

A Primer on Heating Systems

You'll save money and stay more comfortable by matching the heating system to your climate, your house and your needs

by Alex Wilson

I learned to appreciate good heating systems at an early age—by growing up in a 1710 Pennsylvania log home that lacked one. I remember huddling around our oil-fired space heater on winter nights to soak up as much warmth as possible before dashing upstairs to the small corner room my brother and I shared. I even have a distinct—though no doubt exaggerated—memory of a particularly frigid winter night when firewood brought in at bedtime still had snow on it the next morning.

I still live in an old home, but I've worked hard to insulate and Weatherize it against cold Vermont winters. I also spent a lot of time choosing the right heating system to make certain it's a lot more comfortable than my boyhood home.

This article should help you to establish priorities and figure out what questions to ask your heating-system designer or contractor when choosing a heating system. I've tried to provide a broad overview, addressing basics of selection and fundamental decisions about heat-distribution options. Along with providing comfort, other goals that may come up when selecting a heating system include efficiency and size (sidebar, p. 55).

When it comes to heating-system design, there are two primary areas of decision-making: how to produce heat and how to move the heat where it's needed. The latter decision is usually more important and should be made first.

Forced air heats the fastest—Forced air is the most common type of heating system in North America. It accounts for 62% of all home heating, according to the U. S. Department of Energy. A gas-fired or oil-fired furnace (photo facing page), an electric furnace or a heat pump is used to generate hot air, which is then circulated throughout the house via ducts and a fan (air handler). Warm air typically is delivered through

Common heating terminology

Btu: British thermal unit One Btu is the amount of heat it takes to raise the temperature of 1 lb. of water 1°F at a specified temperature. The energy content of various fuels differs. Heating oil contains 139,000 Btu/gal., and propane has an energy content of about 91,300 Btu/gal. Kerosene has an energy content of about 135,000 Btu/gal. Natural gas is metered in units of hundred cubic feet (ccf) or therms (1 therm equals 100,000 Btus). A cubic foot of natural gas contains 1,027 Btus.

AFUE: Annual fuel-utilization efficiency. AFUE is a measurement of the efficiency of furnaces and boilers, averaged over a heating season.

SEER: Seasonal energy-efficiency rating. This is the ratio of the seasonal cooling performance of heat pumps and air conditioners in Btus divided by the energy consumption in watt-hours for an average U. S. climate.

EER: Energy-efficiency rating. This is similar to the SEER used for air-source heat pumps and air conditioners, except that cooling performance is not averaged over a cooling season.

HSPF: Heating-season performance factor. This number is a ratio of the estimated seasonal heating output in Btus divided by the seasonal power consumption in watts. It's used for comparing air-source heat-pump performance.

COP: Coefficient of performance, which is the ratio of the amount of energy delivered to the amount of energy consumed.

floor registers. Air returns to the furnace through centralized return registers in the house (drawing facing page).

Advantages of forced-air heating systems include rapid delivery of heat throughout the house and the potential for integration with other climate-control systems, such as ventilation, humidification, dehumidification, filtration and air conditioning. On the downside are noise from the air handler and ducts, leakage through poorly sealed ducts, increased air leakage in the house resulting from pressure imbalances and the potential for drafts generated by air circulation. Also, it is difficult to set up zones that allow you to heat parts of the house separately.

It's important to plan carefully for ducts during the design of the house. Registers should be situated and the blower sized so that homeowners will not notice airflow. In poorly insulated houses, this may be difficult because the system often has to be designed to throw warm air across a room to offset heat loss at windows.

