Selecting a Home Heating System

January 2000

Introduction

Selection of a home heating system for a new or existing home requires an understanding of how various systems operate, their initial cost, and how much they cost to operate. This fact sheet provides background on common residential heating systems, explains how they work and how they are rated for energy performance, and provides a method of estimating operating costs.

Heating systems covered in this fact sheet include warm-air heaters such as gas and electric furnaces, air- and water-source heat pumps, hot-water boiler systems, and to a lesser extent, radiant floor systems. A discussion on unitary systems such as wall furnaces is included, but a procedure for estimating their operating costs is not included due to the many uncertainties of operation.

Heating system sizing

Residential heating systems need to be properly sized so the home will be comfortable during the coldest weather. If the unit is oversized, energy costs may increase and the home may experience high temperature swings during mild weather. Oversizing also increases the cost paid for the equipment, money better spent on purchasing more efficient equipment.

Determining the proper size for the heating system requires estimating heat loss through the roof, walls, windows, basement, and other home components under severe outside conditions. This is the design heat load for the home. The system size is then matched to the design heat load. For many combustion appliances, size of the unit selected is from 10 to 30 percent above design heat load. This oversizing allows the unit to recover quickly from night setback.

The contractor bidding the new heating system should determine the correct size using techniques that evaluate the insulating value and area of each home component. Using "rule-of-thumb" for sizing heating equipment often results in a unit that is grossly over or undersized. If the unit is a replacement, using the same size as the existing unit should be strongly discouraged. The old unit may not have been sized properly and energy-conserving improvements may have been made to the home since its installation, reducing the need for heating.

Selecting the most cost-effective heating system

Selection of the most cost-effective heating system will depend on price and availability of differing fuels as well as cost of the initial heater installation. Higher initial investments are often justified by reduced utility costs over the lifetime of the unit.

Methods for estimating annual operating costs of central units are provided. To determine the most cost-effective system, it will be necessary to obtain bids from several contractors. The additional cost for the more efficient system must be compared to the energy savings. If this is a new home, the cost of the heating system will be part of the mortgage. If the annual total cost of heating energy plus the mortgage payment for one system is less than for another, then the system is cost effective. If you are considering replacing an existing heating appliance, you must decide if the savings from a more efficient system are enough to justify the additional cost. It is important to remember that heating systems are only replaced about every 20 years, so you will have to live with your decision for some time.

Central heating systems

Central heating systems can typically be divided into two broad classes, those that distribute heat by heated air and those that use water as the distribution medium. Electric and gas-fired warm-air furnaces, air- and water-source heat pumps, and hot-water baseboard or radiant slab are all central systems. Electric baseboard and electric radiant heating are also used on occasion.

Central warm-air heating systems

Warm-air heating systems include gas-fueled furnaces, electric furnaces, conventional heat pumps, and ground-coupled heat pumps. They have in common the warm-air delivery system. Ducts provide a passage for heated or cooled air from the heating or cooling unit to and from the conditioned space.

While this fact sheet focuses on selecting heating systems, understanding the importance of proper duct design and installation on the efficiency of the installed heating system is fundamental to having an efficient system. Duct design is also critical for proper and economical cooling operation.

Ducts

Ducts must be well sealed. Studies throughout the country indicate duct leakage significantly reduces the delivered efficiency of heating and cooling systems. Sealing with duct tape is not satisfactory because most duct tapes fail within a month or two. The duct installer must use a mastic-type sealant or at a minimum, foil-backed tape at all joints.

