7

Sizing

In This Section: Building design loads; balance point; size selection criteria; air-source heat pump sizing; water-source heat pump sizing

Selecting the right heat pump for a building requires that its heating and cooling capacity be accurately sized to match the heating and cooling demands of the building. Sizing a heat pump, in turn, involves determining its balance point temperature, a factor derived from the design loads of the building and the heat pump's capacity.

Building Design Loads

The first step in sizing a heat pump is calculation of the design heating load, or heat loss, and the design cooling load, or heat gain, of the building it will serve. The design heat loss is measured at the winter design temperature; the design heat gain at the summer design temperature. Design temperatures for most locations are listed in the *ASHRAE Handbook 1981 Fundamentals* (3) and in the manual of *Engineering Weather Data* (4).

The winter design temperature usually selected is the outdoor air temperature that is exceeded 97.5% of the time. The temperature exceeded 99% of the time is often given and may be chosen if a more conservative design is desired. It is, however, impractical and uneconomical to size a heat pump for the extreme temperature conditions encountered only a few hours each year, because such a heat pump would be grossly oversized for almost all other times.

The summer design temperature most commonly chosen is the outdoor air temperature that is exceeded 2.5% of the time. The temperature exceeded one percent of the time is usually also listed and, again, might be utilized for conservative design. Because humidity is also important in sizing a heat pump or air conditioner, the mean coincident wet-bulb temperature is tabulated along with the design (dry-bulb) temperature values.

Heat losses and gains calculated at design conditions are gross values. That is, they have not been corrected to take into account the effects of heat generated by people, lights, appliance use, and the sun, or heat loss or gain from ducts. Heat generated within a building by people, lights, and appliances must be estimated and included as part of the design cooling load. The heating effect of the sun on the walls, roof, and glass areas of a building is not usually included in determining design heat loss because solar heat is not available at night. The design cooling load calculation, however, does consider the solar effect on walls, roof, and glass because this heat has to be removed through cooling. In the winter, the solar heat gain contributes to heating the building and reduces the heat pump's running time. Winter heat loss and summer heat gain through ducts should also be considered when calculating the design loads.

Accurate calculation of the design heat loss and heat gain is important because mistakes in estimating building loads can lead to the selection of equipment that is either too large or too small for the heating and cooling needs of the building. This, in turn, can result in an uneconomical system, as well as reduced comfort and reliability. Standard procedures for calculating design heat losses and gains are described in the *ASHRAE Handbook 1981 Fundamentals* (3), *ASHRAE Cooling and Heating Load Calculation Manual* (5), and the Air Conditioning Contractors of America *Load Calculation for Residential Winter and Summer Air Conditioning, Manual J* (6).

Balance Point

The heating balance point is the lowest outdoor air temperature at which a heat pump can provide all of the heat a building requires. At the balance point, the capacity of the heat pump to heat a building is in balance with the heat loss of the building. At temperatures below this point, the heat pump alone is insufficient and supplemental heating is needed. The cooling balance point of a heat pump or air conditioner is the highest outdoor air temperature at which it can meet the cooling requirement of the building.

Determining heating and cooling balance points usually involves plotting a building's heat loss and heat gain as a linear function of outdoor temperature, as shown in Figure 7-1. This assumes that the thermal condition of the building may be represented as a series of steady states dependent on the indoor-outdoor temperature difference. The temperature difference is maximum when the outdoor temperature is at its design value, and minimum (or zero) when it coincides with the indoor setpoint temperature. The ordinate at any value of the outdoor temperature represents the heating or cooling that must be provided by the heat pump to maintain the building at a steady indoor temperature. By plotting the heating and cooling capacities (obtained from manufacturers' technical data for the size and model heat pump selected) on the same coordinates, the balance points can be determined from the points of intersection of the load and capacity curves.

It should be noted that the concept of a heating and cooling balance point is a theoretical one based on the notion of a steady-state load corresponding to each given outdoor temperature. However, internal heat gains due to occupants' activities, the effects of the sun and wind, and frost buildup on the heat pump outdoor coil can cause the actual balance point to vary from the theoretical one. If the design heating load is estimated conservatively it is likely that the balance point will be lower than expected — a hidden benefit to the homeowner.

Size Selection Criteria

Provided certain comfort-related constraints are met, selection of heat pump size is basically an economic decision involving a trade-off in capital cost vs. operating cost. This is especially true where heating is the primary requirement. Sizing criteria and procedures of different dealers and manufacturers vary, as do those recommended by utilities for their

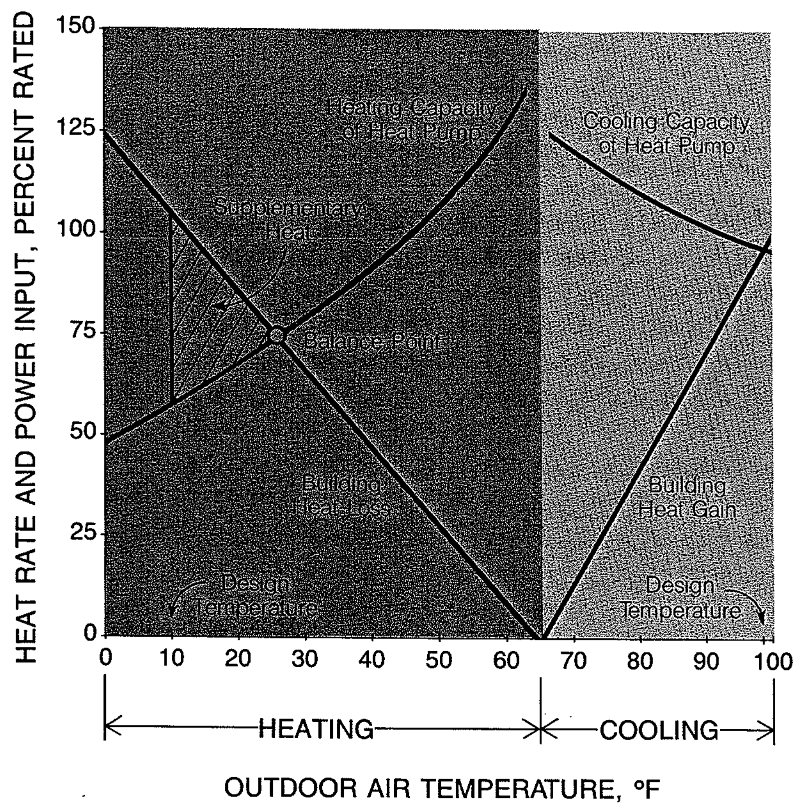

FIGURE 7-1: Heating and Cooling Balance Points of a Typical Air-Source Heat Pump

Source: ASHRAE (14)

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particular service territories. There are, however, several general considerations to keep in mind.

First, because indoor-outdoor temperature differences are usually much greater in the winter than in the summer, the design heating load in most parts of the United States north of the Phoenix-Savannah-Dallas line tends to be greater than the design cooling load. Even for well insulated buildings, heating to cooling ratios of 3:1 or 2:1 are not uncommon.

Second, because the heat pump is a heating and cooling machine in the same assembly, its heating and cooling capacity are not independent of each other. Indeed, the heating capacity at the 47 °F rating point is very similar to the cooling capacity at the 95 °F rating point. The summer design temperatures of many areas in the United States, except perhaps the far south and southwest, are usually 90 to 95 °F. Therefore, it is inevitable that a heat pump sized to meet the cooling demand in most areas would be undersized for heating. And conversely, a heat pump sized for the heating demand in most areas would be grossly oversized for cooling.

Proper sizing of a heat pump helps determine how well a system will perform to keep a home comfortable all year long. Although some sizing criteria call for moderate oversizing under certain conditions, gross over- or undersizing — whether by accident or design — can have adverse consequences on comfort and economics.

7

OVERSIZING OR UNDERSIZING

Oversizing a heat pump to carry the heating load lowers the heating balance point so that less supplemental heat is needed. Although the initial cost of a larger, oversized heat pump would be higher, the annual cost of energy needed to operate the system might be reduced. In the cooling mode, however, an oversized heat pump would operate less efficiently than a properly sized one. This is because during the cooling season, the heat pump would run for shorter periods of time to satisfy the sensible cooling load (i.e., the cooling load sensed by the dry bulb thermostat). Shorter running times provide less time for moisture to flow off the coil and would result in uncomfortable, high humidity. The extra cycling of the oversized heat pump would also lower the seasonal cooling efficiency.

An undersized heat pump, on the other hand, might cost less to purchase but need more supplemental heat. As a result, the seasonal operating efficiency for heating would be less and the seasonal heating operating costs would be higher. The seasonal cooling performance probably would be improved because there are less cycling losses with undersized heat pumps. However, there might also be times during the cooling season when the cooling load would exceed heat pump capacity and, therefore, the indoor temperature would increase.

LATENT COOLING

Humidity is a critical factor in human comfort. One important characteristic of an air conditioner or heat pump in the cooling mode is its ability to remove moisture from the air as well as to decrease the sensible or dry-bulb temperature. Since as much as one-third of the total cooling load may be due to excess humidity, latent load capacities are important considerations in heat pump sizing.

As explained in Section 2, when moist, warm air is brought in contact with the cold surface of the heat pump evaporator, some of the moisture vapor in the air condenses into liquid and drips off the evaporator. For this to occur, the evaporator surface temperature must be below the dew-point temperature of the air it contacts. A coil surface at 45 to 50 °F is much more capable of cooling and dehumidifying air than one at 55 to 60 °F.

The total cooling load on the heat pump or air conditioner is the sum of the sensible load (i.e., the enthalpy contribution attributable to the sensible temperature difference) and the latent load (i.e., the enthalpy contribution attributable to a difference in humidity). The ratio of sensible load to total cooling load is expressed as the sensible heat ratio (SHR). Manufacturers' technical literature usually specifies the total and the latent cooling capacity of a heat pump or air conditioner. This permits the heat pump dealer to verify that the unit has enough latent cooling capacity to remove moisture as well as to maintain the indoor air at the setpoint temperature. Except in arid areas of the country, the latent load poses a constraint that must be observed when sizing a heat pump for cooling.

Air-Source Heat Pump Sizing

Although an air-source heat pump can be sized to meet the design heating load of a building, it is generally uneconomic and undesirable to do so. Therefore, the recommended procedure in warmer areas of the country is to size a heat pump by the design cooling load, and to add one or more stages of supplemental resistance heat to make up the difference between the output of the heat pump and the heating load under winter design conditions. In colder climates, moderate oversizing is desirable in order to decrease reliance on supplemental heating. A 25 to 35% excess cooling capacity is a prudent amount.

Although selecting oversized equipment may slightly increase the purchase cost and operating costs in the cooling mode, operating cost savings in the heating mode usually justify this choice.

Many utilities have developed guidelines for sizing based on electric rates and climatic conditions in their service areas. The map of DOE climatic regions (Section 6, Figure 6-1) may also be used to help size heat pumps for different parts of the country. For Regions I, II, III, and VI in Figure 6-1, the heat pump is normally sized by the cooling load. In Region IV, heat pumps with HSPFs of 7.5 or better should be selected to match the cooling load, and units with lower HSPFs should be oversized for cooling to a maximum of 35%. In Region V heat pumps may also be oversized for cooling, to a maximum of 35%.

SELECTION BASED ON PRESCRIBED BALANCE POINT

Specifying the heating balance point is another way to express a sizing criterion. Figure 7-2 shows how heat pump capacity affects the balance point for a given building load. A large unit shifts the balance point to a lower temperature; a smaller unit raises it to a higher temperature. It is good practice to ensure that at least half of the heating load hours in a given region (that is, hours when the outdoor temperature is below 65 °F) occur above the balance point of the heat pump. This would mean that supplemental resistance heat would be required less than half of the time.

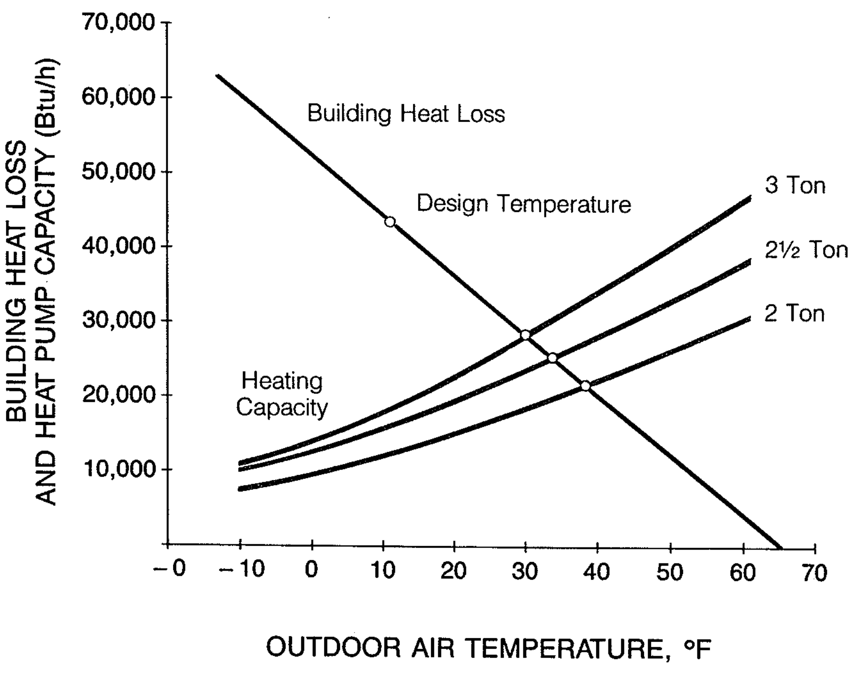

FIGURE 7-2: Effect of Heat Pump Size on Balance Point

Example 7-1: Sizing an Air-to-Air Heat Pump

Problem: A home located in St. Louis, Missouri has a design heating load of 45,000 Btu/hour (Btu/h) and a design cooling load of 22,000 Btu/h. Assuming that the indoor temperature is to be kept at 70 °F in the winter and 75 °F in the summer, and allowing for internal gains and other adjustments, heating would be required below 65 °F and cooling above 70 °F.

Solution: The heating and cooling loads for the house can be plotted as shown in Figure 7-3. Selecting "Heat Pump A" with a rated cooling capacity of 22,500 Btu/h would result in the capacity curves marked "A" on the graph and a heating balance point of 39 °F. A larger size unit (with a rated cooling capacity of 28,000 Btu/h) would give the curves marked "B" and a balance point of 34 °F. With unit A, the heating capacity shortfall under design conditions (i.e., a heating design point of 6 °F) would be 37,000 Btu/h; with unit B it would be 32,500 Btu/h. Unit B would be slightly oversized for cooling (about 27 %), but would require only 9.5 kW of supplemental resistance heat; unit A would require 11 kW.

In terms of comfort control, unit A would provide the desired conditions as long as the outdoor air temperature did not exceed 95 °F. Unit B — the oversized unit — would maintain indoor cooling comfort at outdoor temperatures as high as 99 °F. Heating comfort maintenance below the heating design temperature (34 °F) would depend on the staging of the supplemental heating elements.

SIZING SUPPLEMENTAL HEAT

Since most air-to-air heat pumps are not sized to meet the full heating load at winter design conditions, some supplemental heat is needed. Electric resistance heating elements are commonly used for this purpose, although

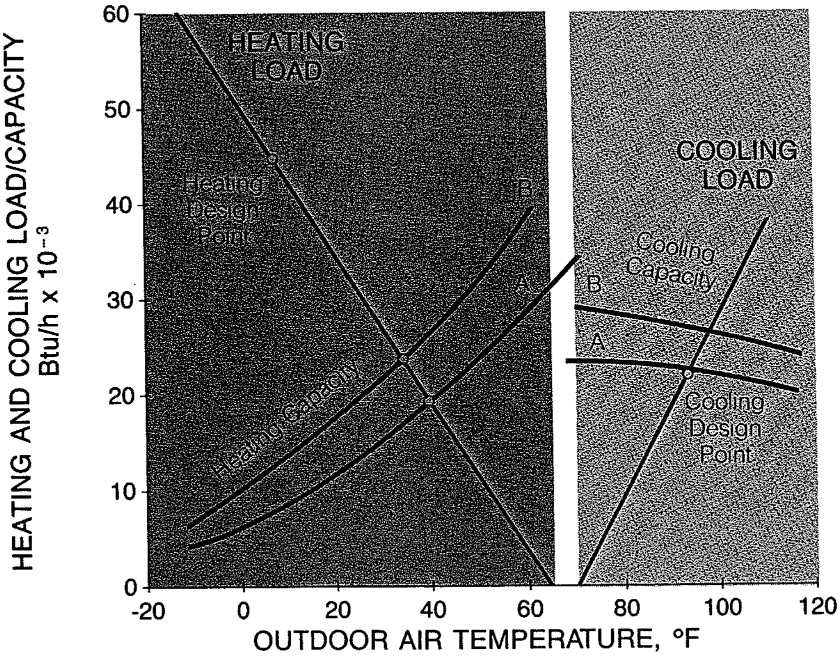

FIGURE 7-3: Heating and Cooling Load and Heat Pump Capacity for St. Louis, Mo. Residence (Example 7-1)

combustion furnaces are gaining in popularity. Regardless of the type of supplementary heat used, the required capacity can be determined from the capacity curves discussed above.

If supplemental resistance heat is used, it can be provided in one or multiple stages. Staging of resistance heaters can have important benefits to the homeowner and to the utility. For example, controlling the second stage heater by a thermostat set not to energize above 25 °F prevents the full amount of resistance heat from coming on during defrost cycles or during morning recovery from night temperature setback. At the same time, at low outdoor temperatures, the full heating needs of the house would be met.

The staging of supplemental heating elements can be illustrated using the example depicted in Figure 7-3. For example, "Heat Pump B" has a balance point of 34 °F. Its heating capacity at the design temperature of 6 °F would be 12,500 Btu/h. A single 10-kW electric resistance element provides about 34,130 Btu/h — more than is needed. A better approach, then, would be to use two 5-kW (17,000 Btu/h) elements to provide two stages of supplemental heat. As shown in Figure 7-4, the first 5-kW stage could meet the home's heating needs down to 20 °F. The second stage could meet the needs down to about 6 °F. The second element should be controlled by an outdoor thermostat set to 25 °F or below. Manufacturers' technical literature should be consulted concerning the size and number of kW increments available for any specific heat pump.