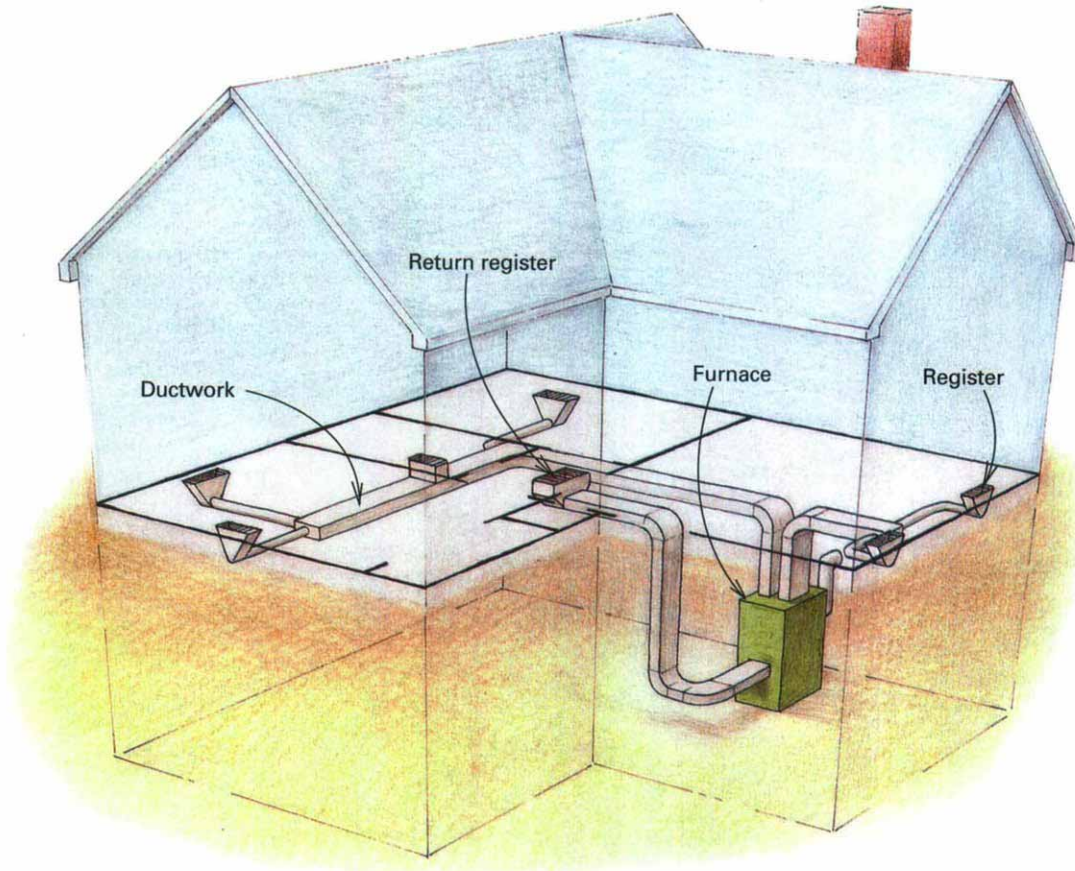
Baseboard radiators take up a bit more room in the house—In baseboard hydronic heating, a boiler heats water and a pump circulates the water through baseboard radiators around the house (drawing p. 52). Heat is delivered through both radiation and convection.

The most common baseboard radiators really don't provide much heat through radiation. Most of their heat is delivered by convection. Heat delivery can be regulated to some extent by using controllable flaps or louvers. Some European-style low-profile radiators, such as those produced by Runtal (800-526-2621), operate at lower temperatures and deliver mostly radiant heat (photo p. 52).

Hydronic heating offers quiet operation, minimal drafts, less heat loss from the distribution system compared with forced-air heating (if a

A system of ducts

Heat is generated in the furnace, which can be oil fired, gas fired, electric or heat pump. The fan, or air handler, creates pressure that forces the warmed air through the ductwork and out registers located throughout the house.



Forced air

Advantages

- Rapid delivery of heat.
- Ducts also available for use with cooling, ventilation, humidification, air filtration.

Disadvantages

- Ducts can develop leaks, reducing furnace effectiveness.
- Fan and ducts make noise.
- Pressure imbalances can cause house to leak air.
- Difficult to zone heating within house.

leak is present, you'll know it), no effect on air leakage from pressure imbalances in the house and ease of zoning different parts of the house. Negatives include high installation cost, interference with furniture placement if using conventional baseboard radiators and the inability to have the distribution system serve other climate-control functions.