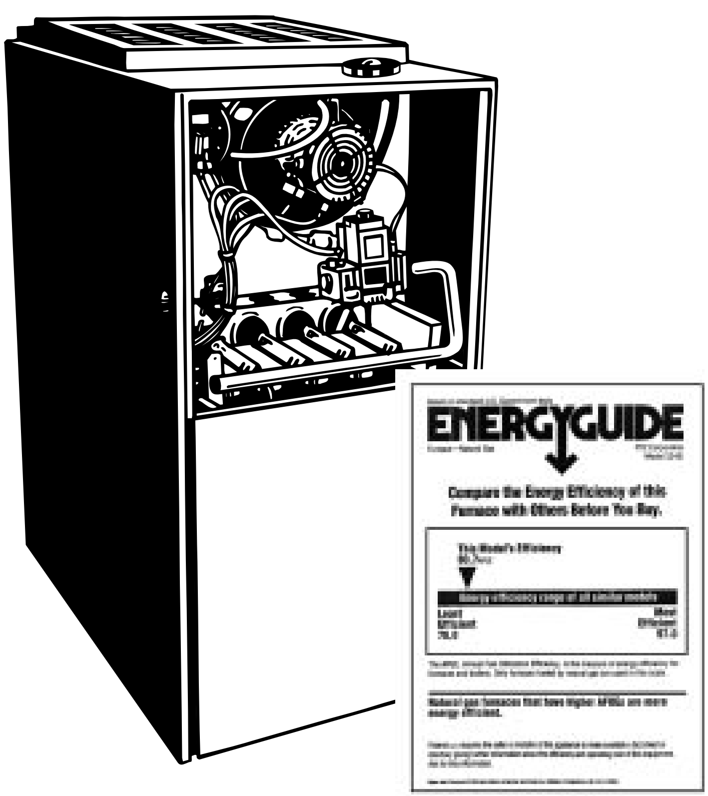
Return ducts must also be sealed. Return air ducts are often constructed by encasing a standard building cavity with sheet metal or gypsum board. The space between floor joists is often panned off with sheet metal, or sections of interior partitions are covered with gypsum board. Building cavity return air ducts must be sealed, just like supply ducts.

It is not uncommon to find up to one-inch gaps between the sheet metal and floor joists. A powerful furnace fan creates a strong negative pressure in the return ducts, drawing air from unheated sections of the home. Because these defects are covered with wallboard, they must be corrected during construction. New techniques in duct sealing allow a mastic to be injected into the ducts where it seeks out and seals most holes. However, it is easier to seal ducts correctly during construction rather than attempt to seal after the home is finished.

In addition to sealing, supply and return ducts running outside the heated space should be insulated to at least R-5. If they are located outside, then they should be insulated to at least R-8.

Gas-fueled warm-air furnaces

One of the most common heating appliances in the Midwest is a natural gas or propane-fired warm-air furnace. The same appliance can often be set up to burn either propane or natural gas



with a change in the burner orifices.

The seasonal energy efficiency of a gas-fired warm-air furnace is reflected by the Annual Fuel Utilization Efficiency (AFUE). The higher the AFUE, the more efficient the heating unit.

Gas furnaces have a minimum AFUE of 78 percent but can have AFUEs into the mid 90 percent range. Furnaces with AFUEs below 85 percent are conventional furnaces and use traditional vent systems. Units with AFUEs in the 90 percent range are condensing furnaces and are vented through plastic (CPVC) pipe, often through the sidewall of the house. Condensing furnaces are often referred to as “high efficiency” units and carry a higher initial cost, but lower operating costs.

When evaluating different manufacturers of warm-air furnaces, compare the warranty on both the heat exchanger and remainder of the unit. Ask for and check references. If comparing units with different AFUEs, compare the increased initial cost against reduced annual heating costs. A method for estimating annual operating costs of fuel-fired furnaces and boilers is provided at the end of this fact sheet. A more detailed method for estimating annual energy costs is available from the Gas Appliance Manufacturers Association (GAMA) Consumer Directory of Certified Efficiency Ratings.

Several manufacturers offer multi-stage furnaces. These units have both a high- and low-heat delivery rating. If it is mild outside, the unit delivers heat at the lower rate. If it is cold outside or the home is recovering from a setback condition, the higher delivery rate is used. The principal advantage is the ability to maintain a more constant inside temperature. Any advantage in efficiency will be reflected in the AFUE.

Conventional or electronic thermostats are used to control fuel-fired warm-air furnaces. For maximum efficiency, use of an electronic thermostat will provide tighter temperature control and allow programmed periods of temperature setback. Setting back temperatures at night and during the day if the house is unoccupied can save up to 20% on heating costs.