Sizing a heat pump to be added to a combustion (fossil-fuel) furnace is more complicated. Ideally, the balance or switchover point should be selected such that the cost of the Btu of heating provided by the heat pump alone and the furnace alone are equal. In practice, guidelines that reflect local electric and gas

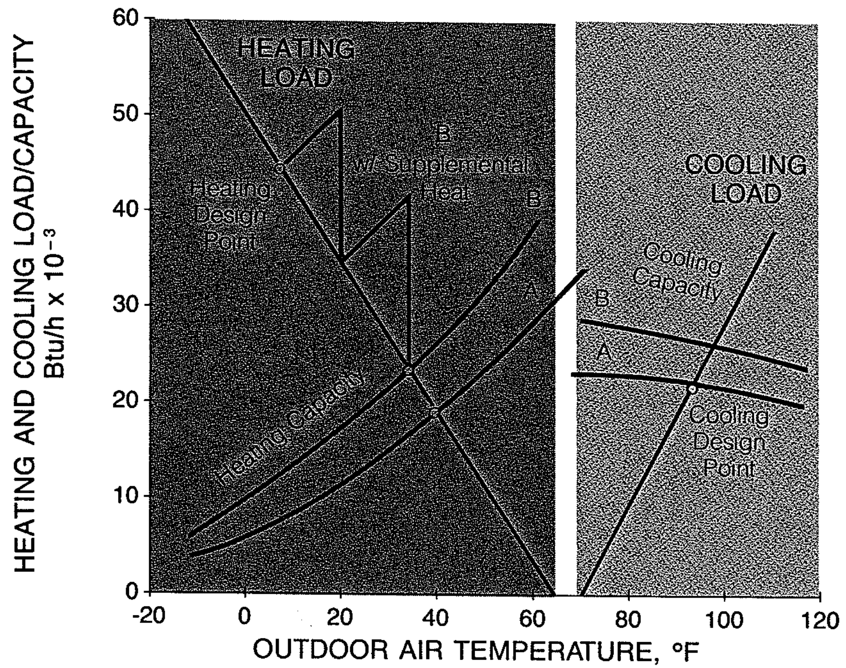

FIGURE 7-4: Adding Resistance Heating Elements to Heat Pump in St. Louis, Mo. Residence (Example 7-1)

or oil rates are often available from heat pump dealers or utilities and can aid in decision making. Because fossil-fuel furnaces are usually severely oversized and operate at low efficiency, it pays to allow the heat pump to displace as much fossil fuel energy as possible.

SELECTION BASED ON HEATING LOAD

All heat-only heat pumps are sized to meet the design heating load without supplemental heat. Where air conditioning is not required, or where a unit will be used only rarely for cooling, the heat pump should be sized so that the balance point occurs at the winter outdoor design temperature. For occasional cooling needs in northern climates, the addition of a small, high-efficiency window air conditioner or portable cooling unit might provide overall maximum energy efficiency for space conditioning.

AIR-TO-WATER HEAT PUMP SIZING

Air-to-water heat pumps provide heating by circulating hot water through the house in radiators or convectors, but do not normally provide cooling. Consequently, they are sized by heating load. System efficiency depends on the performance of both the heat pump and the radiator or convector system.

Convectors are copper pipes with fins on their outside surface. They provide heat by natural convection when hot water at 140 °F or higher (160 to 180 °F) is circulated through them. Radiators function on the same principle, providing some low-temperature radiant heat as well. Performance of convectors and radiators is usually specified in terms of Btu/h heat output per foot of convector, as a function of the temperature of the water entering the convector, and of the water flow rate. Typical data for baseboard convectors are shown in Table 7-1a. The heating capacity of an air-to-water heat pump, shown in Table 7-1b, is also specified as a function of warm water temperature, assuming that loop temperatures remain relatively constant. Both the convector output and the heat pump capacity are plotted against water temperature in Figure 7-5. The points of intersection represent the performance of the combined system. Figure 7-6 shows the hydronic system heating capacity curve plotted together with the heating load for a residence with a design heat loss of 45,000 Btu/h at 6 °F.

TABLE 7-1a: Typical Values of Baseboard Convector Performance

(5 GPM WATER FLOW RATE)

WATER TEMP. (°F)	BASEBOARD CONVECTOR PERFORMANCE (Btu/h per ft.)
90	111
100	178
110	245
120	312
130	378

TABLE 7-1b: Heating Performance of an Air-to-Water Heat Pump

HEATING CAPACITY (Btu/h × 10^{-3})

WATER TEMP. FROM CONVECTORS ENTERING HEAT PUMP	TEMPERATURE OF OUTDOOR COIL FROM WHICH HEAT IS BEING EXTRACTED (°F)					
	7	17	27	37	47	57
100	22.2	31.5	42.2	53.0	61.0	65.8
110	18.6	28.5	38.6	49.0	57.7	64.0
120	15.0	25.7	35.0	45.2	54.0	62.4
130	11.5	22.8	31.5	41.3	50.5	60.6

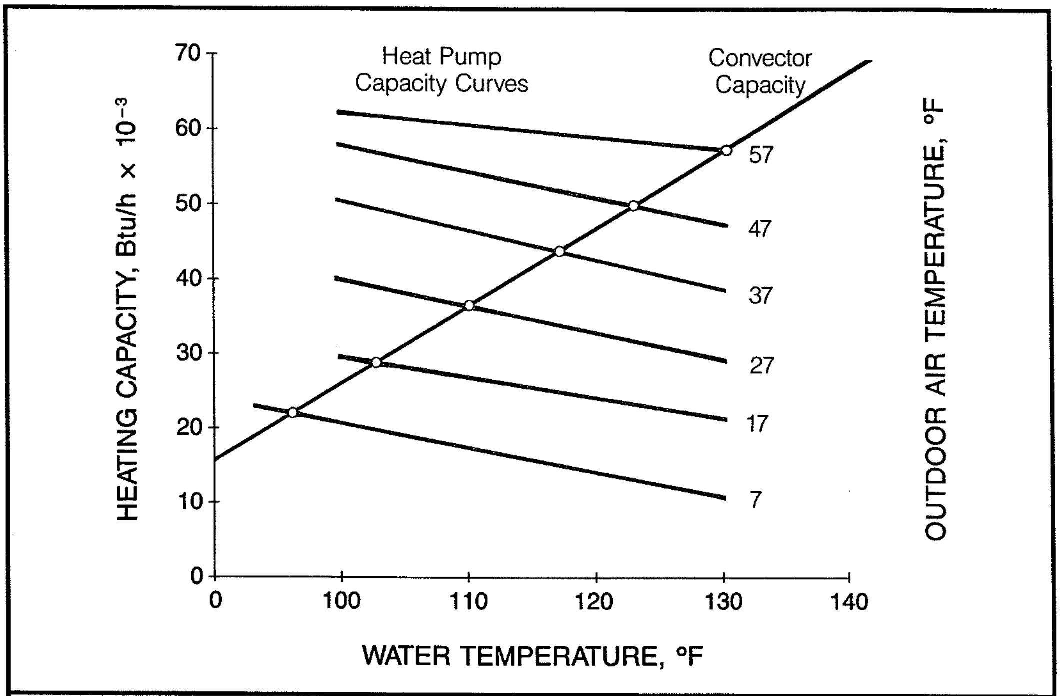

FIGURE 7-5: Heat Pump and Baseboard Convector System Heating Capacity

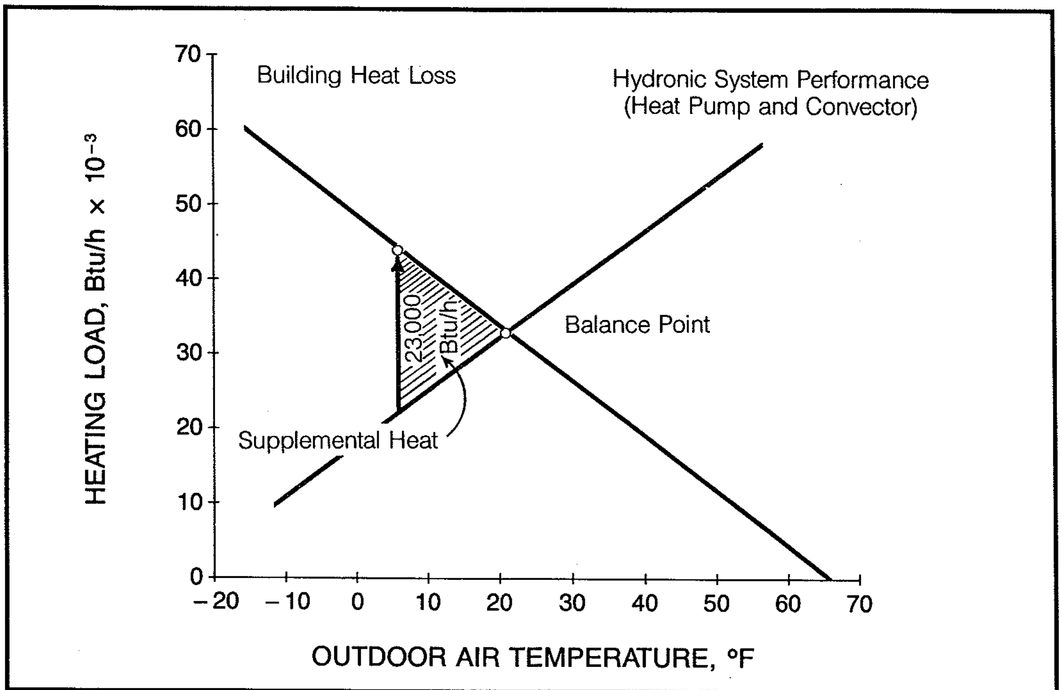

FIGURE 7-6: Air-to-Water Heat Pump System Performance

7

Water-Source Heat Pump Sizing

Selecting water-source heat pump equipment is similar to selecting air-source equipment in that the capacity of the heat pump is a function of the source temperature. Water-source heat pumps can provide both heating and cooling or heating only, and their source temperature remains relatively constant throughout the season. Heat-only types use water as a heat source for winter heating. If the water is cold enough, it is also used in a cooling coil for summer cooling. Because refrigerant is not circulated for cooling, compressor power is saved. Since heating and cooling operations are independent, the size of the heat pump is based on the design heating load, and the size of the cooling coil is based on the cooling load.

Heating and cooling type water-source heat pumps provide both comfort conditions. Water is used as a heat source during heating operation and as a heat sink during cooling operation. This type of water-source heat pump should be sized to meet the design cooling load. In warm climates, supplemental heaters can be used to supply the additional heating requirement. In colder climates, the same criteria for oversizing air-to-air heat pumps applies, although several additional factors — such as water temperature and flow rate, pipe length and diameter, and pumping requirements — must be considered.

Example 7-2: Sizing A Groundwater Heat Pump

Problem: The test home is the St. Louis residence analyzed in Example 7-1. In this example, it is assumed that groundwater is available at a steady temperature of 55 °F, and that the well and pump can deliver five gallons of water per minute.

Solution: The heating and cooling capacity of the heat pump is given in Table 7-2 for various entering water temperatures and water flow rates. Because the main concern is maximizing heating efficiency, a 45% oversized unit for cooling (capacity 31,900 Btu/h) was selected to achieve the necessary 33,400 Btu/h heating capacity. Figure 7-7 shows the unit's capacity in reference to the heating and cool-

TABLE 7-2: Water-to-Air Heat Pump Capacity and Efficiency Data (Example 7-2)

ENTERING WATER TEMPERATURE (°F)	WATER FLOW RATE (GPM)	HEATING			COOLING		
		CAPACITY (Btu/h)	POWER (Watts)	COP	CAPACITY (Btu/h)	POWER (Watts)	EER
45	5.0	27,000	2660	3.0	34,000	2360	14.5
	7.5	27,700	2710	3.0	34,100	2260	15.0
	10.0	28,200	2730	3.0	34,800	2190	15.9
50	5.0	29,700	2740	3.2	32,900	2420	13.6
	7.5	30,500	2775	3.2	33,500	2335	14.3
	10.0	30,900	2805	3.2	33,900	2270	15.0
55	5.0	32,400	2820	3.3	31,900	2490	12.8
	7.5	33,300	2840	3.4	32,900	2410	13.6
	10.0	33,600	2880	3.4	33,000	2350	14.0
60	5.0	34,500	2900	3.5	31,300	2575	12.2
	7.5	35,600	2935	3.5	32,400	2495	13.0
	10.0	35,950	2975	3.5	32,500	2435	13.3

Ratings at 70°F return air for heating and 80°F dry bulb temperature and 67°F wet bulb temperature of return air for cooling. The indoor air flow to the coil is 400 CFM per ton.

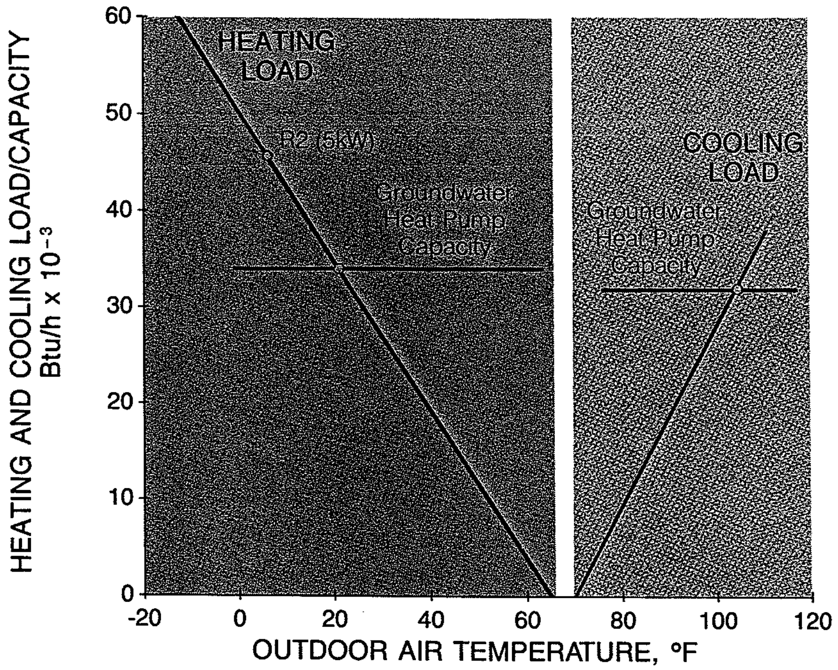

FIGURE 7-7: Sizing a Groundwater Heat Pump for the St. Louis, Mo. Residence (Example 7-2)

ing loads of the house.

In Figure 7-7 heat pump capacities are plotted as horizontal lines. This is based on the assumption that the unaffected groundwater temperature will remain essentially constant throughout the year. The 32,400 Btu/h of heat delivered by the heat pump is less than the 45,000 Btu/h required by the residence at 6 °F. Therefore, supplemental heat will be needed whenever the outdoor temperature falls below the 20 °F balance point temperature.

Sizing groundwater, surface water, and ground-coupled heat pumps should be done on an individual, system-by-system basis because water temperatures can vary with the temperature of the source as well as with the heat-transfer performance of the ground-coil or water-source heat exchanger. Experienced installers, designers, or others familiar with these systems should be consulted for information on heat-transfer performance and sizing criteria based on local conditions.

Ground-coupled heat pumps function much like other water-source heat pumps. Therefore, their sizing procedures are basically the same. With the ground-coupled system, however, it is important to consider the heat transfer performance of the ground-coil because this affects the temperature of the water entering and leaving the heat pump system. Water temperature affects heat pump performance more than heat pump size and should be considered when planning the purchase and installation of ground-source systems. A full range of data on these systems is not yet widely available. Consumers interested in ground-coupled systems should consult industry sources and manufacturers.

8

Energy Estimating

In This Section: Energy estimating methods; heating-degree day method; cooling-degree day method; bin method; simulation methods

Energy estimating methods are used to calculate the energy required to meet a building's heating and cooling loads. Usually the purpose of such calculations is to compare the performance of alternative HVAC systems in terms of their seasonal or annual efficiency, energy consumption, or energy cost. The more complex of these methods are also capable of yielding energy consumption data over shorter time intervals, i.e., on a monthly or even an hourly basis. Estimation of energy consumption is also useful for comparing the merits of a potential investment in a more efficient HVAC system to the savings obtained from installing conservation measures. When it is necessary to compare systems that use several forms of energy (e.g., electricity, natural gas, or oil), it is best to make the ultimate comparison in terms of energy cost rather than energy consumption.

Energy Estimating Methods

The energy used by a heating or cooling system is a function of the building load, the characteristics of the HVAC equipment, and the control system. Building heating and cooling loads depend in a complex way on the weather, building thermal characteristics, control system parameters, and the occupants' activities and appliance usage. This makes exact prediction of the load for any particular building and for a specified period of time impossible. Energy estimates, therefore, generally carry the caveats of being valid for "long-term-average" weather conditions and "typical" usage. Long-term-average weather is not difficult to define precisely, but typical usage is. Significant deviations from both of these assumptions must be expected.

Several procedures for estimating HVAC system energy consumption are available. The simplest of these assume that the energy required to maintain thermal comfort is a function of a single factor: the outdoor dry bulb temperature. At the other extreme are more complicated methods which consider the effects on a building of solar heat, internal heat gain, heat storage in walls and floors, and wind, humidity, etc., and integrate these variables on an hourly basis. This degree of detail is not normally necessary for comparison of residential systems. Annual energy use estimates are also provided by some heat pump manufacturers and dealers for their systems.

In addition, ARI publishes performance data in its directories of certified air conditioners and heat pumps (1, 2). These data may be converted to approximate estimates of energy consumption typical of heat pumps and air conditioners in various DOE climatic regions.

Heating-Degree Day Method

The simplest and quickest method for estimating heating system energy consumption is the heating-degree day method. The heating-degree day method is a measure of the severity and the duration of an outdoor temperature deviation below a fixed temperature (65 °F) and is based on the assumption that heating is required below this temperature. The number of heating-degree days in a period is defined as the mean daily outdoor air temperature deviation below 65 °F in the given period. Deviations above 65 °F are counted as zero heating-degree days. Degree days are officially calculated by the National Oceanographic and Atmospheric Administration (NOAA) by determining the monthly mean of the daily extreme temperatures reported by its weather stations. As an example, there would be 20 heating-degree days on a day when the maximum temperature is 60 °F and the minimum temperature is 30 °F. That is,

$$D = 65 - (60+30)/2 = 20\,^{\circ}\text{F-days}$$

The degree-day method can be utilized with several heating systems, including electric resistance heat, fossil fuel furnaces and boilers, and air-source heat pump systems. However, because it is a steady-state method, it is unable to account for the time variation of building loads and the cyclic nature of HVAC system operation. Its other limitations are that it does not allow comparisons between room-by-room and central thermostatic control, nor take into account ventilation duct losses or thermostat setback, except in a very approximate way.

Another disadvantage of this approach is that when equal temperature deviations above and below 65 °F occur on the same day (as they might during the spring and fall months), calculations may show no heating-degree days, even though heating may have been required. Averaging hourly data from a weather tape generally produces a higher estimate of the number of heating-degree days in a given location.

Table 8-1 gives long-term-average annual heating- and cooling-degree days for selected major cities in the United States. Heating-degree days for many more locations can be found in the *ASHRAE Handbook 1981 Fundamentals* (3) and *Engineering Weather Data* (4). The average number of yearly heating-degree days remains fairly constant — plus or minus 20 % — for most of the United States.

ELECTRIC RESISTANCE HEATING SYSTEMS

The heating-degree day method for electric resistance heating systems is expressed by the formula:

$$E = 24 \left(\frac{H_L}{\Delta t}\right)_{\text{des}} \left(\frac{D}{3413}\right) C_d \qquad (8.1)$$

where:

E = energy consumption, kWh
H_L = design heat loss, Btu/h
Δt = design temperature difference, °F
D = heating-degree days for period, °F-days
C_d = adjustment factor for solar and internal gains, dimensionless .