The most subtle heat is from a radiant floor—Radiant-floor heating turns your floor into a low-temperature radiator. Typically, specialized plastic or rubber tubing is embedded in a concrete-floor slab, and water heated by a boiler is circulated through it (*FHB* #105, pp. 58-63) (drawing p. 53). Electric heating elements can also be used in radiant floors (*FHB* #75, pp. 68-72), but they are far less common and generally much more expensive to operate.

Radiant-floor systems are gaining in popularity because they provide a high level of comfort. Because of their comfortable average temperature and the fact that there is little stratification, homeowners are typically comfortable at air



Forced-air systems offer varied climate control. Hot air delivered from this oil-fired furnace isn't the only use for a forced-air system. It's also used for air conditioning, ventilation, humidification and air filtration.

temperatures several degrees cooler than otherwise. This offers some potential for energy savings. On the downside, radiant-floor heating systems are expensive to put in, and they rely on skilled designers and installers who may not be available to work locally. Additionally, most radiant-floor systems respond quite slowly when the thermostat is raised because the whole mass of the concrete slab has to be warmed.

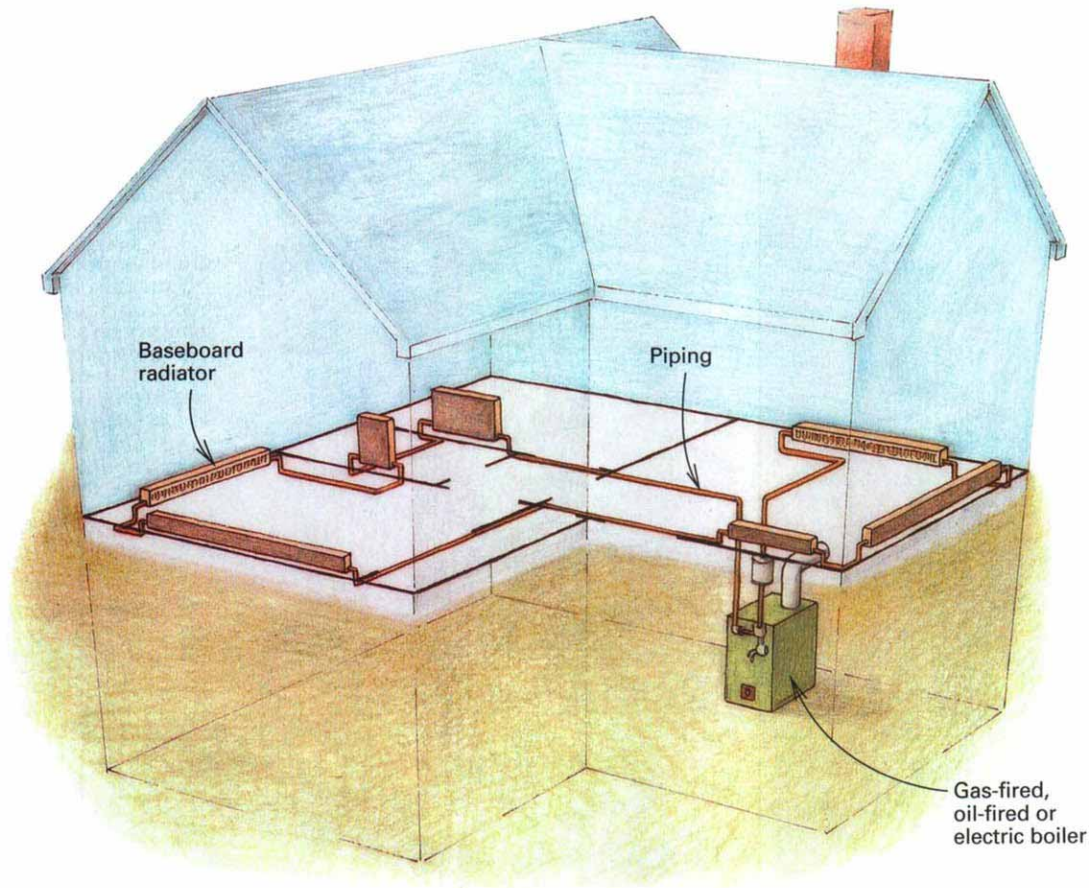
Direct heat originates at the point of use—

Direct space heating is an alternative to the other distribution systems, which produce heat in one place then distribute that heat to where it's needed. Space heaters generate heat where it is used (drawing p. 54). Common examples are gas wall heaters, freestanding gas heaters, woodstoves, kerosene heaters, and wood-fired or gas-fired fireplaces.