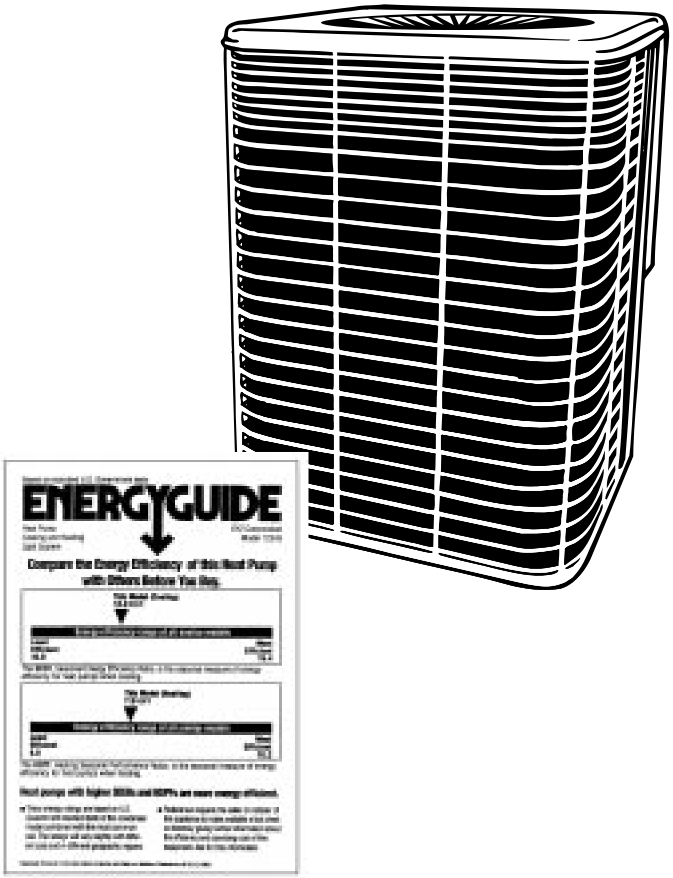
Electric furnaces

Electric furnaces provide heat by using a series of electric resistance heating elements and a central fan. The fan is similar to a blower in a fuel-fired warm-air furnace. Electric furnaces were once quite popular but increasing electricity prices have made them potentially too costly to operate. In areas where the demand for heat is low or where electricity prices are low, they can still be cost effective.

They use warm-air delivery through ducts so they can accommodate air conditioning. Electric furnaces are usually considered to be 100 percent efficient. The appendix can be used to estimate the annual cost of heating with an electric furnace. Use Equation 2 and a Heating Seasonal Performance Factor of 3.14.

Air-source heat pumps

Air-source heat pumps deliver heat at less than half the cost of an electric furnace. An air-source heat pump works like a standard air conditioner in the summer, delivering cool air to the home, but is capable of reversing the flow of heat in the winter so it delivers heat to the home. During the summer, heat is gathered from the house and rejected to the outside air. During the winter, heat is



gathered from outside air and rejected (delivered) to the home.

Air-source heat pump performance is measured as Heating Seasonal Performance Factor (HSPF) in the heating mode and as Seasonal Energy Efficiency Ratio (SEER) for the cooling mode. The higher the HSPF and SEER, the more energy efficient the equipment. HSPFs range from 6.8 to over 10. Annual heating costs for a home equipped with an air-source heat pump are dependent on the heat load of the home, the cost of electricity, and performance of the unit. A simple method for estimating annual heating costs is provided. A more accurate approach is provided in the Air-Conditioning and Refrigeration Institute's Directory of Unitary Equipment. Cooling costs can be competitive with a conventional air conditioner. SEERs range from 10 to above 16.

To avoid poor humidity control when cooling, the heat pump capacity is selected to match the home's cooling needs. As a result, the heating capacity may not meet the home's heating needs during extreme conditions and supplemental heat is often required. This supplemental heat is provided by one or more electric resistance elements installed as part of the heating system. The performance of the heat pump, including the need for supplemental heat, is included in the HSPF rating.

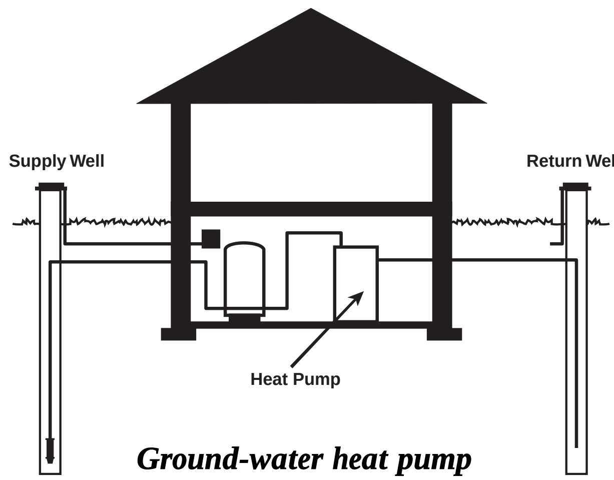
Because the supplemental heat is often electric resistance heat and is expensive relative to heat pump operation, its use should be discouraged. To avoid use of supplemental heat when recovering from setback or when the heat pump can meet the load, use an electronic thermostat designed for use with a heat pump.