The conversion factors 24 and 3413 represent hours/day and Btu/kWh, respectively; the subscript "des" indicates design con-

8

TABLE 8-1: Long-Term-Average Annual Heating- and Cooling-Degree Days for Selected Cities in the United States (65°F) Source: Modified From ASHRAE (3)

CITY, STATE	HEATING-DEGREE DAYS	COOLING-DEGREE DAYS	CITY, STATE	HEATING-DEGREE DAYS	COOLING-DEGREE DAYS
Albuquerque, NM	4348	1345	Memphis, TN	3232	1872
Atlanta, GA	2961	1469	Miami, Fl	214	4189
Birmingham, AL	2551	1654	Minneapolis, MN	8382	894
Bismark, ND	8851	528	New Orleans, LA	1385	2653
Boston, MA	5634	674	New York, NY	5219	1027
Charleston, SC	2033	1983	Omaha, NE	6612	1007
Cheyenne, WY	7381	308	Philadelphia, PA	5144	1081
Chicago, IL	6639	713	Phoenix, AZ	1765	3334
Cincinnati, OH	4410	1147	Pittsburgh, PA	5897	732
Cleveland, OH	6351	670	Portland, ME	7511	292
Detroit, MI	6293	687	Portland, OR	4635	248
Fort Worth, TX	2405	2500	Raleigh, NC	3393	1355
Great Falls, MT	7750	343	Richmond, VA	3865	1236
Houston, TX	1396	2745	Salt Lake City, UT	6052	958
Indianapolis, IN	5699	902	San Francisco, CA	3015	98
Jackson, MS	2239	2361	St. Louis, MO	4900	1390
Kansas City, KS	4711	1475	Seattle-Tacoma, WA	5145	134
Los Angeles, CA	2061	357	Tampa, FL	683	3152
Louisville, KY	4660	1207	Tulsa, OK	3860	1719
Madison, WI	7863	424	Washington, DC	4224	1491

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ditions. The ratio $(H_L/ \Delta t)_{des}C_d$ is the slope of the heat loss line adjusted for solar and internal gains, and represents the average thermal efficiency of the building. Table 8-2 gives typical values of adjustment factor C_d.

If the heating system is an electric forced

TABLE 8-2: Adjustment Factor C_d for Degree-Day Calculations Source: ASHRAE (3)

QUALITY OF CONSTRUCTION AND RELATIVE USE OF ELECTRICAL APPLIANCES	NUMBER OF DEGREE DAYS (65°F)								
	1000	2000	3000	4000	5000	6000	7000	8000	9000
Well-Constructed House. Large quantities of insulation, tight fit on doors and windows, well sealed openings. Large use of electrical appliances. Large availability of solar energy at the house.	0.48	0.45	0.42	0.39	0.36	0.37	0.38	0.39	0.40
House of Average Construction. Average quantities of insulation, average fit on doors and windows, partially sealed openings. Average availability of solar energy at the house. Average use of electrical appliances.	0.80	0.76	0.70	0.65	0.60	0.61	0.62	0.69	0.67
Poorly Constructed House. Small quantities of insulation, poor fit on doors and windows, unsealed openings. Small use of electrical appliances. Small availability of solar energy at the house.	1.12	1.04	0.98	0.90	0.82	0.85	0.88	0.90	0.92

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air furnace or boiler, the energy consumption of the air handler blower or pump must also be accounted for. This value may be computed from:

$$E_a = 0.746\ P\ N_h \qquad (8.2)$$

where:

E_a = energy consumption of blower or pump, kWh
P = blower or pump power, horsepower
N_h = total operation time, hours .

The blower or pump operating hours may be determined by dividing the heating energy requirement from Equation 8.1 by the heating capacity of the furnace or boiler. For continuous operation, total operating hours must be used.

Example 8-1: Energy Consumption of a Baseboard Heating System

Problem: Calculate the heating season energy consumption of a home equipped with electric baseboard heating. The home is located in Chicago and has a design heating load of 64,500 Btu/h. Assume an indoor temperature of 68 °F and an outdoor design temperature of 2 °F.

Solution: Using values of D = 6639 and $C_d = 0.62$ from Table 8-2, and substituting into Equation 8.1 gives

$$E = 24\left(\frac{64{,}500}{68-2}\right)\left(\frac{6639}{3413}\right)0.62$$
$$= 28{,}287\ \text{kWh}\ .$$

The home would use approximately 28,287 kWh for heating during a heating season. This assumes that the home is operated as a single zone, i.e., all rooms are kept at the same thermostat setting. If the temperature was set back in rooms not in use, energy consumption could be reduced by as much as 10 to 20%.

FOSSIL FUEL FURNACES AND BOILERS

The fuel consumption of fossil fuel furnaces and boilers may be calculated from:

$$F = 24\left(\frac{H_L}{\Delta t}\right)_{des}\left(\frac{D}{kV}\right)C_d \qquad (8.3)$$

where:

F = fuel consumption, ft³ (gas) or gal (oil or propane)
H_L = design heat loss, Btu/h
Δt = design temperature difference, °F
$_{des}$ = design conditions
D = heating-degree days for period, °F-days
k = equipment efficiency and oversizing factor, dimensionless
V = heating value of fuel, Btu/ft³ (gas) or Btu/gal (oil or propane)
C_d = adjustment factor for solar and internal gains, dimensionless .

Typical values of k and V are given in Tables 8-3 and 8-4, respectively. Blower or pump horsepower may be estimated using Equation 8.2. The operating hours for a blower or pump are calculated by taking:

$$N_h = FV/q'_h \qquad (8.4)$$

where:

q'_h = input capacity of furnace or boiler, Btu/h .

Example 8-2: Energy Consumption of a Fossil Fuel Furnace

Problem: Calculate the heating season energy consumption of a conventional natural gas-fired warm-air furnace for a single family

TABLE 8-3: Values of k Factors for Use with the Degree-Day Method Source: ASHRAE (3)

HEATING SYSTEM	k VALUE
Conventional Gas-Fired Forced-Air Furnace or Boiler	0.60 to 0.70
Conventional Gas-Fired Gravity-Air Furnace	0.57 to 0.67
Gas-Fired Forced-Air Furnace or Boiler with Typical Energy Conservation Devices, Intermittent Ignition Device, Automatic Vent Damper	0.65 to 0.75
Gas-Fired Forced-Air Furnace or Boiler with Sealed Combustion Chamber, Intermittent Ignition Device and Automatic Vent Damper	0.70 to 0.78
Gas-Fired Pulse Combustion Furnace or Boiler	0.80 to 0.90
Oil-Fired Furnace or Boiler	0.50 to 0.75

house in Chicago with a design heating load of 72,000 Btu/h. The gas furnace is rated at 80,000 Btu/h output and 100,000 Btu/h input. The blower is equipped with a 1/2 horsepower motor.

Solution: Using values of k = 0.65 from Table 8-3 and V = 1050 ft³ from Table 8-4, and substituting into Equation 8.3 gives:

$$F = 24 \left(\frac{72{,}000}{68\text{-}2}\right)\left(\frac{6639}{0.65 \times 1050}\right) 0.62$$
$$= 157{,}903 \text{ ft}^3 \text{ of natural gas .}$$

Blower energy consumption can be estimated using Equations 8.2 and 8.4

$$N_h = \frac{157{,}903 \times 1050}{100{,}000} = 1658 \text{ hours}$$

$$E_a = 0.746 \times \frac{1}{2} \times 1658 = 618 \text{ kWh .}$$

Therefore, during a heating season, the gas furnace would use approximately 157,903 ft³ of natural gas and 618 kWh of electricity.

TABLE 8-4: Heating Values Of Various Fuels

FUEL	UNIT	HEATING VALUE OF FUEL
Natural Gas	Btu/ft³	1050
Propane	Btu/gallon	90,000
No. 2 Fuel Oil	Btu/gallon	140,000

AIR-SOURCE HEAT PUMPS

The heating-degree day method must be modified for application to heat pumps because both the efficiency and the capacity of a heat pump varies with the outdoor temperature. If heating season performance factor (HSPF) data are available from the dealer or manufacturer for the particular heat pump system in the location in question, the energy consumption can be estimated from:

$$E = 24 \left(\frac{H_L}{\Delta t}\right)_{des} \left(\frac{D}{1000 \text{ HSPF}}\right) \qquad (8.5)$$

where:

E = energy consumption, kWh
H_L = design heat loss, Btu/h
Δt = design temperature difference, °F
$_{des}$ = design conditions
D = heating-degree days for period, °F-days
HSPF = heating season performance factor
1000 = conversion factor, Wh/kWh
C_d = 1, because the HSPF is computed on the basis of a corrected load .

Because the HSPF includes the effects of blower energy and supplemental resistance heat, separate computation of these values is not necessary.

The HSPF is the standard rating of heat pump heating performance, as mandated by DOE and specified in ARI Standard 240-81 (7), and is a measure of the total heating output of a heat pump during its normal annual heating period divided by the total electric energy input during the same period. The value of HSPF for a particular DOE region is calculated by the bin method, which utilizes a frequency distribution of hourly outdoor temperatures to produce a seasonal value. However, a regional-average, normalized temperature-frequency distribution is used in the HSPF calculation instead of hourly temperature occurrence data. The effect of on-off cycling is also incorporated in the method.

Example 8-3: Heating Season Energy Consumption of a Heat Pump (HSPF Method)

Problem: Calculate the heating season energy consumption of a heat pump for the single family home in Example 8-1. The heat pump has an HSPF rating of 8.65 Btu/Wh for Region IV, which includes St. Louis.

Solution: Substituting into Equation 8.5

$$\begin{aligned} E &= 24\left(\frac{45{,}000}{70\text{-}6}\right)\left(\frac{4900}{1000 \times 8.65}\right) \\ &= 9559 \text{ kWh} . \end{aligned}$$

The heat pump system would use approximately 9559 kWh during a heating season.

Cooling-Degree Day Method

The cooling-degree day method is used to predict cooling energy consumption of conventional air conditioners and heat pumps used during the cooling season. Like heating-degree days, cooling-degree days are based on an average daily outside temperature of 65 °F. The number of cooling-degree days in a period is defined as the mean daily outdoor air temperature departure above 65 °F in the given period. For example, there are five cooling-degree days on a day when the average daily temperature is 70 °F (reaching a maximum of 80 °F and a minimum of 60 °F). The cooling-degree day method is based on the assumption that cooling is not needed when the average daily temperature is 65 °F or below. It is also assumed that changes in outdoor humidity do not add to energy consumption, and that the solar and internal loads remain at constant values. In practice, these conditions are not always met, therefore, the results of the cooling-degree day method may be subject to significant error. Typical cooling-degree days for major cities in the United States are provided in Table 8-1, and cooling-degree days for many more locations can be found in *ASHRAE Handbook 1981 Fundamentals* (3) and *Engineering Weather Data* (4).

The degree-day method for calculating cooling energy is similar to that used in calculating heating energy. It requires use of the seasonal energy efficiency ratio (SEER) in the following formula:

$$E = 24 \left(\frac{H_G}{\Delta t}\right)_{des} \left(\frac{D}{1000\ \mathrm{SEER}}\right) \qquad (8.6)$$

where:

E = cooling energy consumption, kWh
H_G = design heat gain (cooling load), Btu/h
Δt = design dry bulb temperature difference, °F
$_{des}$ = design conditions
D = cooling degree days for period, °F-days
SEER = seasonal energy efficiency ratio, Btu/Wh .

Energy used by a cooling system's auxiliary equipment must also be accounted for and may be included in the SEER value. Typically, the SEER information source will stipulate whether auxiliary equipment power is included in the SEER. If not, auxiliary equipment energy use can be calculated using Equation 8.2 and then added to the electric energy consumption (calculated using Equation 8.6) to obtain the total energy requirements for the cooling season.

Example 8-4: Energy Consumption of a Central Air Conditioner

Problem: Calculate the cooling energy consumption of a residence in Chicago with a design cooling load of 34,000 Btu/h. The electric air conditioner has a cooling capacity of 34,000 Btu/h and a SEER of 8.4, which does not include the energy for the inside fan. The rated power of the air conditioner is 4.1 kW. The indoor design temperature is 75 °F, the outdoor design temperature is 91 °F. The house has average construction, insulation, window and door fit, and average occupant use of appliances.

Solution: Using the value D = 713 cooling-degree days and substituting into Equation 8.6 yields

$$E = 24 \left(\frac{34{,}000}{91\text{-}75}\right)\left(\frac{713}{1000 \times 8.4}\right)$$
$$= 4329\ \mathrm{kWh}\ .$$

Computing the indoor blower energy from Equation 8.2

$$E_a = 0.746 \times \frac{1}{2} \times \frac{4329}{4.1} = 394\ \mathrm{kWh}\ .$$

Therefore, the total cooling season energy requirement would be 4723 kWh. If the SEER value had included the energy for the inside fan, only Equation 8.6 would have been needed.

Bin Method

The bin method for estimating energy usage utilizes a frequency distribution of hourly outdoor temperature occurrences to weight the hourly building heating requirement and energy consumption and produces a seasonal value. A bin is defined as the size of that temperature increment, usually 5 °F, into which the whole range of temperatures is divided. (Figure 8-1 shows the distribution of hourly temperature occurrences in St. Louis, Missouri.) Energy requirements are calculated for each bin over the full range of outdoor dry-bulb temperatures that occur in the location in question, and the energy requirements for each bin are summed to yield the seasonal total. Weather data appropriate

TABLE 8-5: Hourly Weather Occurrences

Source: Modified From ASHRAE (3)

LOCATION	DEGREES FAHRENHEIT																		
	−18	−13	−8	−3	2	7	12	17	22	27	32	37	42	47	52	57	62	67	72
Birmingham, AL						3	6	17	69	143	292	433	528	614	668	742	805	908	1138
Phoenix, AZ										8	57	182	391	540	659	769	767	776	762
Los Angeles, CA												10	107	428	1054	1904	2193	1654	881
San Francisco, CA											10	99	449	1153	2341	2341	1264	665	285
Denver, CO	1	1	6	22	36	78	119	216	359	553	721	717	692	704	678	731	783	684	549
Washington, DC						2	17	54	138	254	542	744	790	684	690	673	740	766	960
Miami, FL												4	26	71	147	277	452	810	1705
Tampa, FL										1	10	48	137	216	345	570	877	1187	1387
Atlanta, GA						2	8	19	44	112	271	468	598	676	735	784	823	926	1185
Boise, ID				2	6	14	26	53	148	307	522	829	878	798	786	702	643	575	492
Chicago, IL		3	12	25	59	85	117	196	335	551	822	800	591	543	569	592	653	769	762
Indianapolis, IN		2	3	13	35	60	97	152	293	551	791	712	605	579	586	585	722	815	821
Des Moines, IA	1	8	23	59	104	152	211	281	405	557	747	627	510	512	585	600	681	751	707
Wichita, KS			1	3	14	45	85	161	273	426	607	584	611	592	589	603	641	709	758
Louisville, KY			1	3	8	25	45	97	169	332	631	703	649	634	619	654	693	758	869
New Orleans, LA									2	9	47	128	282	449	621	692	850	987	1189
Portland, ME	1	5	15	29	60	109	190	293	408	599	820	839	722	748	760	808	780	627	407
Boston, MA			1	9	4	35	74	151	256	429	674	848	828	757	766	781	804	819	676
Detroit, MI			1	4	17	61	131	248	377	618	884	808	595	566	592	633	695	783	721
Minneapolis, MN	16	31	62	119	186	246	311	383	514	609	632	560	500	482	588	602	695	690	621
Jackson, MS					1	2	2	6	41	103	224	367	484	605	618	677	790	922	1168
Kansas City, MO				4	21	51	99	175	265	407	591	625	628	562	553	572	601	723	761
St. Louis, MO			1	7	15	40	77	134	219	411	650	671	620	578	585	575	646	728	823
Great Falls, MT	62	51	68	101	118	136	167	218	355	533	698	813	832	830	822	754	636	520	407
Omaha, NB		1	15	40	93	135	189	287	390	511	663	655	543	543	539	558	606	721	726
Reno, NV			1	4	15	37	101	277	387	530	733	829	890	909	845	690	572	477	418
Albuquerque, NM				1	1	4	21	66	154	346	552	689	741	734	687	651	719	831	767
Albany, NY	4	5	10	32	63	110	184	278	404	574	793	769	647	625	652	708	740	733	588
New York, NY					1	10	26	2	188	330	603	858	838	796	722	745	754	877	926
Raleigh, NC						1	11	38	103	236	410	527	638	672	707	762	848	937	1087
Bismark, ND	80	77	131	208	278	292	338	371	474	550	653	604	518	520	563	606	614	566	454
Cincinnati, OH			2	8	18	44	68	131	249	460	711	698	627	599	611	639	726	843	879
Cleveland, OH			2	11	22	47	111	201	355	578	806	754	620	607	638	641	723	831	763
Oklahoma City, OK				1	3	12	36	77	173	287	468	570	641	611	645	643	717	769	881
Portland, OR						1	4	10	40	123	343	772	1238	1271	1274	1316	1001	581	373
Philadelphia, PA						9	32	100	189	335	654	818	758	701	663	710	735	809	863
Pittsburgh, PA			1	7	30	60	159	233	360	774	569	688	631	587	637	678	799	910	722
Charleston, SC								5	27	79	192	321	434	576	651	787	889	1090	1267
Memphis, TN						4	10	25	74	196	374	532	614	633	618	690	715	798	977
Dallas, TX						1	4	17	34	91	231	371	504	576	629	656	693	795	831
Houston, TX								2	4	18	64	141	291	452	570	681	772	980	1172
Salt Lake City, UT				2	16	41	80	158	328	564	798	831	755	685	682	635	614	615	569
Richmond, VA					1	2	19	67	138	285	478	632	699	673	690	745	784	850	953
Burlington, VT	8	17	39	81	135	216	272	336	491	561	752	716	637	603	655	694	703	670	573
Seattle, WA							3	20	39	104	427	914	1408	1445	1462	1272	750	448	258
Charleston, WV				1	7	22	73	135	252	356	630	633	607	667	661	689	767	949	912
Milwaukee, WI	3	4	18	47	83	116	176	285	421	659	913	774	611	591	585	634	749	753	597
Casper, WY	5	15	30	45	73	116	200	325	495	683	806	831	782	670	606	642	592	532	423

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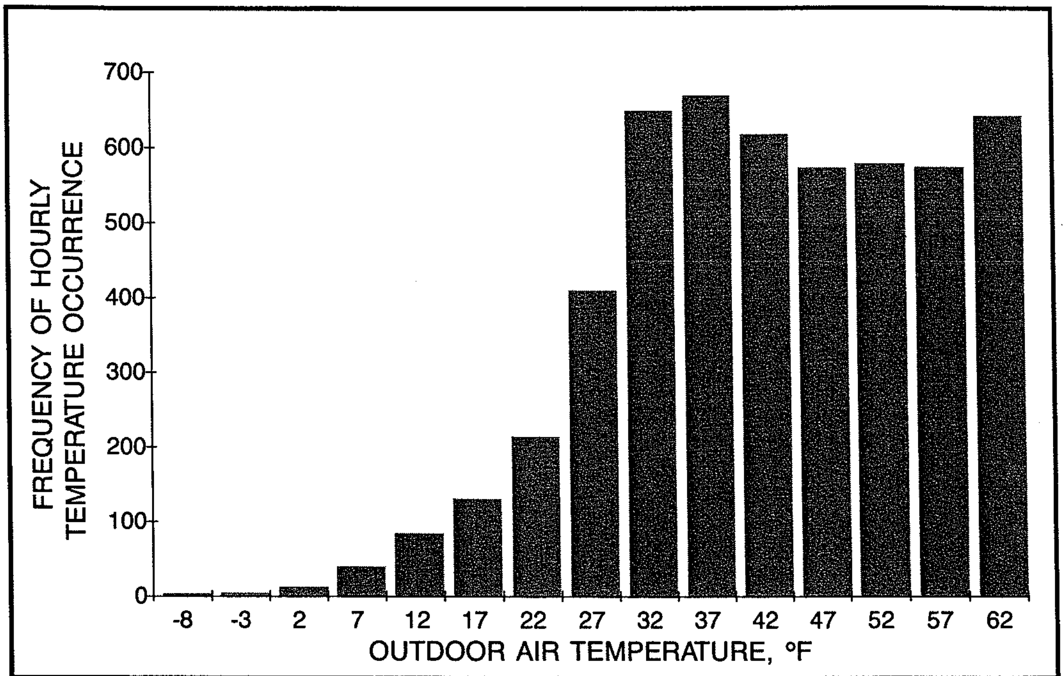

FIGURE 8-1: Distribution of Hourly Temperature Occurences in St. Louis, Mo.