Electric-baseboard heating is really a type of space heating in that the heat is generated at its point of use; but because baseboard-heating elements typically extend throughout the house, it is usually considered a whole-house heating

A system of pipes

In a house heated by hot-water radiators, the boiler heats the water to between 135°F and 180°F, well below the boiling point of 212°F required for steam radiators. Piping that is run through the house delivers the hot water to the radiators, which heat through radiation and convection.



Baseboard radiators

Advantages

- Quiet operation.
- Less heat loss through distribution system.
- Easily zoned.

Disadvantages

- Relatively high installation costs.
- Radiators may interfere with furniture placement.
- Can't be used for other climate-control functions.

strategy. Electric baseboard heating also has a low initial cost and allows easy zoning. Also, there are no combustion byproducts, so there is no need for venting. Like hydronic-baseboard radiators, electric-baseboard heating elements work primarily by convection: Metal fins transfer electrically generated heat to air that circulates through the room.

A furnace or boiler is at the heart of most heating systems

The core of most heating systems is the centralized heating plant that generates the warm air or hot water that is circulated through the distribution system. With forced-air systems, a furnace or heat pump provides the heat. With hydronic heating and with most hydronic-floor systems, a boiler serves as the heat source.

Selecting the right furnace, boiler or heat pump from the wide range of products on the market can be difficult and confusing. The following guide to generic product types should help you to understand what's available. A discussion of space heaters, which are appropri-



Low-profile radiators need little space.

Installed along the exterior walls, baseboard radiators use radiation and convection to heat a room. Air flows upward through the hot-water heated radiator, warms and rises to heat the room.

ate in some heating situations, is beyond the scope of this article.

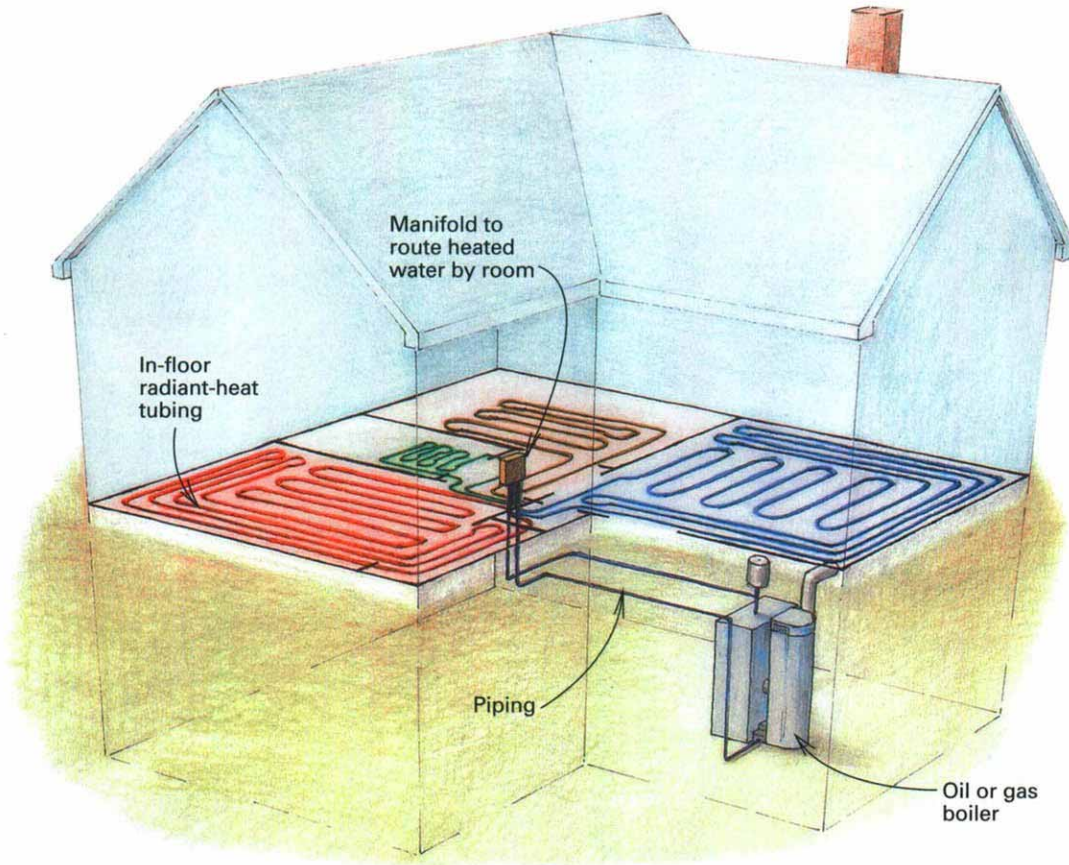
Gas furnaces are among the most efficient