Heat pumps use heated or cooled air delivered through ducts to condition the home. Duct sealing is critical for heat pumps.

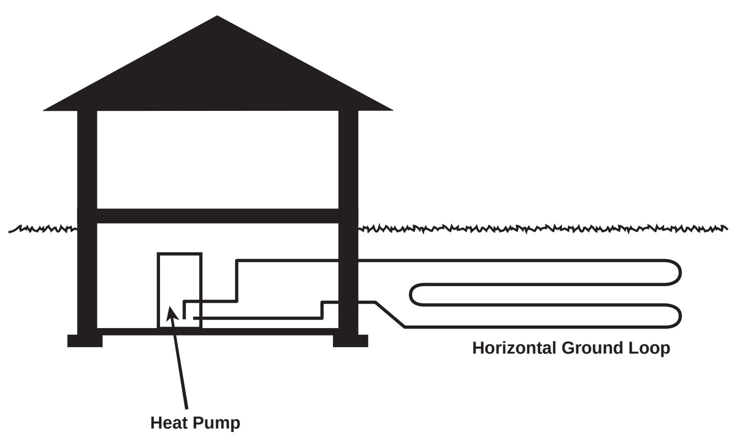
Multi-speed air-source heat pumps are available. They operate at low speed when heating or cooling conditions are low and at high speed when needed. In addition to higher HSPF and SEER ratings, indoor temperatures remain more constant, there is better humidity control, and they are quieter.

Ground-source heat pumps

Ground-source heat pumps work in a fashion similar to air-source heat pumps except they transfer heat from or to the ground rather than the air. Two general approaches are used for coupling the heat pump to the ground. The oldest method, referred to as ground-water heat pump (GWHP), pumps water from a well or other water source, transfers heat from the water in the winter and to the water during the summer, and discharges the water back to the ground. The second and newer approach, referred to as ground-loop heat pump (GLHP), buries a long loop of plastic pipe in which a water and glycol mixture is circulated. The heat



Ground-water heat pump



Ground-loop heat pump

Table 1. Efficiencies of ground-source heat pumps

Heat Pump Systems	Heating COP	Heating* HSPF-Equivalent	Cooling EER	Cooling* SEER-Equivalent
GWHP				
Average	3.2	10.0	14.0	13.5
Above Average	3.5	11.0	15.5	15.0
Top-of-the-Line	3.9	13.0	19.0	18.0
GLHP				
Average	2.8	8.5	13.0	12.5
Above Average	3.1	9.5	14.5	14.0
Top-of-the-Line	3.6	11.0	18.0	17.0

* HSPF-Equivalent and SEER-Equivalent are estimates. More accurate methods for determining system performance and cost are provided in the *Ground-Source Heat Pumps, An Efficient Choice for Residential and Commercial Use* manual prepared for the Kansas Electric Utilities Program.

pump transfers heat to or from the water. The water is circulated in the buried loop of piping where it transfers heat to the ground.

Performance and operating cost of a ground-source heat pump are dependent on performance of the heat pump and the ground loop or water source.

Water temperatures in the loop of a ground-loop heat pump will increase in the summer and fall in the winter as heat is added or removed. If the loop is undersized, it will not be able to transfer enough heat to meet the home needs. The water temperature in the loop will exceed design values. Equipment performance and equipment life will suffer as a result. Similar results can occur if soil conditions do not allow adequate heat transfer between the ground and the ground loop. Sandy soil or dry soil reduces heat transfer rates.

Oversizing the loop will improve system performance but the increased cost of an oversized ground loop will not be cost effective. For cost-effective performance, the loop must be properly sized and installed to meet the home design heat load for the soil conditions on site. Proper backfilling during installation of the loop is critical for satisfactory operation.