SOURCE: Modified from ASHRAE (3)

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for use with the bin method can be found in *Engineering Weather Data* (4). "Binned" hourly temperature occurence data for a number of cities in the United States are shown in Table 8-5.

Example 8-5: Heating Season Energy Consumption of a Heat Pump (Bin Method)

Problem: Estimate the annual heating energy requirements for a home with a design heating load (corrected for duct losses, appliance usage, and solar heat gains) of 45,000 Btu/h for indoor and outdoor design temperatures of 70 °F and 6 °F, respectively. The house is located in St. Louis. Performance data for the heat pump is given in Table 8-6.

Solution: The solution is best carried out in a tabular format, such as is shown in the worksheet in Table 8-7a.

For the outdoor temperatures in Column A, enter the corresponding heat pump heating

TABLE 8-6: Heating Capacity and Power Data for a 3-Ton Air-Source Heat Pump

HEATING INDOOR AIR CONDITIONS 70°F			
OUTDOOR TEMP. °F	**Btu/h**	**Watts**	**COP**
−18	8900	1800	1.45
−13	9700	1830	1.55
− 8	10,600	1880	1.65
− 3	11,800	1940	1.78
2	13,200	2010	1.92
7	14,800	2090	2.07
12	16,600	2170	2.24
17	18,600	2260	2.41
22	20,500	2360	2.55
27	22,700	2470	2.69
32	24,900	2570	2.84
37	27,300	2690	2.97
42	29,600	2800	3.10
47	31,800	2890	3.22
52	34,500	3020	3.35
57	37,000	3140	3.45
62	39,400	3250	3.55
67	41,800	3350	3.66
72	44,100	3450	3.75
77	46,400	3550	3.83
82	48,600	3640	3.91

TABLE 8-7a: Energy Calculation Form for Heat Pumps

SOURCE: Modified from Trane Co. (21)

OUTDOOR TEMP. BINS 5° INCRE.	Btu/h LOSS/ 1 DEG. F.	OD T. DIF. BELOW 65° (65-Col. A)	HEAT LOSS (Btu/h 1000'S) (B×C)	HEAT PUMP HTG. CAP. (Btu/h) Re: MFG. DATA	DUTY FACTOR D ÷ E	CYCLING EFFI-CIENCY-SEE TABLE 8-7b	% RUN TIME ($F_1 \div F_2$)	HT. PUMP INPUT (kW) Re: MFG. DATA	SEASONAL HTG. HRS. RE: N.O.A.A.	SEASONAL HT. PUMP INPUT kWh (F_3×G×H)	RESIST. HT. INPUT (Btu/h) (D—E)	RESIST. HT. INPUT (kW) (J÷3413)	SEASONAL RE-SIS. HT. INPUT kWh (H × K)	DEGREE HOURS (C × H)
A	B	C	D	E	F_1	F_2	F_3	G	H	I	J	K	L	M
62	703	3	2,109	39,400	0.054	0.764	0.0707	3.25	646	148	0	0	0	1938
57	↑	8	5,624	37,000	0.152	0.789	0.193	3.14	575	348	↓	↓	↓	4600
52		13	9,139	34,500	0.265	0.817	0.324	3.02	580	568				7540
47		18	12,654	31,800	0.398	0.850	0.468	2.89	578	782				10,404
42		23	16,169	29,600	0.546	0.887	0.616	2.80	620	1069				14,260
37		28	19,684	27,300	0.721	0.930	0.775	2.69	671	1399				18,788
32		33	23,199	24,900	0.932	0.983	0.948	2.57	650	1584				21,450
27		38	26,714	22,700	1.0	1.0	1.0	2.47	411	1015	4.014	1.18	485	15,618
22		43	30,229	20,500	↓	↓	↓	2.36	219	517	9.729	2.85	624	9417
17	CONSTANT	48	33,774	18,600				2.26	134	303	15.174	4.45	596	6432
12		53	37,259	16,600				2.17	77	167	20.659	6.05	466	4081
7		58	40,774	14,800				2.09	40	84	25.974	7.61	304	2320
2		63	44,289	13,200				2.01	15	30	31.089	9.11	137	945
−3		68	47,804	11,800				1.94	7	14	36.004	10.55	74	476
−8		73	51,319	10,600				1.88	1	2	40.719	11.93	12	73
−13	↓	78												
−18		83												
										8030			2698	118,342

ANNUAL REQUIREMENT DUCTED RESISTANCE HEAT

$$\frac{(B)\ 703 \times (M)\ 118{,}342}{3413} = (P)\ 24{,}376\ \text{kWh}$$

ANNUAL REQUIREMENT HEAT PUMP SYSTEM

$$\underset{I\ (TOTAL)}{8030} + \underset{L\ (TOTAL)}{2698} = (N)\ 10{,}728\ \text{kWh}$$

SEASONAL PERFORMANCE FACTOR

$$\frac{(P)\ 24{,}376}{(N)\ 10{,}728} \times 3.413 = 7.75\ \text{H.S.P.F.}$$

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TABLE 8-7b: Cycling Efficiency Values

SOURCE: Modified from Trane Co. (21)

DUTY FACTOR	CYCLING EFFICIENCY	DUTY FACTOR	CYCLING EFFICIENCY	DUTY FACTOR	CYCLING EFFICIENCY	DUTY FACTOR	CYCLING EFFICIENCY
1.000	1.000	0.750	0.937	0.500	0.875	0.250	0.812
0.990	0.998	0.740	0.935	0.490	0.873	0.240	0.810
0.980	0.995	0.730	0.932	0.480	0.870	0.230	0.807
0.970	0.992	0.720	0.930	0.470	0.867	0.220	0.805
0.960	0.990	0.710	0.928	0.460	0.865	0.210	0.803
0.950	0.987	0.700	0.925	0.450	0.862	0.200	0.800
0.940	0.985	0.690	0.922	0.440	0.860	0.190	0.797
0.930	0.983	0.680	0.920	0.430	0.858	0.180	0.795
0.920	0.980	0.670	0.917	0.420	0.855	0.170	0.792
0.910	0.977	0.660	0.915	0.410	0.852	0.160	0.790
0.900	0.975	0.650	0.913	0.400	0.850	0.150	0.788
0.890	0.972	0.640	0.910	0.390	0.847	0.140	0.785
0.880	0.970	0.630	0.907	0.380	0.845	0.130	0.782
0.870	0.968	0.620	0.905	0.370	0.843	0.120	0.780
0.860	0.965	0.610	0.903	0.360	0.840	0.110	0.778
0.850	0.962	0.600	0.900	0.350	0.837	0.100	0.775
0.840	0.960	0.590	0.898	0.340	0.835	0.090	0.773
0.830	0.958	0.580	0.895	0.330	0.833	0.080	0.770
0.820	0.955	0.570	0.892	0.320	0.830	0.070	0.767
0.810	0.953	0.560	0.890	0.310	0.828	0.060	0.765
0.800	0.950	0.550	0.888	0.300	0.825	0.050	0.763
0.790	0.947	0.540	0.885	0.290	0.822	0.040	0.760
0.780	0.945	0.530	0.883	0.280	0.820	0.030	0.758
0.770	0.943	0.520	0.880	0.270	0.818	0.020	0.755
0.760	0.940	0.510	0.877	0.260	0.815	0.010	0.752

From start-up, time is required for system to reach steady-state efficiency.
Cycling efficiency can be expressed as 1 minus the degradation coefficient: $1\text{-}C_{deg}$

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capacities (from Table 8-6) in Column E. From Table 8-6, find the power demand and enter it in Column G. From Table 8-5, find the seasonal heating temperature frequency distribution and enter it in Column H. Compute the slope of the heat loss line by taking $(H_L/\Delta t)_{des}C_d = 45,000/(70-6) = 703$ Btu/h °F. Enter that value in Column B. To begin the calculation, compare the heat loss (Column D) to the available heat pump capacity (Column E) for each temperature bin. If the capacity is greater than the heat loss, the heat pump will run less than 100% of the time; if the capacity is less than the heat loss, the heat pump will run all of the time and the capacity shortfall will have to be made up by use of supplemental resistance heat.

Total energy consumption of the heat pump system is obtained by summing the heat pump and supplemental heating bin totals. Values in Column M are obtained by multiplying Column C by Column H for each bin. The seasonal total consumption of resistance heat energy is assumed to equal the seasonal total heating load for purposes of HSPF computation. Performance degradation due to heat pump on-and-off cycling is included in this bin calculation. Table 8-7b lists standard values of the cycling efficiency (1 minus the degradation coefficient, C_{deg}). When available, cycling efficiency corrections specific to the equipment should be used.

The bin method could be employed to estimate annual cooling energy requirements as well by using bin data for outside temperatures above 65 °F. However, insolation and humidity effects, which can be significant, are ignored in this procedure. The cooling-degree day procedure is easier to apply and may provide just as reasonable estimates of cooling-season energy requirements.

WATER-SOURCE HEAT PUMPS

The energy consumption of water-source heat pumps can be calculated using either the degree-day or the bin method. The degree-day method requires the use of specific values of HSPF which can be obtained from heat pump manufacturers.

AIR-SOURCE HYDRONIC HEAT PUMPS

Energy estimating for air-source hydronic heat pumps can be accomplished using the bin method. However, additional calculations and evaluations for the combination of the air-source heat pump and the convectors or radiators are required. It is recommended that the manufacturer of the heat pump be consulted for specific details on carrying out the bin method calculation.

Simulation Methods

Energy use simulation methods involve stepwise integration of an unsteady-state heat balance for the building being analyzed. Generally these methods require much more detailed data on the weather, structure and HVAC system characteristics, occupancy and appliance use schedules, and the like.

Estimating energy consumption using a simulation model offers many advantages, including: complete description of the building HVAC system; study of the effects of time dependent internal gains, solar gains, and control settings; determination of the response of the building HVAC system to changing weather patterns and control settings; and modeling of part-load behavior of the equipment. Some simulation models have economic-analysis submodels which allow the introduction of variables such as the cost of fuel and time of day and seasonal electric energy and demand rates.

The disadvantages of using simulation

models include: considerable time expenditure preparing input data, the need for access to a computer, and computer costs. Typically, simulation models involving use of a mainframe computer are used in the study of residential buildings for only research purposes. They are more frequently applied in investigating the energy consumption of commercial buildings where the equipment operation and building use patterns are apt to be more complex.

A number of simulation models are available for estimating the energy consumption of different HVAC system equipment and for determining building loads. Model applications, cost, and availability vary: they can be purchased, licensed, or used on a timesharing basis. Some manufacturers make their own models available to dealers, architects, engineers, and utility companies.

The appendix provides additional information on how to obtain energy use simulation models.

EPRI METHODOLOGY FOR PREFERRED SYSTEMS (EMPS)

EMPS is a simulation model capable of evaluating up to 10 residences, and can be used for energy estimating of central HVAC systems, unitary systems, combination systems, and electric resistance (furnace or baseboard) systems. It can evaluate one- or two-stage compressors for heat pumps, steady-state operating conditions, and part-load operation. In addition, it has the capacity to model ground-coupled heat pumps. One version, EMPS 2.0, has been under development for a number of years. Another version, EMPS 2.1, was recently made available to the public. Currently, the system is being maintained by the Arthur D. Little, Inc.

U.S. DEPARTMENT OF ENERGY'S DOE-2

DOE-2 is a public-domain computer-simulation model suitable for a variety of computer system applications. Although developed primarily for commercial building applications, it can be used to determine thermal loads and energy consumption in typical residential buildings. DOE-2 has the capability of approximating distribution losses of central systems. Electric resistance, single-stage air-to-air heat pump systems, and single-stage air conditioners can be modeled, including simulation of the influence of indoor and outdoor temperature and cycle time on heat pump or air conditioner performance. DOE-2 is available for purchase or use through the National Technical Information Service (NTIS), Data Base Services Section, Computer Products. A quarterly periodical, "DOE-2 Users News," is available through NTIS. It provides DOE-2 users updates, corrections, and other information about program applications.

BUILDING LOADS ANALYSIS AND SYSTEM THERMODYNAMICS PROGRAM (BLAST)

BLAST can account for dynamic performance in buildings and HVAC equipment. Although developed for analysis of commercial buildings, it can be applied to residential buildings as well. However, only a limited set of residential space conditioning systems and standard commercial building-type distribution systems can be represented. BLAST also does not contain specific algorithms for heat transport in attics or basements. Like DOE-2, BLAST is a public-domain computer model. User support services are being provided by a number of companies, including Boeing Computer Service, Control Data Corporation, Martin Marietta, and McDonnell Automation. For information about accessing and using BLAST, contact the local branch offices of any of these companies.

ENERGY SIMULATION PROGRAM II (ESP-II)

ESP-II is being licensed by Automated Procedures for Engineering Consultants, Inc. (APEC), a nonprofit company. There is a membership fee for its use.

EPRI SIMPLIFIED PROGRAM FOR RESIDENTIAL ENERGY (ESPRĒ)

ESPRĒ represents a compromise between very simple energy analysis procedures and more complex mainframe computer simulation programs. It can be run on an IBM-PC or compatible microcomputer to provide an hourly simulation of residential buildings using standardized weather data. Program input is fully interactive and menu driven. Typical residential structures can be represented as one or two conditioned spaces with an attic and basement, crawl space, or slab foundation. Modeled heating systems include electric resistance, single-stage air-to-air heat pumps and add-on heat pumps. The effect of part load operation and defrost on the performance of the heat pump are also modeled. ESPRĒ is currently supported by the Arthur D. Little, Inc.

9 Heat Pump Economics

In This Section: Equipment and installation costs; energy costs; maintenance costs; economic analysis of HVAC system alternatives

Investing in a heat pump or any other heating and cooling system is an important economic decision for a homeowner. The most important costs are the initial cost of the equipment and its installation, the cost of the energy consumed, and the cost of maintaining the system. This section describes methods for evaluating all these costs for a heat pump system. Also described are methods which allow the consumer to select the most cost-effective option between various heat pump models, as well as methods for analyzing alternative systems using techniques such as simple payback and life-cycle cost analysis.

Equipment and Installation Costs

The best source of information on the capital investment required for a heat pump and its installation is a written quotation from the heating and air conditioning dealer who might perform the installation. By comparison shopping among various dealers, the homeowner can get an accurate idea of the expected outlay for a system.

Secondary sources, such as a local utility company customer service representative, neighbors, or acquaintances who have just purchased a unit, are also valuable but, ultimately, a firm quotation is indispensable. In seeking cost information, it is important to make sure that all costs are included: the cost of the heat pump unit (including shipping to the installation site), wiring, refrigerant tubing, controls, concrete pad, installation labor, and applicable taxes and permit fees (if any). If an increase in the rated power service entrance is required, that too should be included in the installation cost. Some heat pump systems require more equipment than others and may involve more complex installation. The water-to-air heat pump, for instance, requires a source well and, possibly, a discharge well. Similarly, a ground-coupled system requires installation of heat exchangers in the ground. Air-to-air systems, requiring neither of these, are the simplest and least expensive to install. Likewise, in alternative HVAC systems, gas and oil furnaces and boilers require a chimney or a flue and piping and/or a storage tank — equipment not required for the electric furnace, boiler, or heat pump.

Equipment and installation costs will vary widely as a result of distance from the dealer or supplier, size of equipment, product quality, difficulty of installation, local labor rates, overhead, contingencies, and dealer profit. For rough comparisons, typical costs of heat pumps and other HVAC equipment, as listed in *Means* (22), are given in Table 9-1. For greater detail, dealers' price quotations or handbooks for estimating the cost of mechanical systems should be consulted.

TAX CREDITS, OTHER INCENTIVES, AND INSURANCE

Certain features that improve the efficiency of a heating and cooling system in a principal residence, such as a set-back thermostat, can qualify the homeowner for a federal, state, or local tax incentive or credit. However, as federal, state, and local laws and regulations governing tax credits and incentives are subject to change, the local utility conservation program representative or federal or regional offices of the Internal Revenue Service should be contacted for current information. Current information concerning state tax credits may also be obtained from the state tax office or office of energy or natural resources. Local tax offices should be consulted to determine if any local tax credits apply to the installation of energy-conserving heating or cooling equipment.

In addition, manufacturers, dealers, or utilities sometimes offer rebates for the purchase and installation of heat pumps. Local utilities or heat-pump dealers should be consulted to determine the availability of rebates.

Finally, in some jurisdictions, retrofit of a more expensive heating or cooling system may increase the taxable value of the property or require additional insurance. The homeowner's insurance company should be consulted to determine if any additional coverage is required, particularly for combustion or solar heating systems.

INSTALLATION COSTS

The cost of installing the heat pump depends on the type of equipment involved, whether it is a new or a retrofit installation, and the installation services needed. Equipment size and quality can also affect costs. For example, add-on heat pumps and air-to-air heat pumps are generally the easiest to install. Water-to-air heat pumps require installation of piping and, often, drilling of wells in addition to the installation of the heat pump. Ground-coupled heat pumps and solar-assisted heat pumps, however, typically require the most labor for proper installation. By comparison, fossil-fuel fired heating systems with central air conditioning generally require more labor for installation than do air-to-air heat pumps — but less than do ground-coupled heat pumps. Labor costs also depend on local wage rates and the time and specific expertise required for installing a particular system.