Induced-draft gas furnaces are what you'll find in most mid-efficiency models sold today. They use a fan to force flue gases either up a chimney or out through a side-venting pipe. Improved heat exchangers extract more heat out of combustion gases; as a result, the flue gases are less buoyant, and a fan is needed to exhaust them (hence the term "induced" draft). Because the flue gases are relatively cool, plastic pipe is sometimes used for side venting. AFUEs (see sidebar on common heating terminology, p. 50) are typically in the range of 78% to 85%.

Condensing-gas furnaces are the highest-efficiency gas furnaces and have such efficient heat exchangers that flue gases cool down enough for water vapor—one of the primary combustion products—to condense into liquid. When the water vapor condenses, it releases its latent heat, which boosts energy performance. AFUE efficiencies for condensing furnaces typi-

A system of tubing

A radiant-floor heating system is powered by a boiler, which raises the temperature of water to between 80°F and 140°F before sending it through the distribution system. The in-floor piping slowly raises the temperature of the surrounding material (concrete, tile, etc.) and helps to maintain a relatively even temperature.



Radiant-floor heating

Advantages

- High comfort level at lower temperatures, which saves money.
- Easy to zone house.

Disadvantages

- Does not respond quickly to thermostat changes.
- Relatively expensive to install.
- Requires designers and specialized installers, who may not be available in all areas.

cally range from 90% to 97%. Flue gases are usually vented out through plastic piping. Condensate is piped to a floor drain.

Sealed-combustion gas furnaces force outside air into the combustion chamber and force exhaust gases outside; there is no need for or interaction with indoor air. Sealed-combustion equipment is considered the safest, with low risk of backdrafting. Sealed-combustion products are available in both condensing and noncondensing furnaces.

Like gas furnaces, gas boilers are available with venting configurations that achieve various efficiencies, but most are mid-efficiency induced-draft models. Practical efficiencies are somewhat lower with boilers than with furnaces because the temperature of the return water from the hydronic-heating loop is generally higher than the condensing point of the water vapor in the flue gases. That makes it difficult to squeeze out that extra efficiency represented by the latent heat of water vapor in the flue gases. Few gas boilers have efficiencies over 90%; most range from 80% to 85%.