With GWHPs, amount and quality of the water available will impact performance. If water flow rates are inadequate to remove or supply the needed heat, or if the water tends to rapidly scale the heat exchanger, performance will suffer. If water quantities and qualities meet design requirements, performance of GWHPs will generally exceed those of GLHPs because the water is at a constant temperature.

Ground-source heat pumps are not rated with a seasonal performance rating. Instead, they are rated with an energy efficiency ratio (EER) for cooling of between 14 and 19, and a coefficient of performance (COP) between 3.2 and 3.9 for heating. The ratings are performed at one or two rating conditions and do not reflect seasonal performance. A listing for current products is available from the Air-Conditioning and Refrigeration Institute. Table 1 provides a range of reasonable values for seasonal COP (HSPF-equivalent) and seasonal EER (SEER-equivalent) values for properly designed and installed GWHP and GLHPs.

To help assure adequate humidity control in the summer, the GSHP is often sized to match the home cooling requirements with the cooling capacity of the equipment. As a result, single-speed units often need supplemental resistance heating to meet peak heating requirements. Multi-speed and multi-staged GSHPs are available that provide a better match between the heating and cooling needs of a home and the capacities of the equipment.

Typically, the unit will operate on low speed or single stage during the summer or when heating needs are moderate. High-speed or two-stage operation will commence during peak heating requirements.

GSHPs can also substantially reduce the cost of heating water. A special heat exchanger is installed to recover the heat being rejected during the summer. Winter water heating needs are partially met by using some of the heat from the heat pump for water heating.

Hot-water boilers

Hot-water boilers have undergone many of the same evolutionary changes that furnaces have. They have become more efficient with some AFUEs in the mid 90 percent range. Minimum efficiencies for gas-fired hot-water boilers are 80 percent and 75 percent for steam boilers. Steam boilers are not as popular as hot-water boilers due to higher maintenance and difficulty in controlling heat delivery.

Hot-water boilers commonly use either baseboard radiation or slab-radiant heating as delivery methods. Baseboard heaters have been used for years and are an adaptation of older cast-iron radiators. Cast-iron radiators needed to be large to provide the surface area needed. Baseboard radiation heaters have fins attached to a pipe to provide the needed area.

Slab radiant heating has gained popularity in the last twenty years. One common approach is to bury plastic or rubber tubing in a concrete slab during the construction process. Hot water from a boiler is circulated through the tubing to warm the floor. The tubing must be designed for this application because it will be subjected to high temperatures and a corrosive environment. Because the slab is heated, it is very important that the perimeter of the slab be well insulated to minimize heat loss. The floor temperature controls the rate of heat release to the room. The thermostat used must be one designed for radiant heating applications.

Radiant heating systems are often considered more comfortable than forced-air delivery heating systems. The warm floor heats objects and people in the room, providing a higher sensation of comfort, often at lower air temperatures. Because the room air temperature is often set lower, heating costs are reduced over forced-air heating systems. Another advantage of both baseboard and slab-radiant heating is the ability to heat different rooms to different temperatures. Thermostatically controlled valves regulate the flow of hot water to maintain the desired temperature in each room.

One of the major disadvantages for hot-water baseboard or radiant heating is a separate air-delivery system is needed if the home is to be air conditioned.

To estimate the annual heating costs of hot-water heating systems, use the method described for gas-fired warm-air furnaces. Savings resulting from a lower thermostat setting are not included in this method but savings of up to 15 percent have been reported.

Pipes

Hydronic heating systems use pipes to transport hot water to baseboards or in-floor heating coils. Exposed piping should be insulated to an R-5, and if exposed to the outside, R-8.