Energy Costs

The largest expense over the life of an HVAC system is the cost of the energy to operate it. Operating costs can outweigh the initial equipment and installation cost several times, making high-efficiency systems an important consideration. Section 8 provides techniques for estimating the energy requirements of various systems. Since electricity and fuel prices vary significantly across the country, current energy cost information should be obtained from local utilities or suppliers.

ELECTRICITY

Electric heat pumps, electric furnaces, air conditioners, and electric water heaters all require electrical power service, the cost of which must be considered in the economic evaluation of alternative HVAC systems. A fossil fuel furnace or boiler also uses electricity for blowers and pumps. For example, the electrical energy use by a high-efficiency gas furnace may add 15 to 20% to the cost of the gas itself.

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TABLE 9-1: Typical Equipment and Installation Costs for Heat Pumps and Alternative Heating and Cooling Equipment (1985 Dollars)

Source: Means (22)

CONVENTIONAL HEATING SYSTEMS	Electric Furnaces (Hot Air Blower, Standard Controls, Heat Staging, 240 Volt)	47,000 Btuh* $610	76,000 Btuh $720	131,200 Btuh $935			
	Gas Furnaces (Hot Air Blower, Standard Controls, Direct Drive, Does Not Include Gas or Flue Piping)	42,000 Btuh $470	79,000 Btuh $515	126,000 Btuh $760			
	Oil Furnaces (Hot Air, Blower, Standard Controls, Atomizing Gun Burner, Does Not Include Oil or Flue Piping or Tank)	85,000 Btuh $795	100,000 Btuh $850	125,000 Btuh $960			
	Electric Boiler (Standard Controls and Trim, No Wiring)	41,000 Btuh $3125	52,000 Btuh $3175	82,000 Btuh $3375	123,000 Btuh $3525		
	Gas-Fired Boiler (Standard Controls and Trim, No Gas or Flue Piping)	51,200 Btuh $1400	72,000 Btuh $1575	101,000 Btuh $1800	132,000 Btuh $2050		
	Oil-Fired Boiler (Standard Controls and Trim, Steel, No Oil or Flue Piping)	103,000 Btuh $1800	122,000 Btuh $1850	137,000 Btuh $1975			
	Oil-Fired Hydronic System (Boiler and Burner Unit, Pump, Expansion Tank, Piping, Baseboard Radiator, Fuel Oil Piping and Tank, Etc.)	109,000 Btuh $6540	$6.54/Sq. Ft. of Residence				
	Electric Baseboard Radiation (187 Watts per Linear Foot, Heaters, Conduit, Wiring)	$1.72/Sq. Ft. of Residence					
	Gas/Oil Venting (Galvanized Steel, Double Wall)	3″ $8.65/Vert. Linear Ft.	4″ $9.55/Vert. Linear Ft.	5″ $10.45/Vert. Linear Ft.	6″ $11.50 / Vert. Linear Ft.	8″ $14.55 / Vert. Linear Ft.	
	Steel Oil Storage Tank (Above Ground, No Pump or Piping)	275 Gallon $265	550 Gallon $760				
CENTRAL HEATING AND COOLING	Central Heating and Cooling (Electric Heating and Cooling, Humidifier)	Heating	20,400 Btuh	30,600 Btuh	40,800 Btuh		
		Cooling	20,000 Btuh	20,000 Btuh	20,000 Btuh		
		Cost	$1240	$1265	$1343		
	Central Heating and Cooling (Gas-Fired, Electric Cooling, Humidifier)	Heating	80,000 Btuh	100,000 Btuh	120,000 Btuh		
		Cooling	36,000 Btuh	36,000 Btuh	42,000 Btuh		
		Cost	$3075	$3325	$3820		
	Central Heating and Cooling (Oil-Fired, Electric Cooling, Humidifier)	Heating	84,000 Btuh	95,200 Btuh	112,000 Btuh		
		Cooling	36,000 Btuh	36,000 Btuh	42,000 Btuh		
		Cost	$3250	$3475	$3925		
HEAT PUMPS	Air-To-Air Heat Pump (With Supplementary Electricity) (Split) (Heating at 0°F)	Heating	8500 Btuh		13,000 Btuh		27,000 Btuh
		Cooling	24,000 Btuh		36,000 Btuh		60,000 Btuh
		Cost	$1835		$2565		$4305
	Air-To-Air Heat Pump (With Supplementary Electricity) (Single Package) (Heating at 0°F)	Heating	6500 Btuh	8000 Btuh	10,000 Btuh	13,000 Btuh	27,000 Btuh
		Cooling	24,000 Btuh	30,000 Btuh	36,000 Btuh	48,000 Btuh	60,000 Btuh
		Cost	$1711	$2106	$2393	$2800	$3679
	Water-To-Air Heat Pump (With Supplementary Electricity) (Heating at 0°F)	Heating	19,000 Btuh	25,000 Btuh	27,000 Btuh	31,000 Btuh	29,000 Btuh
		Cooling	24,000 Btuh	30,000 Btuh	36,000 Btuh	48,000 Btuh	60,000 Btuh
		Cost	$1420	$1590	$1719	$2208	$2968

*Btuh=Btu/h
These are average prices for 1985 in the United States and they can vary by local supplier and installer.
These prices include material, installation, overhead, and profit.

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Electrical energy is readily available almost anywhere in the United States and is an economically attractive source of energy for residential heating and cooling. The price of electricity is normally expressed as cents per kilowatthour (kWh). One kWh is the thermal equivalent of 3413 Btu (that is, it will produce 3413 Btu of heat when converted to thermal energy in an electric resistance heater or other conversion device with 100% efficiency). Electricity rates in the United States consist of one or more of the following components: a customer charge for the cost of providing electrical service to the building, an energy charge, and a demand charge. For simplicity of metering and billing for residential service, the demand charge is usually incorporated with either the customer or the energy charge. In addition, a fuel adjustment charge, taxes, and other surcharges may be imposed. Rates may also vary by time of day or season. For purposes of energy cost analysis, the average price per kWh, which incorporates all of the above charges, may be used. On that basis, the cost of electricity for homes in the United States typically ranges from $0.02 to $0.15 per kWh.

NATURAL GAS

The price of natural gas is typically expressed as dollars per therm. A therm is defined as 100,000 Btu. In many localities gas is metered in units called CCF, or hundreds of cubic feet. One CCF contains approximately one therm, but this varies with the heating value of the gas being supplied. A conversion factor is usually stated on the utility bill. If natural gas is to be used as supplemental fuel with an add-on heat pump, for example, its cost needs to be included as well. In a few instances, gas utilities have attempted to impose a surcharge for gas backup service. The cost of natural gas currently ranges from $0.35 to $1.00 per therm.

FUEL OIL

The cost of fuel oil is normally expressed in dollars per gallon. A gallon of Number 2 fuel oil, the most common grade for home heating, is thermally equivalent to approximately 140,000 Btu. The potential fuel-oil user should consider the current and projected local availability of fuel oil as well as its cost, which currently ranges $0.90 to $1.25 per gallon.

LIQUEFIED PETROLEUM GAS (LPG)

LPG is typically found in sparsely populated areas where natural gas is not available. The cost of LPG is normally expressed in dollars per gallon. A gallon is the thermal equivalent of approximately 90,000 Btu. The approximate range of LPG cost is $0.50 to $0.90 per gallon.

ENERGY PRICE TRENDS

In comparing heat pumps to other heating and cooling systems, it is important to take into account that the cost of alternative fuels — such as natural gas, oil, and LPG — is expected to rise in the future. Fuel price escalation is difficult to predict, however. Since the 1973 oil embargo, rate increases have generally exceeded the rate of inflation as measured by the Consumer Price Index. Electricity prices have increased too, but usually at less than the rate of inflation.

Trends in the costs of energy to residential users are shown in Figure 9-1. The comparison is on a constant dollar basis, with both historical data and the Energy Information Administration's projections shown as percentage increases from 1970 base year prices. This does not account for differences in energy utilization efficiency in the home, which is highest for the electric heat pump. In constant 1983 dollars, (that is, excluding inflation), the three energy forms have increased in cost by 130% (natural gas), 129% (heating oil), and 25% (electricity) since 1970.

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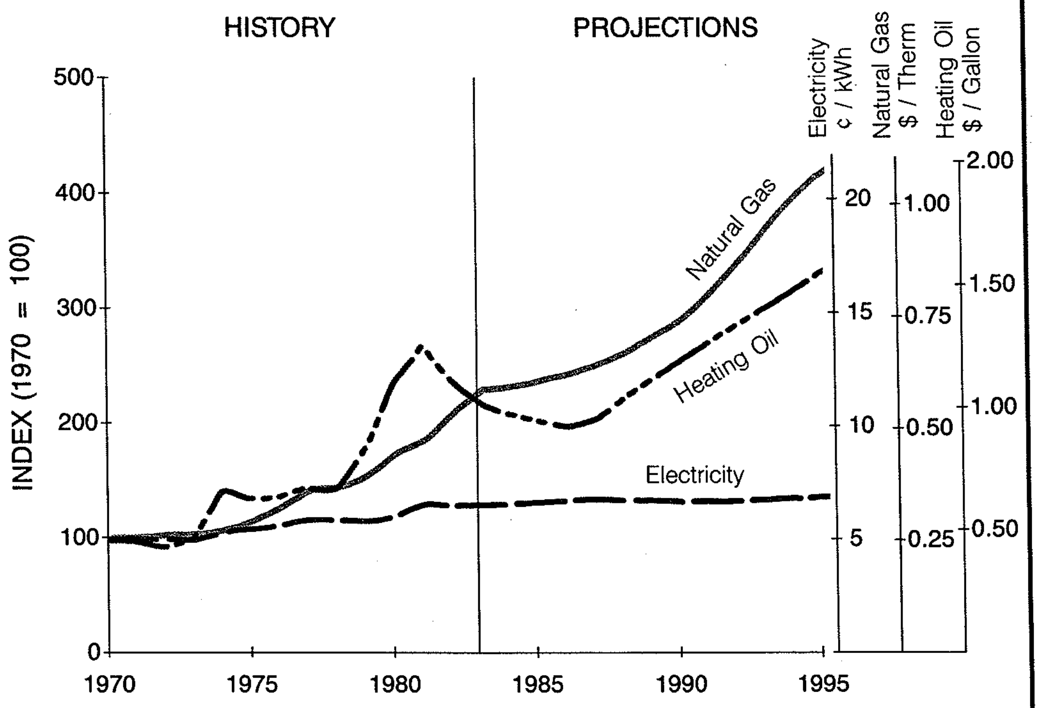


FIGURE 9-1: Energy Prices for Residential Consumers, Constant 1983 Dollars

Source (20)

Maintenance Costs

Maintenance costs consist of the cost of corrective and preventive servicing and repair. These may include materials costs for replacement parts and filters, chemicals, cleaning materials, refrigerant, oil and grease, and labor costs for cleaning and painting, testing, belt adjustment, burner adjustment, and pump and well maintenance. Dealers and, in some cases, utilities offer maintenance contracts which cover the cost of servicing and repairs for a fixed price.

Because the cost of maintenance service varies by location and supplier, local estimates should be obtained. Some maintenance cost estimates for heating and cooling equipment are summarized in Table 9-2. The cost of maintaining an add-on heat pump is about the

TABLE 9-2: Estimated Maintenance Costs (1983 Dollars) SOURCE (9,24,25,26)

ITEM	EST. COST/YR.
Gas Furnace or Boiler and Air Conditioner*	$30 to $100
Oil Furnace or Boiler and Air Conditioner*	$60 to $130
Electric Furnace and Air Conditioner*	$25 to $90
Electric Resistance Heating	None
Air-to-Air Heat Pump	$100 to $170
Water-to-Air Heat Pump	$70 to $115

*Costs vary depending on make and model, number of inspections, filter changes, repair parts, and labor rates.

same as that of maintaining an air-to-air heat pump because both are of similar design. For the gas or oil-fired furnace with an add-on heat pump, however, additional maintenance would be required for the fuel burners. Air-to-water heat pumps have maintenance costs similar to air-to-air heat pumps. Ground-coupled heat pumps have slightly higher maintenance costs than water-to-air heat pumps because of their ground-coil heat exchangers. Solar-assisted heat pumps generally cost the most to maintain because of the large number of system components and because outside collectors are exposed to the elements. Local service contractors can provide information regarding maintenance costs for various heating and cooling systems. In some areas, annual service contracts are available.

Economic Analysis of HVAC System Alternatives

Selecting a heat-pump system involves a decision between performance levels and economic merits. Systems are usually selected on the basis of the user's needs, the designer's experience, local building codes, and cost. When all other factors are equal, the system with the lowest lifetime cost — including both initial cost and energy costs — should be selected.

There are various methods for making an economic analysis of heat pumps. Two of these are discussed and illustrated: simple payback method and life-cycle costing (present value) method.

When the real cost of energy was low, HVAC systems were frequently selected on the basis of initial costs only. Indeed, builders, developers, or owners of rental housing who do not pay the operating costs for a heating and cooling system may think it is cheapest to select a system with the lowest initial cost. But this, in the long run, is not good economics, because the least expensive equipment often has the lowest operating efficiencies and, therefore, the highest operating cost. High heating and cooling system operating costs depress the attractiveness of the system to future users.

SIMPLE PAYBACK

Simple payback is a method for comparing alternative HVAC system choices. "Payback" refers to the length of time it takes for an annual energy and maintenance cost savings to offset an initial difference in cost between two systems. Although the simple payback method is popular, it has two drawbacks: a) it does not consider benefits of energy and operating cost savings after the payback period is over; and b) it does not consider the time value of money or the escalation of maintenance and energy costs over time (hence the name "simple" payback). The simple payback period is calculated from Equation 9.1:

$$Y_{PB} = \frac{K_2 - K_1}{(E+M)_1 - (E+M)_2} \qquad (9.1)$$

where:

Y_{PB} = payback time, years
K = capital investment
E = annual energy cost
M = annual maintenance cost
$_1$ = system under consideration
$_2$ = alternative system .

Note that the order of the subscripts differs in the numerator and denominator. This is because the simple payback method is applied when one system costs more initially but has lower annual energy and maintenance costs. If a system were both cheaper to own and operate, then it would be the logical economic choice according to the simple payback method (i.e., the payback would be negative).

Example 9-1: Selection of a High Efficiency vs. Conventional Heat Pump

Problem: A house requires a 36,000 Btu/h heat pump and two air-source heat pumps are under consideration: low-efficiency Model A and high-efficiency Model B. The pertinent economic data used for this example are shown.

Solution: Substituting into Equation 9.1:

$$Y_{PB} = \frac{3100 - 2500}{(683+70) - (483+70)} = \frac{600}{200}$$

$$= 3 \text{ years.}$$

The payback period for purchasing the high-efficiency, higher initial cost Model B heat pump is three years. The homeowner will then save $200 per year over the additional 12 years of life of the heat pump. Not considering inflation, this amounts to $2,400.

ITEM	MODEL A HEAT PUMP	MODEL B HEAT PUMP
HSPF	6.2	8.0
Initial cost	$2200	$2800
Installation labor	$300	$300
Annual energy cost	$683	$483
Annual maintenance cost	$70	$70
Estimated service life, years	15	15

Example 9-2: Selection of a Groundwater Heat Pump vs. Electric Furnace and Central Air Conditioner

Problem: A rural homeowner who has an electric air furnace without air conditioning is planning to add electric air conditioning and wants to compare its life-cycle cost with the life-cycle cost of a groundwater heat pump. The homeowner would have to drill a new supply well for the heat pump but could discharge the used water into an existing pond.

Solution: Again, from Equation 9.1:

$$Y_{PB} = \frac{3800 - 950}{(1600+75) - (600+60)} = \frac{2850}{1015}$$

$$= 2.8 \text{ years.}$$

The payback period for the groundwater heat pump would be less than three years, and the homeowner would realize considerable savings for the remaining 12 years of the unit's life.

ITEM	GROUNDWATER HEAT PUMP (A)	ELECTRIC FURNACE PLUS A/C (B)
Initial cost	$2200 (heat pump + labor) $1600 (well, pump, piping)	$950 (air conditioner + labor)
Annual maintenance cost	$60	$75
Annual energy cost (summer & winter)	12,000 kWh × $.05/kWh = $600	32,000 kWh × $.05/kWh = $1600
Estimated service life, years	15	15

Example 9-3: Selection of a Heat Pump vs. LPG-Furnace and Central Air Conditioner

Problem: An LPG-furnace with central air conditioning and an air-to-air heat pump are being considered for installation. The initial cost for the furnace and air conditioner includes the furnace, gas piping, ductwork, air conditioner, controls, chimney, labor, and electrical service. For the heat pump, the initial cost includes the heat pump, ductwork, controls, electrical service, and labor. LPG consumption is estimated at 1500 gallons a year at $0.70 a gallon, and heating season fan energy use is estimated at 525 kWh. The heating season estimate for heat pump energy consumption is 11,333 kWh. The price of electricity is $0.06/kWh.

The cost for air conditioning may be ignored in this case, assuming that the central air-conditioner and the heat pump will use about the same amount of energy.

Solution: The difference in the initial cost of System B and System A is $763.00. The energy cost difference is $401.50; the maintenance cost difference is $20.00. From Equation 9.1:

$$Y_{PB} = \frac{4263 - 3500}{(1050+31.50+50)-(680+70)}$$

$$= \frac{763}{381.50} = 2 \text{ years.}$$

The payback period for the higher initial cost of System B is two years, after that, $381.50 a year will be saved for the remaining 13 years of the life of the heat pump.

ITEM	LP GAS FURNACE (SYSTEM A)	AIR-TO-AIR HEAT PUMP (SYSTEM B)
Initial cost	$3500.00	$4263.00
Heating season energy cost (gas)	$1050.00	—
Heating season energy cost (electricity)	$31.50	$680.00
Annual maintenance cost	$50.00	$70.00
Estimated service life, years	15	15

LIFE CYCLE COST

The life-cycle cost method considers all the significant costs of ownership during the service life of each system under consideration and can be used to compare more than two alternatives. In addition, the method accounts for the time value of money. For example, if an investor can earn 10% return on invested capital, $100 in savings available at the end of a year has a present value of only $P = \$100/(1+0.1) = \$91$ (approximately), because the investor could have earned $10 in additional interest — if the $100 savings had been available at the beginning of the year. That is, future savings (or expenditures) are discounted by the interest return the investor could have earned (or avoided paying) on an equivalent amount invested (or borrowed). The discount rate or factor reflects the investment opportunities or alternatives available. For a new homeowner, paying for the HVAC system as part of a house mortgage, it is sufficiently accurate to assume the mortgage interest rate as the discount factor. For a retrofit, the cost of a house improvement loan, the passbook savings rate, or other appropriate discount factor may be employed.

PRESENT VALUE METHOD

There are various ways of computing the life-cycle cost of a system. The present value method is presented here because it is easy to apply to heating and cooling system alternatives. The present value method determines the amount of money that — if invested at the prevailing interest rate on the same day as HVAC system installation — would be enough to pay for the initial capital investment, the energy costs, and the maintenance costs over the life of the system. The sum to be invested is the present value of the future expenditures for the system. The system with the smallest present value would be the most economical to own.