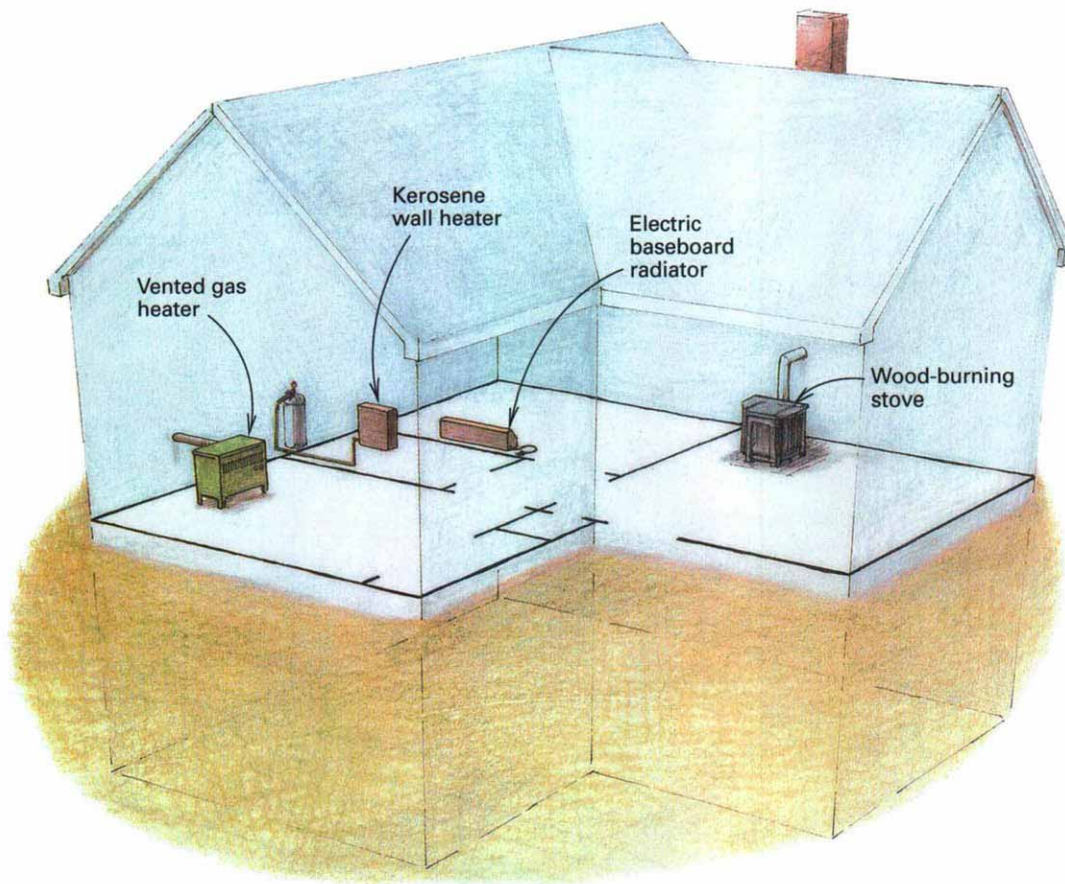
Oil-fired furnaces have become more efficient. This oil boiler has an efficiency rating of 84% or better. Most oil furnaces and boilers on the market today have annual fuel-use efficiencies in the range of 78% to 82%.

Oil-fired furnaces and boilers are different animals—Oil combustion (photo left) is significantly different from gas combustion. Because the fuel is a liquid, it must be separated mechanically into tiny droplets and mixed with air for complete combustion. This is done with an injector-head burner that sprays air and atomized oil into the combustion chamber. Most oil burners today have flame-retention heads that increase turbulence in the combustion chamber to improve combustion. As with gas-fired equipment, oil furnaces and boilers built since 1992 have been required to have AFUE efficiencies of at least 78%. Most oil furnaces and boilers on the market today have AFUE efficiencies in the range of 78% to 82%.

Condensing-oil heating equipment is less common than condensing-gas equipment because of fundamental differences in the fuels. Oil combustion generates only half as much water vapor as natural-gas combustion, so there is less latent heat to be recovered from the condensation of the water vapor. Also, the condensate from oil combustion is much more corrosive than con-

Heat just where you need it

From direct-vented gas or kerosene heat to wood-burning stoves and fireplaces to plug-in electric baseboard radiators and heaters, space heating can be used to heat a whole house, a room or part of a room.



Direct-source heat

Advantages

- Generates heat at point of use.
- Inexpensive to buy and install (except for those that require venting and flues).
- Easy room-by-room control of heating.
- In superinsulated house, may be cheaper than furnace or boiler.

Disadvantages

- Heats only small area.
- Doesn't perform other climate-control functions.
- Takes up space in rooms.

densate from gas combustion. For these reasons, many heating experts recommend against condensing-oil furnaces and boilers, suggesting instead mid-efficiency models with AFUEs in the low 80s to the mid-80s. Few oil-fired furnaces and boilers are sealed combustion. In northern climates, mixing cold outside air with oil can reduce furnace performance or even cause start-up problems.