Unitary systems

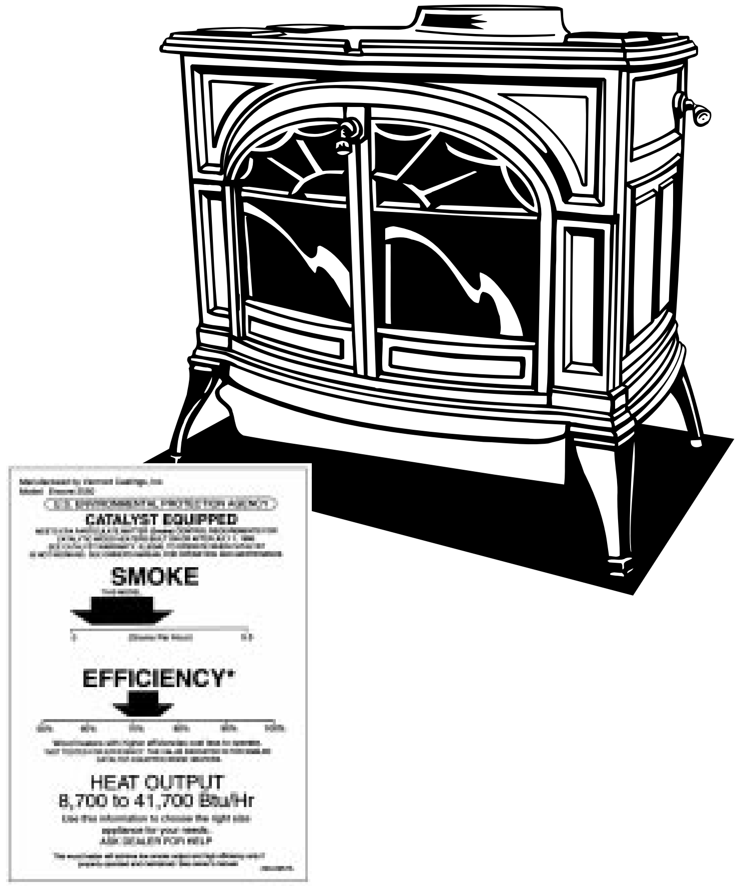
Some heating systems provide heat to only a portion of a home. These included window or through-the-wall heat pumps, electric baseboard heaters, vented and unvented room heaters, wall furnaces, and wood stoves.

Wood stoves

Wood stoves gained popularity because of the availability of low- or no-cost fuel as well as the ambience created from a wood fire. Stoves have changed dramatically over the years. In 1988, the Environmental Protection Agency established rules to control the efficiency of and emissions from wood stoves. As a result, only approved stoves are on the market today.

Three types of stoves are marketed: non-catalytic, catalytic, and pellet. Pellet stoves are exempt from wood stove certification regulations. Non-catalytic stoves are the types most people are familiar with. Efficiencies range from 50 to 60 percent. Control of primary and secondary air and the use of baffles help these stoves to burn cleanly and efficiently. Catalytic stoves contain a ceramic combustor that is coated with a chemical catalyst. The combustor helps assure unburned fuel is combusted prior to leaving the stove. Efficiencies often exceed 80 percent for catalytic stoves. Admitting combustion air adjacent to the stove will reduce home infiltration and provide a more comfortable home.

As with all heating systems, it is important to match the stove's size to the home's heating needs. Oversized stoves will overheat the home and must be operated in a choked condition, reducing performance and increasing emissions.



Room heaters

Space heaters are available in both vented and unvented configurations. Vented room heaters burn natural gas or propane and exhaust the products of combustion to the outside. Room heaters are rated with an AFUE as are fuel-fired warm-air furnaces. Table 2 provides minimum AFUEs based on appliance size.

Vented room heaters are available in regular-vented and sealed-combustion designs. Regular venting requires an approved venting system to route combustion products outside. Conventionally

Table 2. Minimum efficiencies of room heaters

Heater Size	AFUE
< 18,000 Btu/hr.	57%
Between 18,000 and 20,000 Btu/hr.	58%
Between 20,000 and 27,000 Btu/hr.	63%
Between 27,000 and 46,000 Btu/hr.	64%
Greater than 46,000 Btu/hr.	65%

vented units use room air for combustion. Before installing, make sure there is adequate air for combustion. More efficient sealed-combustion systems use combustion air brought into the stove from the outside and vent the products of combustion outside.

Unvented heaters use room air for combustion and discharge products of combustion back into the room. Most are fitted with an oxygen-level sensor that shuts off the unit if oxygen levels drop below safe level. One of the products of combustion is water vapor. If unvented heaters are used in a confined space, moisture will build up and potentially cause mold and mildew growth. Other indoor air quality problems may occur when unvented heaters are regularly used for space heating. Unvented heaters are not recommended for regular space heating use in confined spaces. Their occasional use for supplementary heat or in rooms where significant infiltration exists may be acceptable.