It is important to compare systems over an equal service-life period. Given unequal service life, a time would come when one system would have to be replaced. Otherwise, the system with the longer service life would have salvage value only at the end of the comparison period. (For procedures for incorporating unequal service lives into the present value method, see References [8] and [9].) To compare systems over equal service lives requires compromise on estimates of the service lives.

The present value for a heating and cooling system is given by the following formula:

$$P = K + E \times f_E + M \times f_M \qquad (9.2)$$

where:

P = present value
K = initial capital investment for the heating and cooling system
E = annual energy costs
f_E = the present value factor for the annual energy costs for a given interest rate (I), and useful life (N) (See Table 9-3.)
M = estimated annual maintenance costs for the system (See Table 9-2.)
f_M = the present value factor for the annual maintenance costs. (See Table 9-3.)

Present value factors for energy costs and maintenance costs may be different. Figure 9-2 provides a form for calculations using present value factors.

This form can be used to calculate the present value of alternative HVAC systems. Fill in the appropriate data as shown, and perform calculations in Box 8. Compare analysis for two systems.

ITEM	SYSTEM A	SYSTEM B
1. Total Initial Cost, $ (See Table 9-1).		
2. Annual Energy Cost, $, Units of fuel × cost per unit. Include all forms of fuels used. Estimate fuel requirements from Section 8 or obtain from a reliable dealer or supplier.		
3. Annual Maintenance Costs, $ (See Table 9-2).		
4. Estimated Service Life, Years – N (See ASHRAE [27]).		
5. Interest Rate, % – I		
6. f_E (Find from Table 9-3 at I and N.)		
7. f_M (Find from Table 9-3 at I and N.)		
8. Present Value (From Equation 9.2) Line 1 + Line 2 × Line 6 + Line 3 × Line 7	Select System with lowest present value	

FIGURE 9-2: Present Value Analysis Form

TABLE 9-3: Present Value Factors (f)

Source: (23)

(YEARS)	INTEREST RATE, % PER YEAR (I)								
(N)	2%	4%	6%	8%	10%	12%	14%	16%	20%
1	0.980	0.962	0.943	0.926	0.909	0.893	0.877	0.862	0.833
2	1.942	1.886	1.833	1.783	1.736	1.690	1.647	1.605	1.528
3	2.884	2.775	2.673	2.577	2.487	2.401	2.322	2.246	2.107
4	3.808	3.630	3.465	3.312	3.170	3.037	2.914	2.798	2.589
5	4.714	4.452	4.212	3.993	3.791	3.605	3.433	3.274	2.991
6	5.601	5.242	4.917	4.623	4.355	4.111	3.889	3.685	3.326
8	7.326	6.733	6.210	5.747	5.335	4.968	4.639	4.344	3.837
10	8.983	8.111	7.360	6.710	6.145	5.650	5.216	4.833	4.193
12	10.575	9.385	8.384	7.536	6.814	6.194	5.660	5.198	4.439
14	12.106	10.563	9.295	8.244	7.367	6.628	6.002	5.468	4.611
16	13.578	11.652	10.106	8.851	7.824	6.974	6.265	5.669	4.730
18	14.992	12.659	10.828	9.372	8.201	7.250	6.467	5.818	4.812
20	16.351	13.590	11.470	9.818	8.513	7.469	6.623	5.929	4.870
25	19.523	15.622	12.783	10.675	9.077	7.843	6.873	6.097	4.948
30	22.396	17.292	13.765	11.258	9.427	8.055	7.003	6.177	4.979

Inflation. A simple but sufficiently accurate method to account for inflation in future energy or maintenance costs is to use an effective interest rate in determining the present value factor from Table 9-3:

$$I_{eff} = I_{act} - J \qquad (9.3)$$

where:

I_{eff} = effective interest or discount rate, %
I_{act} = actual interest rate including inflation, %
J = inflation rate, % .

That is, if the current mortgage or passbook loan rate is 12%, but electricity costs are expected to escalate at a rate of 4% per year, and maintenance costs at 6%, the effective values of I to use in determining f_E and f_M from Table 9-3 are 8% and 6%, respectively. Examples 9-5 and 9-6 illustrate how to account for inflation in present value calculations.

Example 9-4: Selection of a High-Efficiency vs. Conventional Heat Pump

Problem: A homeowner wants to choose between the purchase of a low- or high-efficiency heat pump (see Example 9-1). The effective interest rate is 8%.

Solution: Figure 9-3 shows a completed form (from Figure 9-2) for this example. Because no values are listed in Table 9-3 for N = 15, it is necessary to interpolate between N = 14 and N = 16. The present value of System B — the high-efficiency heat pump —

is the lowest. Therefore, compared to System A, System B will require $1100 less in current dollars to purchase and operate over the life of the heat pump. Note that by using simple payback, as in Example 9-1, the homeowner would have estimated savings of $2400 over the life of the equipment, but accounting for the time value of money has reduced estimated savings to $1100.

Example 9-5: Selection of a High-Efficienty Heat Pump vs. LPG Furnace and Central Air Conditioner

Problem: The homeowner is Example 9-3 is now considering either an air-to-air heat pump or an LPG furnace and central air conditioner. The interest rate rate is 12%; the annual inflation rates are: electricity, 4%;

ITEM	SYSTEM A	SYSTEM B
1. Total Initial Cost, $ (See Table 9-1).	$2500	$3100
2. Annual Energy Cost, $, Units of fuel × cost per unit. Include all forms of fuels used. Estimate fuel requirements from Section 8 or obtain from a reliable dealer or supplier.	$683	$483
3. Annual Maintenance Costs, $ (See Table 9-2).	$70	$70
4. Estimated Service Life, Years – N (See ASHRAE [27]).	15	15
5. Interest Rate, % – I	8	8
6. f_E (Find from Table 9-3 at I and N.)	8.548	8.548
7. f_M (Find from Table 9-3 at I and N.)	8.548	8.548
8. Present Value (From Equation 9.2) Line 1 + Line 2 × Line 6 + Line 3 × Line 7	$8937	$7827

FIGURE 9-3: Present Value Method (Example 9-4)

ITEM	SYSTEM A	SYSTEM B
1. Total Initial Cost, $ (See Table 9-1).	$ 3500	$4200
2. Annual Energy Cost, $, Units of fuel × cost per unit. Include all forms of fuels used. Estimate fuel requirements from Section 8 or obtain from a reliable dealer or supplier.	Elec. $31.50 LPG $1050	$680
3. Annual Maintenance Costs, $ (See Table 9-2).	$50	$70
4. Estimated Service Life, Years – N (See ASHRAE [27]).	15	15
5. Interest Rate, % – I	Elec. 8%/LPG	+Maint. 6%
6. f_E (Find from Table 9-3 at I and N.)	8.548/9.700	8.548
7. f_M (Find from Table 9-3 at I and N.)	9.700	9.700
8. Present Value (From Equation 9.2) Line 1 + Line 2 × Line 6 + Line 3 × Line 7	$14,439	$10,692

FIGURE 9-4: Present Value Method (Example 9-5)

LPG, 6%; and maintenance, 6%.

Solution: Figure 9-4 shows a completed form for this example. The present value of System B — the air-to-air heat pump — is lowest. Compared to System A, System B will require $3747 less to purchase and operate over the life of the heat pump. In Example 9-3, the simple payback method indicates a lifetime savings of $4960.

Example 9-6: Selection of an Add-On Heat Pump

Problem: A homeowner has a functioning oil furnace and an electric, central air-conditioner that has failed and needs replacement. The oil furnace is expected to last an additional 15 years. The cost of replacing the central air-conditioner must be compared with the cost of an add-on heat pump. In this case, the homeowner compares costs for the heating season only, assuming that summer energy requirements will be approximately equal.

The interest the homeowner can earn is 12%. However, the cost of maintenance is expected to escalate at a rate of 6% per year, and the cost of oil and electricity at 8% and 4%, respectively.

Solution: Interpolating for N = 15 from Table 9-3 gives $f_{E,\text{elec.}} = 8.548$, $f_{E,\text{oil}} = 9.974$, and $f_M = 9.700$. Accounting for electricity and oil separately in Equation 9.2

$$P\ (\text{System A}) = \$2{,}200 + \$528 \times 8.548 + \$330 \times 9.974 + \$60 \times 9.700 = \$10{,}587\ .$$

The present value of System B is:

$$P\ (\text{System B}) = \$900 + \$36 \times 8.548 + \$1430 \times 9.974 + \$45 \times 9.700 = \$15{,}907\ .$$

The homeowner should select the add-on heat pump (System A) because it has the lowest current value. It will save $5320 in current dollars over the life of the heat pump.

ITEM	ADD-ON HEAT PUMP (A)	REPLACES AIR CONDITIONER (B)
Initial cost	$2200 (unit + labor)	$900 (unit + labor)
Annual maintenance cost	60	45
Annual energy cost	$528 (13,200 @ $.04/kWh)	$36 (900 kWh @ $.04/kWh) (blower operation)
(Estimated from Section 9)	$330 (300 gallons oil @ $1.10 per gallon)	$1430 (1300 gallons oil @ $1.10 per gallon)
Estimated service life (N)	15 years	15 years
Interest rate (I)	12%	12%

10

Selection, Installation, Operation and Maintenance

In This Section: Selecting a heat pump system for a new home; selecting a heat pump system for an existing home; installation of air-source heat pumps; special requirements for installation of water-source and ground-coupled heat pumps; operation; maintenance; troubleshooting; choosing a dealer; warranties and service agreements

This section discusses basic aspects of selecting, installing, operating, and maintaining residential heat pump systems and provides some guidelines for obtaining warranties and troubleshooting heat pump problems. Consumers with questions specific to their systems should refer to their owners' manual for basic, how-to information and recommended procedures for simple repair and maintenance tasks. The heat pump dealer or a heat pump specialist should be contacted for additional information about operation, maintenance, and service.

Selecting a Heat Pump System for a New Home

New home builders — be they owner-builders or developers — who are considering using heat pumps must evaluate many factors, including: system cost and economics, building location and local weather, building codes, and for water-source units, regulations concerning water use and disposal.

In assessing system cost and economics, heat pump installation costs should be closely examined and compared with installation costs for alternative systems. Current price information on equipment can be obtained from local dealers or from manufacturers' literature. Cost estimates for various types of equipment are given in Section 9, Tables 9-1 and 9-2. In addition to equipment costs, however, home builders in newly developed or rural areas should also consider the cost of bringing fuel to the homesite — for example, the cost of installing gas lines. Further, in comparing heat pumps with furnaces and boilers, the costs of fuel storage or distribution should be considered, as well as construction costs for chimneys and other vents. Requirements for fire-walled utility rooms or outside air ventilation can also add to a system's cost.

New home builders should also investigate whether they would qualify for a higher mortgage loan as a result of selecting an efficient HVAC system with low annual operating costs. Moreover, higher efficiency and lower operating costs are often good selling points later. Some manufacturers, dealers, or utility companies provide rebates and incentives for installing efficient systems and these may increase a heat pump's economic advantage. Extended warranty or service agreements may be an additional attractive benefit.

Local weather and climate must be taken into consideration when determining the appropriate size of heat pump to purchase. In Section 6, Figure 6-1 presents a guide for sizing heat pumps for use in different parts of the country, based on differences in climate. In Regions I, II, III, and VI, the heat pumps are normally sized based on cooling load. In Region V, the units are oversized for cooling as much as 35%. In Region IV, units with HSPFs exceeding 7.5 should be selected to match the cooling load; units with lower HSPFs should be oversized for cooling as much as 35%.

Local building code requirements and specifications can potentially increase heat pump installation costs, although there are typically few restrictions on heat pump use. Five national organizations develop model building standards that are used as the basis for codes and standards in 30 states and approximately 40,000 local jurisdictions, including cities, towns, and counties. In addition, most code jurisdictions in the United States rely on the National Electric Code for home wiring.

Access to underground water, and legal rights to water use, are important issues to assess in considering installation of water-source heat pumps. Water-disposal regulations or prohibitions should also be considered, as they can be a problem with open-loop systems. Ground-coupled systems are an alternative in areas that have restricted water availability or disposal limitations.

Selecting a Heat Pump System for an Existing Home

When selecting a heat pump system for an existing home, the decision on the type of system to buy sometimes depends on the type of heating and cooling system already in place. For example, if the home has a water (hydronic) heat distribution system, a heat pump with water distribution is needed. These are often more costly than air-to-air systems. If the home already has central air conditioning, the size of existing ductwork is probably adequate for a heat pump. If the ducts were sized for warm air heating only, the existing ductwork must be examined for adequate size as larger ductwork may be needed. To avoid expensive re-ducting, the blower fan speed can be increased (by changing the pulley and motor drive size), or a higher capacity fan can be installed. Either of these options may increase noise and blower energy usage. Refer to industry standards (7, 10) or ask heat pump distributors about proper duct sizing.

Another consideration when installing a heat pump in an existing home is the age of the current heating and cooling system. The life expectancy of the existing system should be calculated to determine whether add-on or replacement with a heat pump is appropriate. Using an add-on heat pump as the primary heat source and the existing furnace solely as backup can greatly extend the useful life of a furnace. Alternatively, an add-on heat pump is a particularly good option when a central air conditioning system requires replacement.

An add-on heat pump or a heat pump water heater should also be considered if the existing heating system uses hydronic heat distribution without a separate water heater or boiler for the household water. Higher system efficiency can be achieved — particularly in the summer — if a separate water heater is used.

Installation of a water-source heat pump can be considered if adequate water supply — from surface water or well water sources — can be assured. Water flow rate, temperature, and water quality are also important information on these factors can be obtained from state geological surveys or local well drillers.

When considering installation of a ground-coupled heat pump system, the condition of the soil is a critical factor as hard, rocky soil can present trenching problems. Also, systems using a horizontal ground coil require an unobstructed area of approximately 5000 square feet near the house.

Installation of Air-Source Heat Pumps

When installing an air-source heat pump, the location of the unit (whether a split or package unit), the adequacy of the power supply, location of the thermostat, and location and insulation of refrigerant piping are important factors to consider. These considerations, and several others, are highlighted in Figure 10-1.

LOCATING THE OUTDOOR UNIT

The location of the outdoor unit is particularly important. Location will differ for every house depending on its orientation and prox-

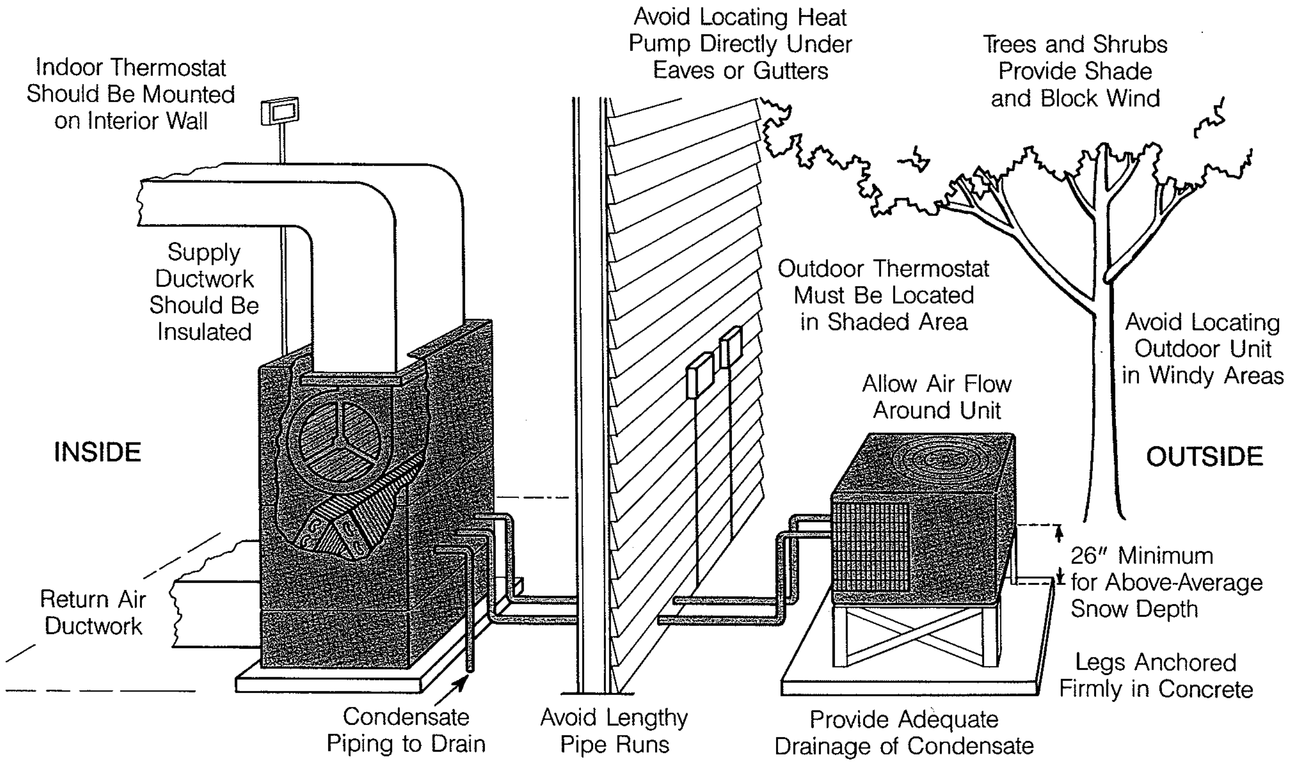


FIGURE 10-1:
Installation Considerations for Air-Source Heat Pumps

imity to other structures or to trees. To limit exposure to compressor and fan noise, the outdoor unit should be located away from bedrooms and at least 15 to 20 feet away from adjacent buildings. In cold climates, it should not be located under gutters, drains, roof overhangs, or trees, where it could be damaged by falling ice. Also, it should not be located in the path of high winds because lower outside temperatures caused by wind chill factors can reduce performance. In warm climates, it should not be located in sunlit areas because heat from direct exposure to the sun can reduce performance. Shrubbery and trees placed around the unit can help to protect it from wind and direct sunlight, but they should be planted at least 18 to 24 inches away from the unit to permit free flow of air.

The outdoor unit must also be mounted on the proper type of foundation. In mild climates with little or no snowfall it can be mounted on a concrete slab. The mounting should be isolated from the house or should have built-in vibration isolators to reduce transmission of vibration to the house. In cold climates, the unit must be mounted on stilts anchored in a concrete slab about two to three feet above the ground, or well above common snow depths, to prevent blockage by snow. Vibration-absorbing legs or stilts should be used if vibration isolators are not built into the outdoor unit.

Adequate water drainage is another important consideration in installation. Water that condenses on the evaporator or other parts of the outdoor unit during normal operation must be adequately drained. A gravel bed can be used to promote proper drainage and should extend about 12 inches around the perimeter of the unit, whether the unit is ground-mounted or on stilts. When the unit is mounted directly on a slab, a small trough or recession in the concrete is necessary for drainage. In all cases, provision should be made for proper water drainage away from the house foundation and sidewalks to avoid winter icing.