Electric furnaces are more expensive in colder climates—Electric furnaces are common in the southern United States, where heating loads are small and whole-house ducting is used for air conditioning. Low Btu (sidebar p. 50) output can be achieved without risk of spilling combustion products, and the heat can be readily distributed through air-conditioning ducts.

In all but the warmest climates, however, electric furnaces can be expensive to operate. Although the conversion of electricity into heat in the furnace is 100% efficient and a chimney or exhaust vent is not needed, electricity is usually

Fuel choices depend on where you live

Fuels are sold in cubic feet, gallons, cords and kilowatt-hours, and even when fuel units are the same, the energy contents differ. Some fuels burn more efficiently than others. Also, fuel prices differ from one region to the next.

When considering which fuel to use, it makes sense to compare them based on dollars per million Btus of delivered heat. First, you need to know how many Btus per unit of fuel there are and the efficiency at which you're burning that fuel. These values should be available from your heating-fuel supplier.

To compare the costs of various fuels, call the U. S. Department of Energy's Energy Efficiency and Renewable Energy Clearinghouse (800-363-3732) and ask for their brochure on the comparison of heating fuels.—A. W.

much more expensive than gas or oil, and losses in the duct system may reduce the overall heat-delivery efficiency dramatically. Also, unlike baseboard electric-resistance heating, room-by-room zoning is difficult.

If your heating season is short, an electric heat pump may be the best bet—Air-source heat pumps are amazing devices (drawing facing page). They extract heat from one place and deliver it to another. We're used to thinking of heat moving from warmer to cooler objects (for example, from inside your house in the winter to outside where it's colder). Heat pumps do just the opposite. Air-source heat pumps extract heat from the outside air—even if it's as cold as 30°F—and deliver it to your house, which may be at 70°F. The heat is delivered to the house as it is with a furnace—through ducts and registers.

Heat pumps accomplish this feat by circulating a special fluid called a refrigerant through a cycle in which it alternately evaporates and condenses. In the process, the refrigerant absorbs and releases heat. The process is controlled by a

The high cost of oversize systems

One of the biggest problems with heating-system design today is oversizing. According to the United States Department of Energy, it's not uncommon for heating systems to be two or three times larger than is needed for a given structure.

Many heating contractors and designers use simplified rules of thumb to determine how large a

heating system is needed. Some of the older—but still used—rules of thumb were developed when R-11 walls and single-glazed windows were state of the art. As a result, heating systems are often too big. An oversize furnace or boiler operates inefficiently because it cycles on and off frequently and rarely operates long enough to reach optimal

efficiency. In general, a heating system for a house should be sized no more than 25% larger than the calculated heating load.

To size a heating system properly, there is no way to get around the need to calculate the heating load. This means measuring wall and ceiling areas, window areas, door areas, etc.; computing total R-values for these areas; estimating air leakage; and determining both the expected

indoor temperature and the design temperature you believe that you need for comfort for where you live.

Design temperatures, available for about 700 locations in the United States and Canada, are accepted minimum temperatures for use in sizing heating systems. Design temperatures are published in the *ASHRAE Handbook of Fundamentals*, available in libraries.—A. W.