Wall furnaces

Wall furnaces have application similar to room heaters. They are available in both traditional vented and sealed-combustion designs. Heat delivery can be natural convection or a blower can be used to aid heat delivery. Minimum AFUEs range from a low of 59 percent to a high of 65 percent for gravity units, and up to 74 percent for fan-assisted heat delivery.

Wall furnaces can be used to heat up to three rooms. They are often fitted with a supply grill from both the front and back of the unit. Like other gaseous-fueled appliances, most can be configured to burn either natural gas or propane.

Electric baseboard radiation

Electric baseboard radiation heaters are often used where supplemental heat is needed. They have the advantage of being inexpensive and simple to install with no combustion products or vents, and no refrigerant lines. Electric baseboards can be controlled room by room so savings are possible by only heating a portion of the home. Operating costs are the same as for an electric furnace. Electric baseboard may be the ideal solution where it is difficult to extend an existing heating system and some additional heat is needed.

Window and through-the-wall heat pumps

Packaged heat pumps are used a great deal in motels. They supply heat with a minimum HSPF of 6.6. This means they deliver heat at twice the efficiency of resistance heaters. Supplemental heat is often provided with electric resistance.

While package heat pumps are not common in Midwestern homes, they provide an excellent supplemental heat source when extending an existing heating system is not possible or if combustion heating is undesirable.

Like window air conditioners, noise is a common problem. The compressor is located in the room, as is the distribution fan. However, year-round conditioning can be achieved for reasonable operating costs.

Solar heating

Active solar energy systems are not commonly cost effective unless energy is expensive. However, use of passive solar heating principles in the design and operation of the home can provide a significant amount of a home's heating needs.

Passive solar homes do not have to look significantly different than a traditional home. The principles are simple: Admit the sun's energy into the home when heat is needed; provide a means to store some of the heat for when the sun doesn't shine; and keep heat out when it is not needed.

To accomplish these simple concepts, a combination of overhangs, glazing, and thermal mass is used. Much of the house's glass should be located on the southern exposure. Because the sun is to the south and low in the sky during the winter, south-facing glass lets the sun in. Avoid large expanses of east and west glass because they provide very little winter heating benefit but allow lots of heat in during the summer when the sun has moved north.

Overhangs are used to shade the south-facing glass during the summer. This minimizes summer heat gain which increases the cooling penalty. Trees and other vegetation should be used to shade east and west glass.

Thermal mass inside the home helps store the heat during the day for evening use. Thermal mass doesn't have to be Trombe walls, stacks of water-filled containers, or other visually dominant house features. It can be a quarry tile floor over a four-inch concrete slab, or plaster walls. Thermal mass is any house component that is heavy and exposed directly to the sun during the day.

Even if you do nothing but orient the house's windows so most face south and provide a properly sized overhang, you have helped heat your home with solar energy.

Estimating annual energy costs

Cost of fuel, efficiency of the heating equipment, and heating requirements of the home all impact the cost of heating. The method described below can be used for obtaining a rough estimate of the annual cost of operating central heating systems. More accurate methods are available in references 1 and 3.

To obtain an estimate of your annual heating cost, first determine the seasonal heating requirements of the home using Table 3 and Figure 1.

Compare the energy features of your home to those listed in Table 3 to determine if your home resembles a current practice, MEC-compliant, energy-efficient, or super-insulated home. You will need to examine Figure 1 to determine which climate zone you are in. Look up the seasonal heating index (SHI) in Table 3.

Annual energy cost examples

For fuel-fired furnaces and boilers, use Formula 1.

Formula 1.

$$\text{Annual Cost} = \frac{\text{SHI x house area x fuel price}}{\text{AFUE x 1,000}}$$

Fuel price in Formula 1 is the price per thousand cubic feet ($/MCF) for natural gas. If you purchase gas in units of therms (100,000 Btus), multiply the price per therm by 10 to convert to price per MCF. If you purchase propane, multiply the price per gallon by 10.9 to convert to an equivalent price per MCF.

Example 1:

A 2,300-square-foot home in Newton, Kansas, has the following features: ceiling = R-38, walls = R-19, windows U-value = .58, R-8 foundation insulation, and the home is fairly tight. It most closely resembles an MEC-compliant home in Zone 2 with a seasonal heating index of 32.3 Mbtu/ft2. The home uses propane which costs $.65 per gallon or $7.08 per MFC equivalent. The furnace being considered has an AFUE of 80 percent.

$$\text{Annual Cost} = \frac{32.3 \text{ x } 2{,}300 \text{ x } \$7.08}{.80 \text{ x } 1{,}000} = \$657$$

For heat pumps, use Formula 2.