LOCATING THE INDOOR UNIT AND OTHER EQUIPMENT

The location of the indoor unit depends on the type and size of the heat pump and the type of indoor space available for the installation. Installation of a room heat pump is much like that of a standard window air conditioner. Some room units can be window-mounted; others can be mounted through a wall, usually beneath a window. These fit into a metal sleeve that holds them firmly in place.

The indoor unit of a dual-split system can be located in a basement, utility room, attached garage, closet, or roof. Many of these units can be installed either upright or on their sides. As shown in Figure 10-2, the indoor compressor unit of a triple-split system should be located in a utility room, basement, or garage to avoid excessive noise within the indoor living space.

Multizone heat pumps, which pipe refrigerant directly into fan coil units in each room, are installed differently. The outdoor condensing unit is installed in the same fashion as a conventional air-source heat pump. The refrigerant piping leading indoors to the fan coil units can be installed on the interior or exterior of the house, or within the walls. Decisions as to where to install refrigerant piping will differ for new and existing homes and depend on the construction style of the home and the materials used. Separate fan coil units are available for installation in the floor or on the wall.

Electric Power Supply. Adequate electric power supply should be ensured. The house should have high voltage wiring (205 to 230 volts) and the corresponding amperage to fulfill all electric demand. Both voltage and amperage should be labeled clearly on the home's electric power supply box.

Thermostats. The outdoor thermostat should not be exposed to direct sunlight, which

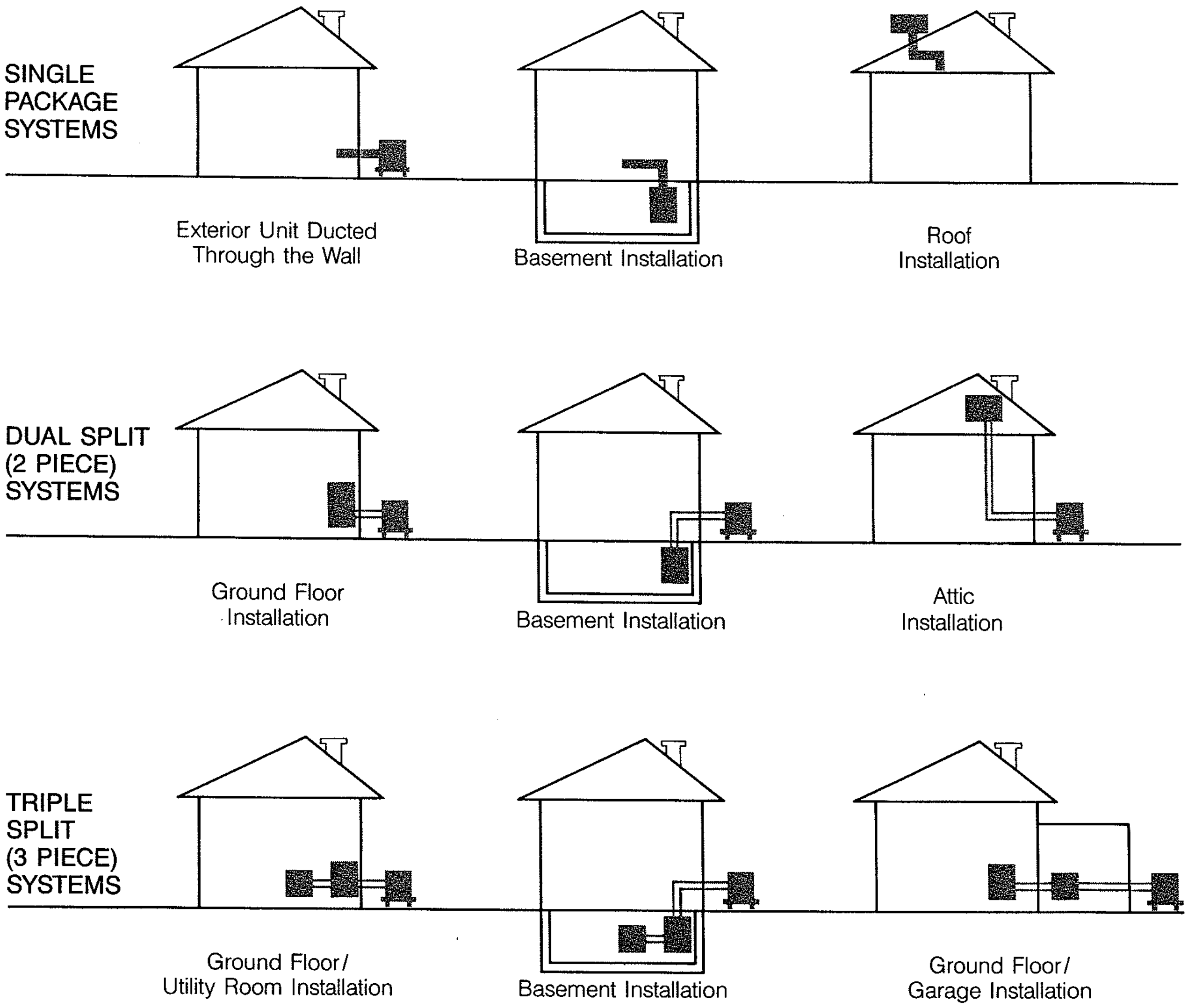


FIGURE 10-2: Recommended Installations of Residential Heat Pumps

can trigger inaccurate signals to the heat pump system. The indoor thermostat should be located on an interior wall in an occupied area. It should not be on a sunlit wall, in the direct beam of nearby electric lights, or in line with the air flow from a register.

Refrigerant Piping. During the installation of refrigerant piping, care must be taken not to flatten, kink, twist, break, or sharply bend any of the lines. Any constriction in either the liquid or suction line will adversely affect the operation of the heat pump and can cause damage to the system. Location and insulation are also important. Refrigerant lines embedded directly in concrete slab floors can allow unwanted heat exchange. However, lines may be run through a conduit or a large pipe and, if thoroughly insulated, embedded in concrete — although access then becomes a problem if leaks occur. Lengthy runs of refrigerant lines through a building may require support at intervals to prevent sagging. And, as the pipes can conduct vibration noise throughout the house, they should be isolated from ductwork and framing where they run through stud spaces, enclosed ceilings, or pipe chases. To facilitate this, piping can be slipped through isolation hangers — insulated, tubular holders. In all cases, uninsulated liquid and gas piping must be kept separate. If they are separately and thoroughly insulated, however, they can be taped together.

Special Requirements for Installation of Water-Source Heat Pumps

Installation of water-source heat pumps is similar to that of air-source heat pumps with regard to indoor unit location, power supply, thermostats, and refrigerant piping. However, a number of special considerations related to pipes, pumps, and wells apply to the installation of these units. Many of these considerations are illustrated in Figure 10-3.

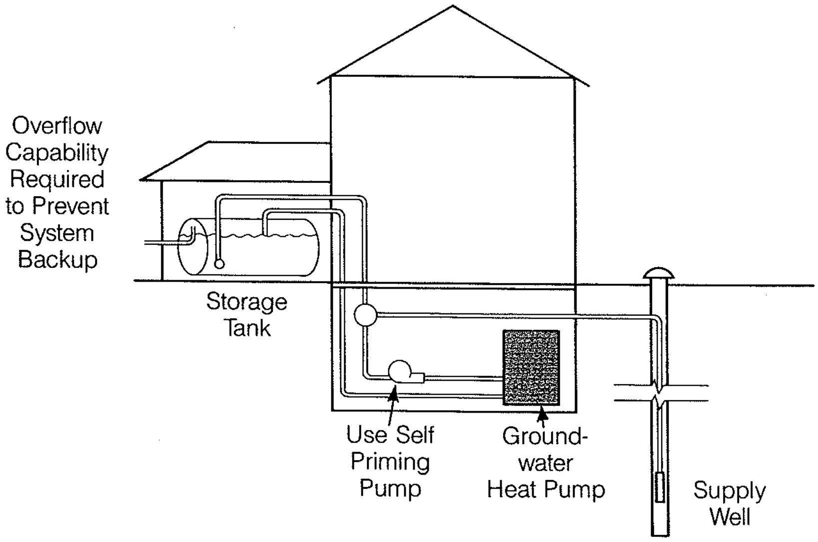
Pipe insulation is essential to efficient operation of water-source heat pumps. To limit unwanted heat exchange, insulation should be installed between the cold water discharge pipe and the warm water intake pipe. Also, in cold climates, pipes should be buried below the frost level to protect them from freezing. Frost level data can be obtained from local meteorologists, well drillers, or water-source heat pump installers.

Adequate water flow, pressure, temperature, and quality are essential; water supply wells should be evaluated carefully for these characteristics. Manufacturers' recommendations regarding water flow should be followed; however, a rough rule of thumb is five gallons per minute of 12,000 Btu/hour heat pump output. Atmospheric or open-fluid system supply wells should be equipped with centrifugal self-priming pumps, rather than circulator pumps, to prevent malfunction caused by inadequate water supply. Atmospheric systems need the centrifugal self-priming pump because water may have to be drawn up from lower depths. The centrifugal self-priming pump can develop enough head pressure with air alone to prime itself and draw water from deeper sections of the well. Circulation pumps are used in pressurized or closed-fluid well systems — those not exposed to atmospheric pressure — where water is always available.

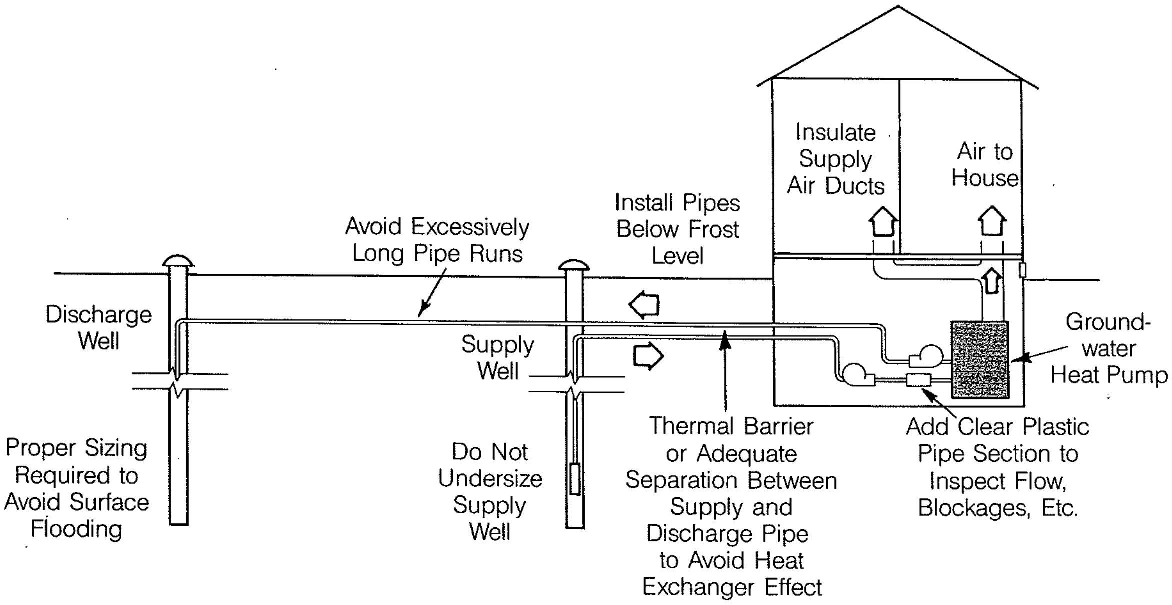
To minimize any drop in water pressure or flow which could alter the performance of a system, pipes to and from the water supply should run no more than 300 to 400 feet in length. Supply pipes less than 3/4 to 1 inch in diameter can limit flow within the system. Inside diameters can be smaller when plastic piping is used rather than metal piping, since the latter generates more fluid friction.

Adequate water temperature is essential because heat pump efficiency decreases as the water temperature approaches 32 °F. Acidic or saline water quality can affect heat pump performance, choice of heat exchanger, and maintenance requirements.

To detect obstruction of air, sand, or other materials within the pipe, a short length of clear plastic pipe can be installed in a part of the pipe easily seen by the homeowner. For easy identification of electrical problems, separate electrical fuses should be used for the water pump and heat pump.



ATMOSPHERIC OR OPEN-FLUID SYSTEM



PRESSURIZED OR CLOSED-FLUID SYSTEM

FIGURE 10-3: Installation Considerations for Water-Source Heat Pumps

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Special Requirements for Installation of Ground-Coupled Heat Pumps

Installation of ground-coupled heat pumps is similar to air-source heat pumps with regard to indoor unit location, power supply, thermostats, and refrigerant piping. The most difficult aspect of ground-coupled heat pump installation is ground preparation for placement of the heat exchanger system — be it vertical (in a cased or uncased hole), or horizontal (laid in a looping or serpentine pattern beneath the ground).

One problem associated with vertical heat exchangers is earth cave-ins when the heat-exchanger piping system is inserted, particularly in deeper holes (250 to 300 feet). Casings of plastic piping about five inches in diameter may be required to stabilize the hole for heat exchanger pipe insertion. When a heat pump system requires a deeper well than is practical to drill, two or more wells may be connected in series spaced at least 10 feet apart. In general, the hole casing needs no gravel packing. The bore around the casing and just below the water surface lines to the hole can be cemented closed to prevent surface water contamination of aquifers. Local regulations should be consulted about this requirement. Pipes should be pressure tested for leaks before the heat exchanger is sealed and the hole closed.

Conventional backhoes can be used for trenching horizontal heat exchanger systems; however, special equipment has been developed to lay the systems in the ground. A trenching machine may be required to cut through hard or rocky soil, while backhoe equipment can help remove large rocks in the path of the trench. And, as rocks can cause problems when laying the pipe, sand may be needed to form a bed for the piping. Multiple pipes may be used in a single trench to reduce the need for long trenches, but care must be taken to allow two to three feet of separation to ensure proper heat transfer to the ground. When pipes are laid individually in trenches, trench separation of four to five feet assures adequate heat transfer.

Operation

As with other mechanical equipment, the efficiency and cost of operating a heat pump will be affected by the operator's lifestyle and attendance to maintenance routines. Heat pump owners should look to their owners' manual for special instructions on how to use their systems wisely and efficiently.

THERMOSTAT

Heat pump owners should review their owners' manual for information about thermostat use. Night setback, an energy conservation practice typically recommended for fossil-fuel furnaces, is not recommended for heat pumps with two-stage thermostats. Night setback is, however, applicable with room thermostats that have an outdoor thermost at controlling the supplementary heating unit. In any case, homeowners should be advised not to jiggle the thermostat or to alter the settings, because unnecessary equipment cycling and use of supplemental heat degrades seasonal efficiency.

DEFROST CYCLE

During the defrost cycle, the outdoor section of a heat pump may smoke or steam due to the melting of frost and ice on the outdoor heat exchanger. Condensate dripping from the heat exchanger can make it appear as if the outdoor unit is leaking. These phenomena are part of the normal operation of a heat pump and should not cause concern.

ELECTRIC POWER

If electric power fails, the heat pump compressor will shut down and the entire system will cool. As a result, the refrigerant may migrate to the outdoor heat exchanger, condense, and blend with the crankcase oil, some of which always circulates within the pipes of the heat pump. Before the heat pump is reactivated when power is restored, supplemental heat should be used for a period roughly equal to the length of time the power was off — up to a maximum of about eight hours. This recovery period allows the oil to warm the liquid refrigerant. It also helps to prevent the oil from frothing, which can damage the compressor.

AIR REGISTERS

Users of heat pumps with a forced-air distribution system should not close registers or vents or otherwise block the air flow. Air-to-air heat pumps are designed and sized to meet the heating and cooling needs of an entire house; closing registers restricts air flow and can reduce mechanical performance. Similarly, registers and vents should never be blocked by furniture, carpets, curtains, or even sleeping pets. Substantial temperature stratification between the upstairs and downstairs can be minimized by periodic operation of the air blower fan.

CONDENSATE DRAINING

The outdoor unit should be checked occasionally for shifting, as this can constrict the proper draining of the heat pump condensate. Similarly, indoor units should also be checked for shifting and blockage.

Maintenance

Air-source heat pumps are easy to maintain, requiring only simple upkeep operations, such as the cleaning of coils and the cleaning and changing of filters. Water-source heat pumps, wells, pumps, and pipe systems require additional maintenance; the owners' manual should be consulted to identify necessary tasks. Regardless of the type of equipment, however, a competent service contractor should be employed to perform the more difficult tasks, including pressure testing, recharging refrigerant, and repairing electrical or mechanical components. Owners should also be encouraged to consider extended service and repair contracts. The basic maintenance tasks an owner should undertake are described below.

AIR-SOURCE HEAT PUMPS

Filters should be inspected monthly to prevent clogging from dirt buildup. Reusable filters should be washed according to manufacturers' instructions, and replaceable filters should be changed.

Some fan motors need lubrication as indicated in manufacturers' instructions; newer units may require infrequent or no lubrication. Similarly, belts on blower units may need adjustment. Loose belts are not only ineffective, they waste energy. Drive belts that are cracked, broken, or excessively worn should be replaced.

Indoor unit coils should be cleaned periodically with a vacuum cleaner or brush. Outdoor coils can be sprayed and cleaned with a garden hose. The outdoor coil should be free of grass, loose leaves, shrubbery, and any obstruction — including snow, which should be removed from the outside unit with a brush or broom. Snow accumulation beneath the heat pump is not a problem as long as air flow is not blocked.

WATER-SOURCE HEAT PUMPS

All water-source heat pump equipment — whether connected to a surface water source, well, or coupled with the earth — is subject to problems of water freezing, mineral and bacteria formation within the systems, and corrosion. Professional assistance is recommended unless the homeowner is experienced in dealing with these problems.

Freezing. Equipment must be protected from freezing. Pipes leading to wells must be installed below the frost line or otherwise protected from frost. In addition, the compressor unit and the refrigerant-to-water heat exchanger must be enclosed in a conditioned space where the temperature is 45 to 50 °F. The air side of the heat pump should also be in a conditioned space so that excess energy is not lost. For this reason, the indoor units of most water-source heat pumps are designed for installation within a conditioned space.

Common techniques to prevent freeze-up of water-to-refrigerant heat exchangers include increasing the water flow rate in the heat exchanger to the point that only a small temperature drop occurs — 2 to 4 °F — and installing a suction pressure switch to shut off the unit above a predetermined minimum suction pressure. This prevents the heat exchanger temperature from dropping below freezing. Most heat pumps with freeze protection need wells with high water flow rates. Ground-coupled heat exchangers use antifreeze and pipe burial below the frost level for freeze protection.

Encrustation. Dissolved minerals in the water can cause encrustation — buildup of a hard, thick, mineral substance — and fouling of heat exchangers. Owners should have their equipment serviced annually to alleviate fouling. Fouling can be detected by monitoring and recording the system suction pressure in comparison to that measured during operation when the heat pump was new. A decrease of 10 psi in suction pressure at constant water temperature and ambient temperature usually indicates that the exchanger has become fouled and needs to be cleaned.

