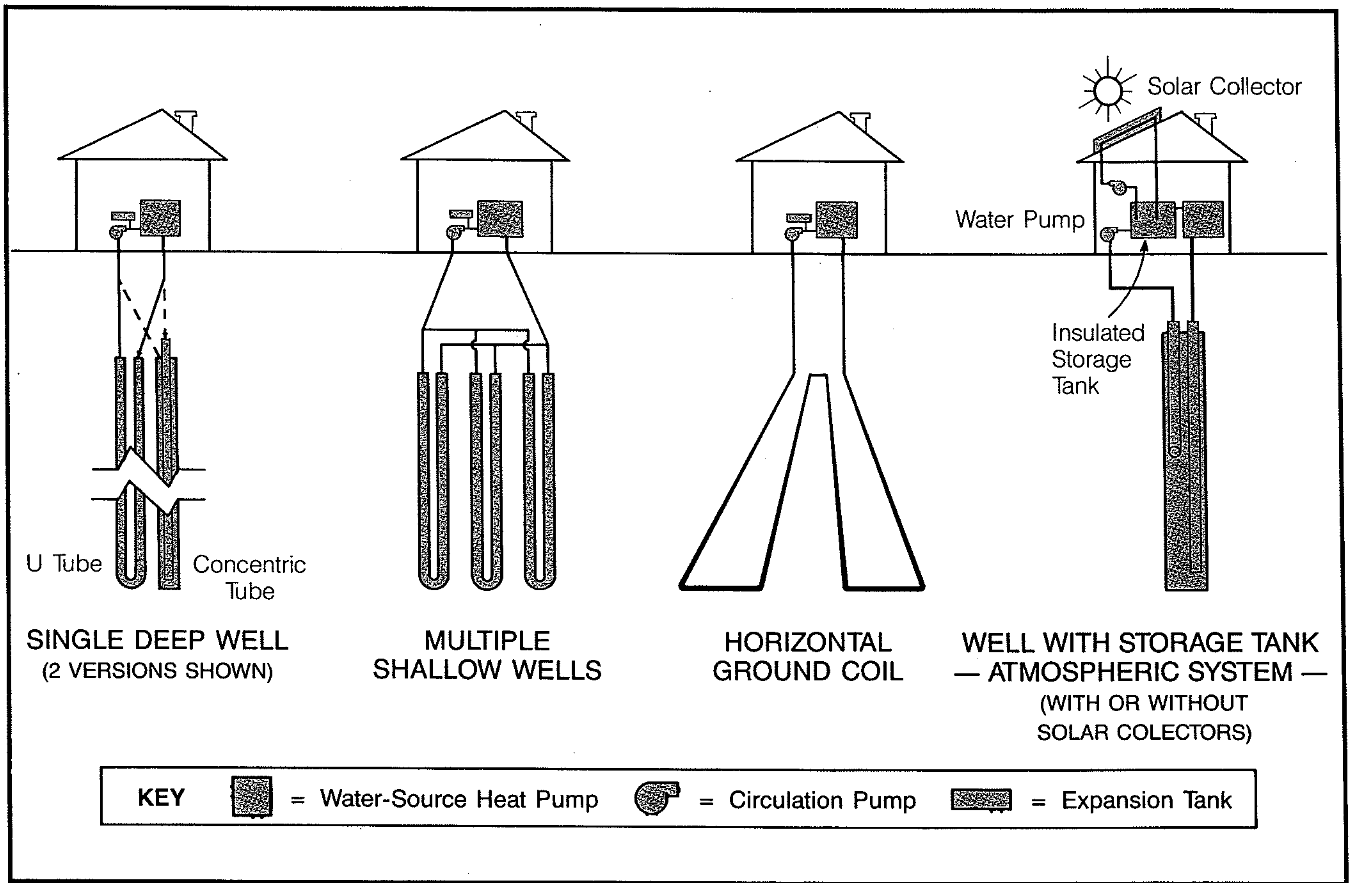


FIGURE 5-5: Ground-Coupled Heat Pump Designs

Solar-Assisted Heat Pumps

All air-source heat pumps use solar energy, but heat pumps coupled with solar heating systems have received special attention from researchers and manufacturers in recent years. It is doubtful, however, due to their high costs and low reliability, that they will have a major impact on the residential heating and cooling market in the near future.

Solar heat pump combinations operate either directly or indirectly. In the direct or solar-assisted system, the heat pump is combined in a series with the solar system such that heat pump refrigerant circulates through a solar collector and absorbs heat from the sun. In the indirect or solar-augmented system, the heat pump is combined in parallel with the solar system. In this case, water or air circulates through the solar collector and transfers absorbed heat to the refrigerant in the attached water-source or air-source heat pump. Experimentation is continuing to determine if either system — direct or indirect — is preferable in terms of performance. In both cases, however, the use of solar panels provides a means to boost water source temperature and provide nighttime radiative cooling.