Formula 2.

$$\text{Annual Cost} = \frac{\text{SHI x house area x electricity price}}{\text{HSPF}}$$

Example 2:

The same house is considering an air-source heat pump with a HSPF of 8.5 and electricity costs of $0.07 per kWh.

$$\text{Annual Cost} = \frac{32.3 \text{ x } 2{,}300 \text{ x } \$0.07}{8.5} = \$612$$

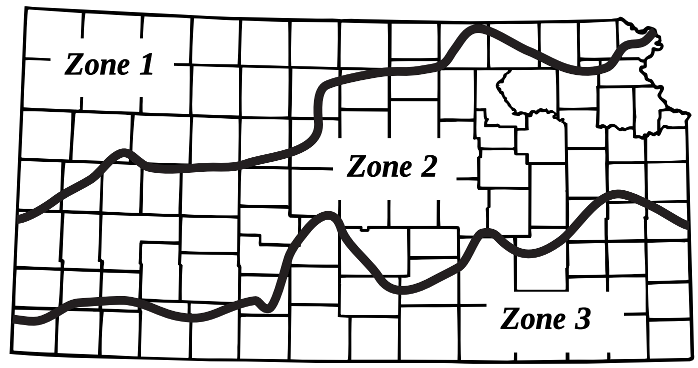


Figure 1. Kansas climate zones

Table 3. Seasonal heat loads for housing in Kansas

Efficiency Level	Ceiling R-value	Wall R-value	Glass[1] U-value	Foundation[2] R-value	Infiltration[3] ACH	Seasonal Heat Index MBtu/ft²
Current Practice	R-30	R-13	U-0.60	R-0	0.6	
Zone 1						49.6
Zone 2						45.1
Zone 3						40.6
MEC Compliant	R-38	R-19	U-0.60	R-5	0.4	
Zone 1						35.5
Zone 2						32.3
Zone 3						29.1
Energy Efficient	R-38	R-19	U-0.35	R-10	0.4	
Zone 1						28.1
Zone 2						25.5
Zone 3						23.0
Super Insulated	R-45	R-24	U-0.25	R-10	0.2	
Zone 1						19.4
Zone 2						17.6
Zone 3						15.8

[1] Glass U-value is center of window.

[2] Foundation R-value for basements. Insulation is to bottom of wall.

[3] Infiltration is expressed in air changes per hour (ACH). The rate for a super-insulated home of .2 ACH is below the minimum recommendation of .35 ACH and would require mechanical ventilation with heat recovery.

Further information

For questions regarding this fact sheet or further information on home heating systems, please contact Engineering Extension at 785-532-6026. This fact sheet is posted on the Kansas State University Engineering Extension Web page at *www.oznet.ksu.edu/dp_nrgy/ees*. Other KSU Engineering Extension Fact Sheets posted at this site include the following:

- Tips for Purchasing an Energy-Efficient Home
- Foundation Insulation
- Selecting a Home Cooling System
- Energy-Efficient Mortgages
- Energy-Efficient Windows
- Residential Insulation
- Air Sealing Your Home

References

[1] Gas Appliance Manufacturers Association, *Consumers' Directory of Certified Efficiency Ratings*, GAMA, 1901 North Moore Street, P.O. Box 9245, Arlington, VA 22219

[2] Directory of Certified Unitary Equipment Standards 210/240/270, Air-Conditioning and Refrigeration Institute, 4301 North Fairfax Drive, Arlington, VA 22203

[3] Directory of Certified Applied Air-Conditioning Products, Air-Conditioning and Refrigeration Institute, 4301 North Fairfax Drive, Arlington, VA 22203

[4] Kansas Electric Utilities Research Program, *Ground-Source Heat Pumps, An Efficient Choice for Residential and Commercial Use*, 700 S.W. Harrison, Suite 1430, P.O. Box 1007, Topeka, KS 66603

[5] Colorado State University Cooperative Extension, *Selecting a Wood Stove*, no. 10.613, Ft. Collins, CO, Lloyd Walker, 1992

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