Scaling. Scaling, a buildup of thin layers of mineral material, is caused by temperature or pressure changes in areas with hard water containing limestone (calcium carbonate, $CaCO_3$). Scale buildup reduces the heat exchange capacity of wells and well piping. Symptoms of scaling are loss of system capacity, increased compressor head pressure, increased water flow (compensating for increased compressor head pressure), and reduction in the discharge temperature of summer cooling water. Periodic chemical cleaning can help remedy scaling problems.

Bacteria Formation. Bacteria growth normally does not occur in a flow-through, groundwater system that extracts and discharges water from the earth. When it does occur in open- or closed-loop systems it can be controlled with chlorine. Electrochemical and acid cleaning may be the best remedy if the problem becomes so severe that bacteria are found to clog filters and plumbing. This type of cleaning should be done by professionals.

Corrosion. Corrosion is the result of a chemical reaction between air and a metal, or between two dissimilar metals. Preventing corrosion requires keeping water in the system at all times. Check valves and an expansion tank should be installed to ensure that wet metal parts are not regularly exposed to air. If installation involves two dissimilar metals coming into contact, the metals should be electrically isolated from one another by a synthetic material coupling device or by a sacrificial anode. Without this protection, the system will eventually corrode and develop leaks.

Troubleshooting

Table 10-1 lists common symptoms and problems in air- and water-source heat pumps. In most instances, a heat pump contractor should determine the best solution to the problems of a particular system.

TABLE 10-1: Common Symptoms and Problems for Heat Pump Systems

AIR-SOURCE HEAT PUMP	
SYMPTOM	**POSSIBLE PROBLEM**
1. Frequent cycling, loss of temperature and humidity control.	1. Oversized equipment, thermostat needs adjustment or replacement.
2. Low indoor air flow, high compressor suction and discharge pressure, high pumping rates and compressor failure.	2. Inadequately sized ductwork, dirty air filters, registers closed or blocked, fan belts slipping.
3. Frequent fuse failure (fire and safety hazard).	3. Undersized power wiring (especially for supplemental heat), improper refrigerant charge.
4. Liquid slugging, compressor mechanical failure.	4. Oversized liquid refrigerant tubing, improper refrigerant charge.
5. Heat pump operating but indoor temperature less than thermostat setting.	5. Thermostat setting or switches may not be at correct setting (i.e., fan is on but heat is not). Outdoor unit clogged by leaves, snow, ice, or other obstruction. Improper refrigerant charge. Ducts blocked. Filter clogged with dirt. Fuse blown, relay failure on supplementary heater.
6. Supplemental heat does not turn off when balance point temperature is reached.	6. Outdoor or indoor thermostat may not be set at correct temperature, thermostats may need repair.
7. Unit does not turn on.	7. Switches on both heat pump unit and thermostat may not be in the “on” position, fuse or circuit breaker may be open.
8. Excessive vibration in compressor unit.	8. Unit may not be properly anchored to concrete slab or stilts, stilt mounting may not be properly anchored in ground, piping may be installed incorrectly.
9. Compressor does not run, or shuts off and will not restart.	9. Compressor, transformer burned out, electrical failure in power supply or circuit, compressor stuck.
10. Compressor runs, but cooling is insufficient.	10. Blocked ducts or registers, improper refrigerant charge.
11. Compressor cycles on and off.	11. Improper refrigerant charge, refrigerant system dirty, faulty timer or defrost controls, fan motor intermittent.
12. Compressor runs, but heating is insufficient.	12. Electric resistance heat malfunctioning, fan failure.
13. Compressor runs, but cycles on internal overload.	13. Refrigerant charge needs to be checked, defective fan motor, restrictions in refrigerant or discharge lines.
WATER-SOURCE HEAT PUMP	
1. Loss in system capacity, increased compressor head pressure, increased water flow to compensate for increased head pressure, reduction in outside water discharge temperature.	1. Scaling or encrustation, obstruction to water flow.
2. Loss of performance due to temperature drop of intake water.	2. Lack of separation between cold water discharge and warm water supply-source wells, excessively long pipe runs, pipes not below frost level, clogged well or filter, pump wear.
3. Water backup or loss of flow in system (system with storage tank).	3. Lack of overflow mechanism in storage tank.
4. Water backup at ground level.	4. Undersizing or clogging of disposal well.

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Choosing a Dealer

It is best to work with experienced dealers and installers. The extent of a dealer's experience can be determined by how long he has been in business, how many systems he has sold and installed, and how many customers he services. Doing business with local dealers can facilitate periodic servicing of equipment. Often, other satisfied customers in the neighborhood can recommend a good dealer; customer references may also be requested from dealers or installers.

Manufacturers often authorize dealers and installers to distribute their equipment. Although it is not necessary to use an authorized dealer or installer, certification or official backing can be beneficial with regard to warranties and after-sales services. Reputable dealers and installers should provide service contracts and warranties and be able to obtain parts and provide regular and emergency service without delay.

Warranties and Service Agreements

Most heat pumps are guaranteed by the manufacturer, as well as by the dealer or installer. Parts and servicing are usually covered for one year. Extended warranties are available for five years or more at a relatively low cost. Warranties may not, however, include the cost of servicing. Homeowners should investigate different warranties to determine the various costs, time periods, and terms and conditions governing repair, parts, and labor. Any disagreements over warranties initially should be reconciled with the heat pump dealer. Further assistance with specific terms and conditions of the warranties may be sought directly from the heat pump manufacturer.

Service contracts with qualified technicians are strongly recommended to ensure that a heat pump will receive the best possible care to prolong its life. To maintain the validity of the service contract, homeowners should follow the heat pump owners' manual, keep filters clean, keep debris out of the outside heat exchanger, and follow through on other basic maintenance tasks.

Many dealers and installers offer service plans to cover routine and emergency service. The service agreement should clearly indicate:

- Corrective maintenance, labor, parts, materials, and service to keep equipment in good operating condition, and the specific equipment parts included and excluded;
- The specified period of the agreement;
- All covered costs, including travel, routine service, and emergency service;
- Limitations, if any, on labor or materials for a specified defect;
- Terms and conditions for cancellation; and,
- How to obtain service — including emergency service after normal business hours and on weekends.

11

Heat Pump Water Heaters

In This Section: Heat pump water heaters; desuperheaters; integrated water heating; performance ratings; installation and maintenance.

Water heating is likely to represent a more significant portion of home electrical demand in the future, if the current trend towards better-insulated houses continues. Heat pump water heaters and desuperheaters can provide water heating with minimum use of electrical energy. At present, heat pump water heaters for domestic water heating, spa, and swimming pool heating are offered by more than 15 manufacturers.

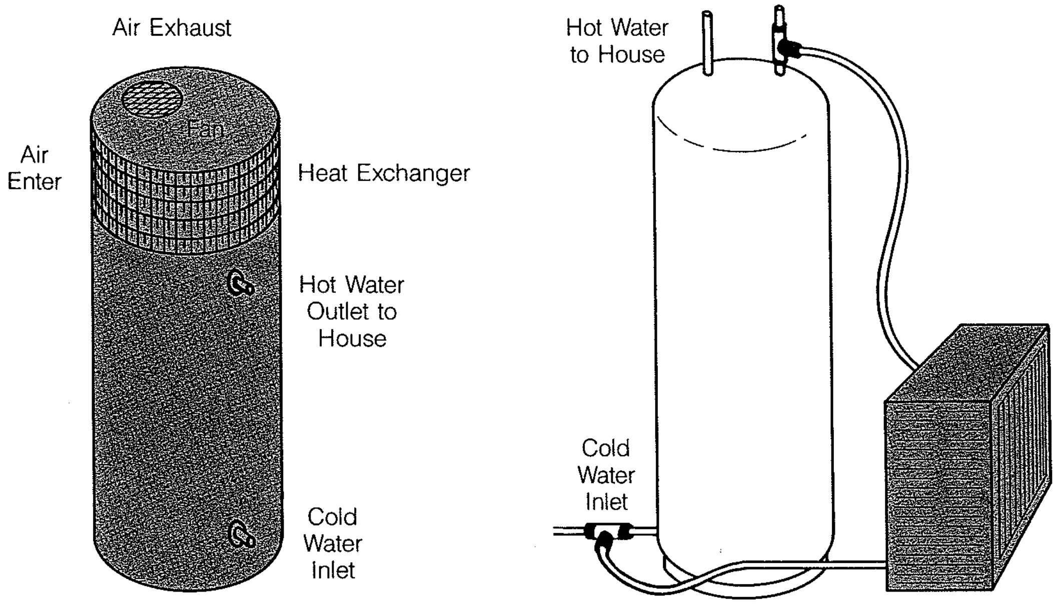
Heat Pump Water Heaters

Heat pump water heaters are a class of small, heat-only, air-to-water heat pumps designed for residential use. There are two types of units — integral and remote — and both basically consist of a compressor and heat exchanger unit and a water tank. When the heat pump unit is located on top of the water tank (adding about one foot to its height), the system is called an integral unit, as shown in Figure 11-1a. The first integral units used a condenser immersed in the water tank itself; most integral units now pump water out of the tank through the condenser. One new integral unit uses a cylindrical, bonded-metal condenser which forms the outer shell of the water tank.

The remote heat pump water heater is an assembly consisting of an air-source evaporator and a water-cooled condenser, a compressor, fan, and pump. This unit is connected to the water tank by flexible hoses or pipes, as shown in Figure 11-1b. In some cases, water is drawn from the cold water supply directly. Remote units are especially suitable for retrofit installation, while the integral unit is intended to replace an existing water heater.

Heat pump water heaters operate at a COP of two or greater (i.e., they are at least twice as efficient as conventional electric resistance water heaters). Because they cool the surrounding air, they should be placed in partially conditioned or unconditioned spaces — utility or furnace rooms, crawl spaces, laundry rooms, basements, and garages in warmer climates — or in rooms that have year-round dehumidification or cooling requirements. Heat pump water heaters should not be installed where the temperature can fall below 40 °F since high compressor discharge pressures and lack of a defrost mechanism would impair their proper operation. An ambient temperature range of 45 to 95 °F is recommended.

11



a) INTEGRAL

b) REMOTE

FIGURE 11-1: Heat Pump Water Heaters

Desuperheaters

Desuperheaters, also called heat recovery water heaters, are devices for recovering superheat from the compressor discharge gas of a heat pump (or central air conditioner) for use in heating or preheating water. The desuperheater consists of a pump, heat exchanger, and controls, and is often housed in a single cabinet, as shown in Figure 11-2. Some split-system model heat pumps combine the desuperheater and the compressor in a single module.

During desuperheater operation, hot refrigerant vapor (taken from the compressor discharge) exchanges heat in the desuperheater unit with cool water pumped from the water heater. The water is heated and returned to the water heater while the saturated, high pressure refrigerant is returned to the condenser of the heat pump or air conditioner.

A desuperheater produces about 15 gallons of heated water per hour, per ton of air conditioning. A desuperheater unit can cause a small improvement in heat pump cooling performance but, on the other hand, can reduce the heating capacity. During the hottest summer months, almost all of the water heating requirements of a home may be provided by desuperheater operation. In cooler months, when less or no air conditioning is needed, less discharge heat is available for water heating. And, because the desuperheater operates only when the heat pump or air conditioner is operating, backup water heating may be needed. Therefore, desuperheater units are most attractive for use in warmer climates where air cooling is required throughout much of the year.

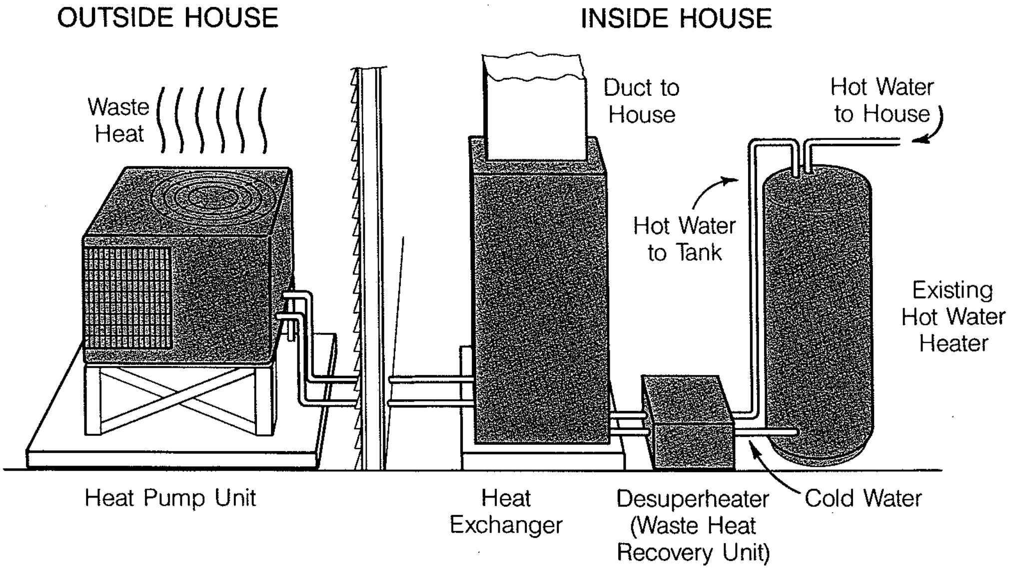


FIGURE 11-2: Desuperheater

Integrated Water Heating

Integrating water heating with space conditioning using a heat pump or air conditioner is a new concept that is likely to become widespread. Recovering condenser reject heat or unused heating capacity to heat domestic water and, at the same time, utilizing the water reservoir storage of heat for backup heating or defrosting is a logical development. While the desuperheater water heater operates only when the heat pump or air conditioner is running, an integrated system with two condensers — one dedicated to water heating, the other to space heating — would allow the heat pump to be run to produce hot water even if no comfort conditioning were required. One manufacturer in the United States has developed and is now testing such a two-condenser heat pump system.

Performance Ratings

The performance of a heat pump water heater is affected by the temperature of the surrounding air, the temperature of water entering the heater, and the desired exit water temperature. The Department of Energy estimates that heat pump water heaters reduce electrical energy consumption for domestic water heating by 40 to 60%. Table 11-1 gives average energy-performance data for a residential size heat pump water heater.

Determining the annual energy consumption of a residential heat pump water heater requires calculating, first, the annual energy consumption of a conventional electric water heater from:

$$E = 0.89\ Q_w(t_2 - t_1)/\eta \qquad (11.1)$$

where:

E = energy consumption for water heating, kWh
Q_w = hot water consumption, gal
t_2 = hot water temperature, °F
t_1 = city water temperature, °F
η = efficiency, dimensionless .

The efficiency term in this equation corrects for standby or jacket losses. For conventional electric water heaters, efficiencies are usually on the order of 80% (11). For gas-fired water heaters, efficiencies are approximately 50 to 70% (11, 12).

The annual energy consumption of a heat pump water heater can be deduced from Equation 11.1 by substituting the COP of the heat pump water heater for the efficiency term. Typical values of the COP are also given in Table 11-1.

Desuperheater performance depends on the inlet water temperature, the desired exit water temperature, the unit's design, the size of the space cooling system equipment, and the overall operational characteristics of both the home's cooling system and the water heater. Because of the nature of these variables, it is not possible to give a specific equation for estimating the energy required for heating water with a desuperheater. Manufacturers report, however, that use of a desuperheater can reduce annual electric water heating bills by 30 to 80%. The higher savings occur in areas of the country with a long cooling season, the lower savings in areas with a short cooling season.

TABLE 11-1: Typical Coefficient of Performance Data for a Residential Heat Pump Water Heater

Surrounding Air Conditions: Dry Bulb Temperature (°F)/Wet Bulb Temperature (°F)	COEFFICIENT OF PERFORMANCE*			
90/75	3.28	3.10	3.19	3.00
80/67	2.92	2.75	2.84	2.60
70/66	2.56	2.40	2.48	2.32
60/53	2.20	2.04	2.12	1.97
50/45	1.83	1.68	1.77	1.62
BUILDING WATER SUPPLY TEMPERATURE (°F)	55	55	65	65
DOMESTIC HOT WATER TEMPERATURE (°F)	125	135	125	135

*COP = Heat delivered to water during year (including tank losses) divided by electrical energy delivered to heat pump water heater.

Installation and Maintenance

Two conditions must be assured when installing a heat pump water heater: adequate ventilation around the unit, and accessibility for routine removal or drainage of condensate. By following manufacturers' installation recommendations, an experienced plumber should be able to install a heat pump water heater as easily as a regular water heater. Representative replacement costs for heat pump water heaters, desuperheaters, and alternative equipment are given in Table 11-2.

As with conventional water heaters, maintenance required for heat pump water heaters is minimal and should be done in accordance with manufacturers' specifications. Most importantly, once or twice a year homeowners should remove the sediment that settles to the bottom of the water heater from the source water. This sediment can be removed by opening the drain valve and releasing one to two gallons of water into a pail. (A hose can be attached to most water heater drain valves, thus allowing the water to drain directly into a floor drain or sink.)

TABLE 11-2: Replacement Costs of Water Heating Equipment (1985 Dollars)

Source: (22)

REPLACEMENT COSTS					
Electric Water Heater (Glass-Lined, Double Element)	30 Gallons $275	40 Gallons $315	52 Gallons $345	80 Gallons $550	120 Gallons $880
Gas-Fired Water Heater (Glass-Lined, Vent Not Included)	30 Gallons $295	40 Gallons $340	50 Gallons $390	75 Gallons $645	
Oil-Fired Water Heater (Glass-Lined, Vent Not Included)	30 Gallons $865	50 Gallons $1125		70 Gallons $1275	85 Gallons $1700
Heat Pump Water Heater (Price Depends on Size and Quality of Product)	$600 to $1300				
Desuperheater Water Heater (Price Depends on Size of Unit it is Applied to and Quality of Product)	$400 to $1000				

NOTES: These are average prices for 1985 in the United States and they can vary by local supplier and installer. These prices include material, installation, overhead, and profit.

APPENDIX

Sources of Information on Energy Use Simulation Models

1. EPRI Methodology for Preferred Systems (EMPS)

EMPS 2.1 is available from:

EPRI Software Center
1930 Hi Line Center
Dallas, TX 75207
(214) 655-8883

Information about its use can be obtained from:

EPRI
Energy Management
and Utilization Division
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CA 94303

2. U.S. Department of Energy DOE-2

DOE-2 is available from:

National Technical
Information Service (NTIS)
5283 Port Royal Road
Springfield, VA 22161
(703) 487-4763

National Energy Software Center
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

3. Building Loads and System Thermodynamics Program (BLAST)

Information about BLAST can be obtained from:

University of Illinois
Department of Mechanical
and Industrial Engineering
1206 West Green Street
Urbana, IL 61801
(207) 333-2072

U.S. Army Construction
Engineering Research
Laboratory
P.O. Box 4005
Champaign, IL 61820
(217) 352-6511

4. Energy Simulation Program II (ESP-II)

Information about ESP-II can be obtained from:

Automated Procedures for
Engineering Consultants (APEC)
Miami Valley Tower, Suite 2100
40 West 4th Street
Dayton, OH 45402
(513) 228-2602

5. EPRI Simplified Program for Residential Energy (ESPRĒ)

Information about ESPRĒ can be obtained from:

EPRI
Energy Analysis
and Environment Division
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CA 94303

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