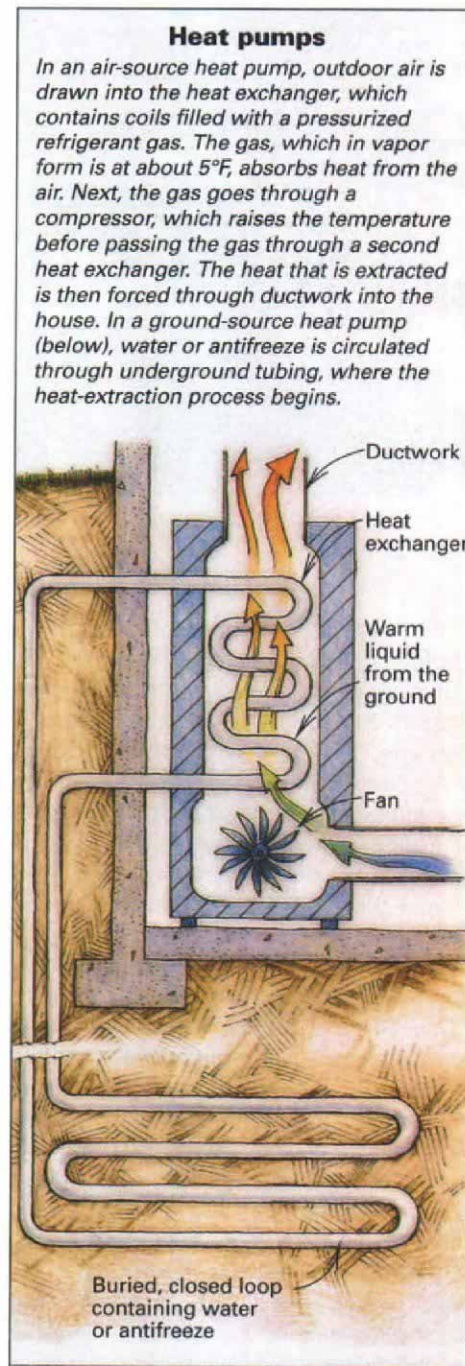
compressor, which changes the pressure of the refrigerant, and by heat exchangers, which allow the refrigerant to absorb or release heat from the surrounding air.

One of the best features of heat pumps is that they can be used for both heating and cooling simply by reversing the evaporation-compression cycle. In the cooling mode, a heat pump takes heat from inside a house and dumps it outside. Air-source heat-pump performance is measured by calculating its heating-system performance factor (HSPF; see sidebar p. 50).

If outdoor-air temperatures in winter commonly drop below 30°F, the seasonal-heating performance of an air-source heat pump will be compromised. Air-source heat pumps are most practical for moderate to warm climates.

Ground-source heat pumps benefit from the earth's constant temperature—Ground-source and water-source heat pumps are different from air-source heat pumps because they extract heat from the ground or from groundwater rather than from outside air (drawing right). Temperatures 8 ft. to 10 ft. underground are fairly uniform year-round. During the heating season, the temperature underground is considerably higher than that of the outdoor air; during the cooling season, underground temperatures are considerably cooler than the outside air.

In a ground-source heat pump, water or an antifreeze fluid is typically circulated through tubing that is buried underground; heat is transferred from the water to the heat pump's refrigerant through a heat exchanger. A water-source heat pump typically circulates groundwater through a heat exchanger to transfer heat to the refrigerant. The result is much better performance than can be obtained when outside air is used as the heat source. With ground-source heat pumps, a coefficient of performance (COP; see sidebar p. 50) of 3 to 4 and summertime energy-efficiency ratings (EERs) as high as 20 can be achieved.



The bottom line isn't always price or efficiency—When selecting heating equipment and components, specify durable products that will provide years of trouble-free operation. With major heating components, look for long warranties that are indicative of quality components and a long expected life. It is not uncommon for furnaces to have warranties of 20 years or more and boilers 30 years. Heat-pump warranties are shorter.

The equipment warranty doesn't tell you the whole story, however. Often more important is the availability of local service. "The warranty doesn't mean much if you don't have someone familiar with the equipment," notes engineer Mark Kelley of Building Science Engineering in Harvard, Massachusetts. Kelley recommends that his clients avoid heating equipment that isn't serviced locally, even if it is the most efficient or carries the longest warranty.

As you make decisions on heating equipment, don't lose sight of the fact that heating is part of an integrated system. The decisions that you make in designing a house and figuring out what construction details and insulation levels to incorporate will affect what type of heating system to use and how large it has to be. Also, don't forget that your overall goal with the heating system is to provide comfort, convenience, reliability and safety. The goal is not the heating system itself.

Before you begin thinking about what type of heating plant to purchase, decide on the heat-distribution system. Deciding how to get heat where it's needed is a more fundamental decision than how that heat will be generated. With a highly energy-efficient house, don't rule out the idea of using a space heater rather than a central heating system. □

Alex Wilson is coauthor of The Consumer Guide to Home Energy Savings (American Council for an Energy Efficient Economy, 1996) and is editor and publisher of Environment Building News in Brattleboro, Vermont.