Solar heat pump systems are currently custom designed to suit specific homes and applications and have been installed in various regions of the United States. Some unitary solar systems, however, are beginning to enter the market. Only the market forces, experience in the field, and the efficiency of the technology's performance can determine their future commercial success.

ANNUAL CYCLE ENERGY SYSTEM

The experimental Annual Cycle Energy System (ACES) uses a single-direction heat pump operating in the heating mode and a large insulated tank of water that serves as both the heat sink and heat source (Figure 5-6). During the winter, the heat pump removes heat from the storage water and uses it to heat the home and the domestic hot water supply. Over a period of months, the stored water turns to ice and this ice is used during the summer months as a heat sink to provide air conditioning. By the end of the summer, the ice is melted and can be used once again for heating.

The ACES system can be used in hot or

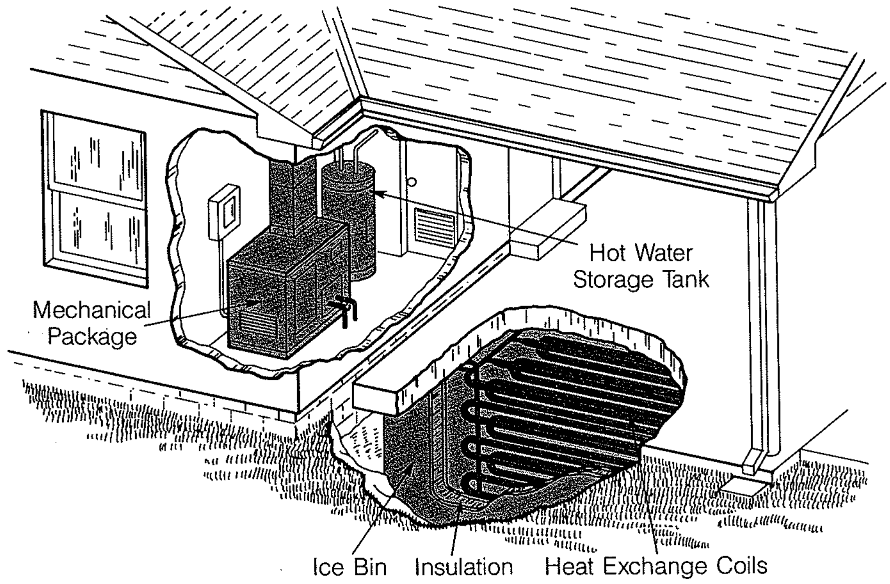


FIGURE 5-6: Annual Cycle Energy System (ACES) Source: (17)

cold climates and can incorporate solar collectors with the system. In northern areas, the use of solar energy would reduce heat pump run time and slow down the accumulation of ice, to compensate for a shorter cooling season. In southern climates, a larger storage bin can be used to store enough ice for the longer summer season. To be economically attractive, the ACES system must be designed to balance winter heating and summer cooling operation. In addition, the system is expensive to install and requires up to 1800 square feet for storage. However, it can achieve savings of up to 56% over electric furnace, electric air conditioner, and electric water heater combinations, and electricity savings of about 47% over an electric air-to-air heat pump.

SHORT-TERM STORAGE HEAT PUMPS

Some heat pumps have been used with short-term storage capacity using water, ceramics, or other media to retain thermal energy. These systems may be useful to reduce energy costs during peak hours, if and where time-of-day rates are in effect. Integration with domestic water heating is possible, if water is the thermal storage medium. Heat pumps with short-term thermal storage have not yet found a mass market in the United States.

6

Performance Ratings

In This Section: Single point performance ratings; other standard tests; seasonal performance ratings; technical data sources

Heat pumps are rated in terms of their heating and cooling capacities. Most manufacturers test and rate their heat pumps in accordance with the standard methods prescribed by the Air-Conditioning and Refrigeration Institute (ARI). Certain air-to-air heat pumps are tested and rated in accordance with more elaborate procedures prescribed by the U.S. Department of Energy (DOE) under the authority of the Energy Policy and Conservation Act (PL 94-163) and its amendments. Specifically, heat pumps with cooling capacities of 65,000 Btu/hour or less (and meeting certain other criteria) fall under the provisions of PL 94-163. They are listed as "DOE covered products" in the ARI unitary directory.

Testing and rating procedures fall into two categories: those that measure and rate heating/cooling capacity and power consumption under specific operating conditions, and those that measure performance under several operating conditions. Single point ratings indicate performance under conditions where, for example, the temperature and humidity of air or the temperature of water entering the indoor and outdoor coils is fixed. Seasonal testing and rating procedures indicate performance under several operating conditions. Single point performance is rated by two measures, the Coefficient of Performance (COP) and the Energy Efficiency Ratio (EER). Seasonal performance is rated in terms of the Heating Seasonal Performance Factor (HSPF) and the Seasonal Energy Efficiency Ratio (SEER).

Single Point Performance Ratings

ARI has established standard single point performance ratings and testing conditions for the various types of heat pumps. These ratings, which are summarized in Table 6-1, establish the capacity and efficiency of heat pumps under specified steady-state conditions, and form the basis for seasonal efficiency measures.

COEFFICIENT OF PERFORMANCE

The coefficient of performance (COP) is the scientifically accepted measure of the heating or cooling performance of any refrigeration machine — heat pump, air conditioner, or refrigerator. The COP is defined as:

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TABLE 6-1: Air-Conditioning and Refrigeration Institute (ARI) Standard Rating Conditions For Heat Pumps

SOURCE: ARI (18)

System	Rating Point	Measured Variable	Temperature (°F) Dry Bulb	Wet Bulb
Unitary Air-Source Heat Pumps (ARI Std. 240-81)	High Temperature Heating	Air entering outdoor coil	47	43
		Air entering indoor coil	70	60
	Low Temperature Heating	Air entering outdoor coil	17	15
		Air entering indoor coil	70	60
	Cooling	Air entering outdoor coil	95	75
		Air entering indoor coil	80	67
Packaged Terminal Heat Pumps (ARI Std. 380-82)		Same as unitary air-source heat pumps		
Water-Source Heat Pumps (ARI Std. 320-81)	Heating	Water entering outdoor heat exchanger	70	
		Air entering indoor coil	70	60
	Cooling	Water entering outdoor heat exchanger	85	
		Water leaving outdoor heat exchanger	95	
		Air entering indoor coil	80	67
Ground-Source Heat Pumps (ARI Std. 325-83)	High Temperature Heating	Water entering outdoor coil	70	
		Air entering indoor coil	70	60
	Low Temperature Heating	Water entering outdoor coil	50	
		Air entering indoor coil	70	60

$$\mathrm{COP} = \frac{\text{Heating (or cooling) provided by the system}}{\text{Energy consumed by the system}} \quad . (6.1)$$

The total heating output of a heat pump includes heat generated by the circulating fan but excludes supplemental resistance heat. Because the COP is a dimensionless measure, the heating and cooling output and energy input must be expressed in the same units. If the output is expressed in Btu, the system energy consumption, typically expressed in watthours, must be converted to Btu. This is done by multiplying the denominator by the conversion factor 3.413 Btu/watthour.

COP is more commonly used to measure heating performance than cooling performance and varies with source and sink temperature. Good performance is indicated by a high COP. The higher the COP, the higher the equipment efficiency.

ENERGY EFFICIENCY RATIO

The Energy Efficiency Ratio (EER) is a dimensional quantity usually employed for specifying cooling performance. The EER is defined as:

$$\mathrm{EER} = \frac{\text{Cooling provided by the system, Btu}}{\text{Energy consumed by the system, watthours}} \quad . (6.2)$$

The EER can be converted to COP by dividing by the factor 3.413 Btu/watthour.

Other Standard Tests

The single point performance ratings described in this manual are the only ratings prescribed for packaged terminal heat pumps, water-source heat pumps, window air conditioners, room heat pumps, unitary heat pumps, and central air conditioners that do not fall in the DOE covered product category.

Heat pumps in the DOE covered product category require four additional tests. Two of these are used to measure performance during part-load operation where there is efficiency loss due to cycling. The remaining two are used to establish the performance of the heat pump under other conditions. These tests, along with the COP and EER ratings, are used in calculating the seasonal performance ratings. Manufacturers may use an assigned value for the degradation coefficient in lieu of conducting the cycling tests (see pg. 74).

Seasonal Performance Ratings

Federal regulations introduced under PL 94-163 and its amendments specify two additional ratings for DOE covered product air-source heat pumps and central air conditioners. These are the Heating Seasonal Performance Factor and the Seasonal Energy Efficiency Ratio.

HEATING SEASONAL PERFORMANCE FACTOR

The Heating Seasonal Performance Factor (HSPF) combines the effects of heat pump heating — under a range of weather conditions assumed to be typical of the location or region — with performance losses due to coil frost, defrost, cycling under part-load conditions, and use of supplemental resistance heat during defrost. Figure 6-1 shows six regions defined by the DOE and gives estimated heating load hours for each region.

The HSPF is defined as:

$$\text{HSPF} = \frac{\begin{array}{c}\text{Total heating}\\ \text{provided during heating}\\ \text{season, in Btu}\end{array}}{\begin{array}{c}\text{Total energy consumed by}\\ \text{the system, in watthours}\end{array}} \quad . (6.3)$$

Computation of the HSPF requires specification of the building heating load as well as the outdoor temperature distribution for the location. These specifications vary from building to building and location to location. Standard HSPFs are determined by manufacturers for each of the six DOE regions and are specified on equipment labels.

SEASONAL ENERGY EFFICIENCY RATIO

The Seasonal Energy Efficiency Ratio (SEER) is a measure of seasonal cooling efficiency under a range of weather conditions assumed to be typical of the location or DOE region in question, as well as of performance losses due to cycling under part-load operation. The SEER is defined as:

$$\text{SEER} = \frac{\begin{array}{c}\text{Total cooling provided}\\ \text{provided during cooling}\\ \text{season, Btu}\end{array}}{\begin{array}{c}\text{Total energy consumed by}\\ \text{the system, watthours}\end{array}} \quad . (6.4)$$

As in the case of the HSPF, the SEER is dependent on the cooling load of the specific building and outdoor temperature distribution. Standard SEERs are determined for conventional, single-capacity DOE covered product heat pumps and air conditioners, according to a simplified procedure that does not take weather into account explicitly.

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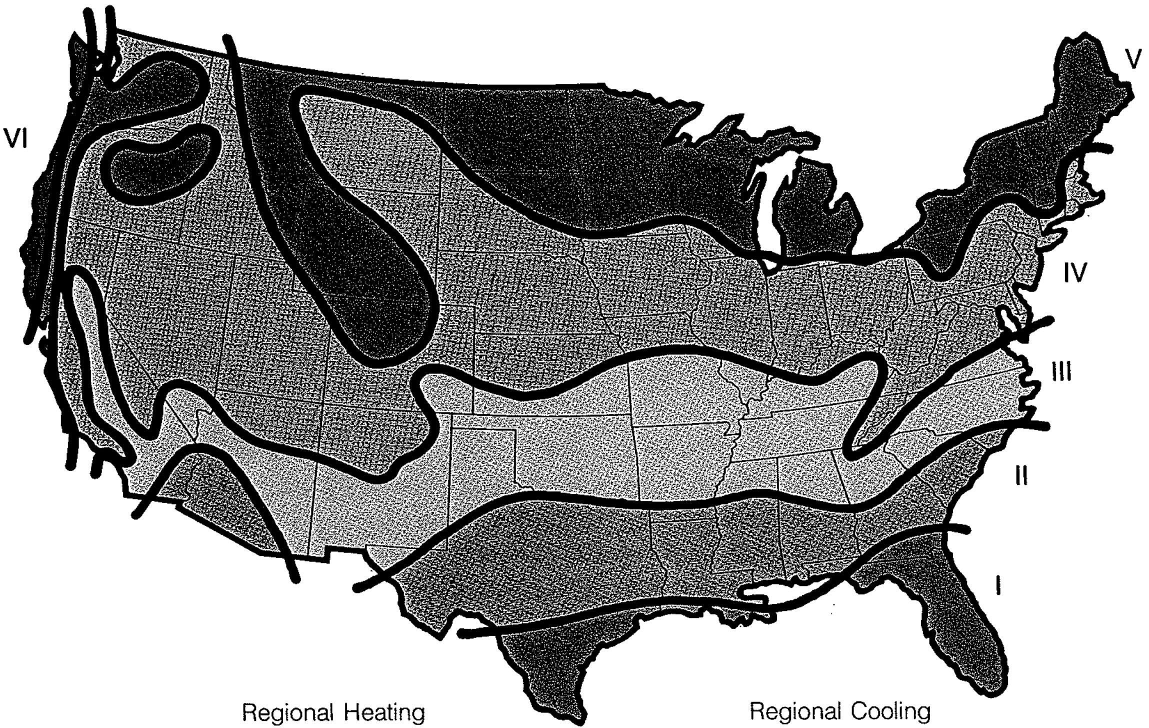

Regional Heating Load Hours	
I	750
II	1250
III	1750
IV	2250
V	2750
VI	2750

Regional Cooling Load Hours	
I	2400
II	1800
III	1200
IV	800
V	400
VI	200

FIGURE 6-1: Heating and Cooling Load Hour Regions

Source: (19)

Technical Data Sources

Technical data on the capacities, power consumption, and efficiencies of heat pumps and air conditioners are published by manufacturers. This information is required to size a heat pump and determine requirements for supplemental heating, as well as to estimate seasonal heating and cooling energy consumption. Data for approximate comparison of different manufacturers' products may be obtained from the ARI directory of certified unitary air conditioners and unitary air-source heat pumps (1), and the ARI directory of certified applied air conditioning products (2). The latter contains data on packaged terminal heat pumps and water-source heat pumps. Both directories are updated biannually and list manufacturer- and model-specific performance at the standard rating points.