HEATING AND COOLING SYSTEMS

The average Virginia household uses 50% of its total energy budget for space heating and another 9% for air conditioning. Your heating system is most likely the number one energy user in your home, with water heating second and air conditioning a close third.

Heating systems, cooling systems, and the power plants that supply them with electricity emit large amounts of carbon dioxide - a major greenhouse gas - into the atmosphere, which adds to global warming. They also emit sulfur dioxide and nitrogen oxide - both major ingredients in

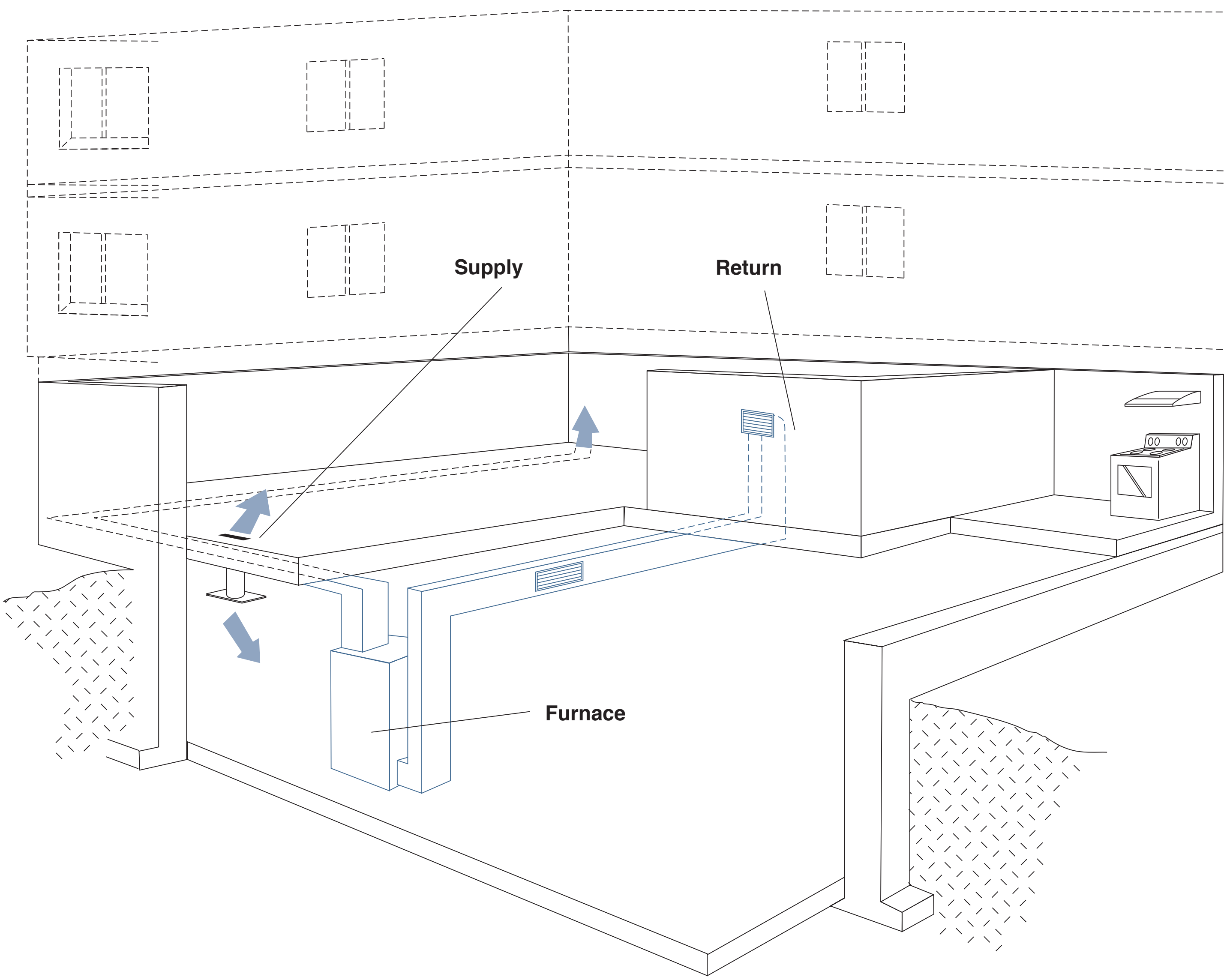

Figure 5-1 - The most common type of central heating system is a ducted forced air system with central furnace or heat pump.

acid rain. So improving the efficiency of your heating and cooling equipment will not only save you money but it will reduce pollution output and help to preserve the environment.

If your home is insulated and airtight, you've already done a lot to reduce heating and cooling energy. The next step is to further reduce energy use by improving the efficiency of the mechanical systems themselves. This can be done with better maintenance, with upgrades to a few components, and/or with total system replacement.

Remember that your house is a system and the performance of your heating and cooling equipment will depend directly on how well the shell of your home is insulated and how the occupants of the home operate and maintain the mechanical equipment inside the home.

Four Ways To Improve Your Heating And Cooling Systems' Efficiency

1. If your present heating and cooling systems are old and tired, you may be able to cut utility costs by as much as 50% by replacing the old system with a new high efficiency system.
2. Even if your furnace and air conditioner are in fairly good shape, you may be able to improve the overall efficiency of the system through adjustments, maintenance, and repair to the distribution system.
3. With the mechanical system in good shape and well maintained, you may still be able to reduce fuel costs by changing the way you operate your thermostat.
4. Be sure that all heating systems are vented properly and that all vent pipes and chimneys are installed and lined according to code requirements. Improperly lined chimneys, vent pipes that are incorrectly installed or are of the wrong material, and dirty and obstructed pipe and chimneys can impact how the systems draft. This compromises energy efficiency, indoor air quality, and fire safety.

Understanding Central Heating And Cooling Systems

Your home may be heated by individual room heaters and window air conditioners, or it may have central heating and cooling systems. Central systems typically present the greatest opportunity for savings.

A central heating system has four main elements:

• The heating and cooling plant - furnace, boiler or heat pump, and possibly air conditioner - that converts fuel or electrical energy into a temperature change.

• The distribution system - ducts for forced air or pipes for hot water or steam - that carries heat (and cool) from the central unit to each room in the house.

• The venting system - vent pipes and chimney - that are responsible for efficiently and safely removing the poisonous flue gases from your home (if the system is a combustion appliance).

• The thermostat, which controls the whole system.

The following sections focus on all four elements of your central heating system, discussing how they work and what you can do to improve their energy efficiency.

Gas furnaces

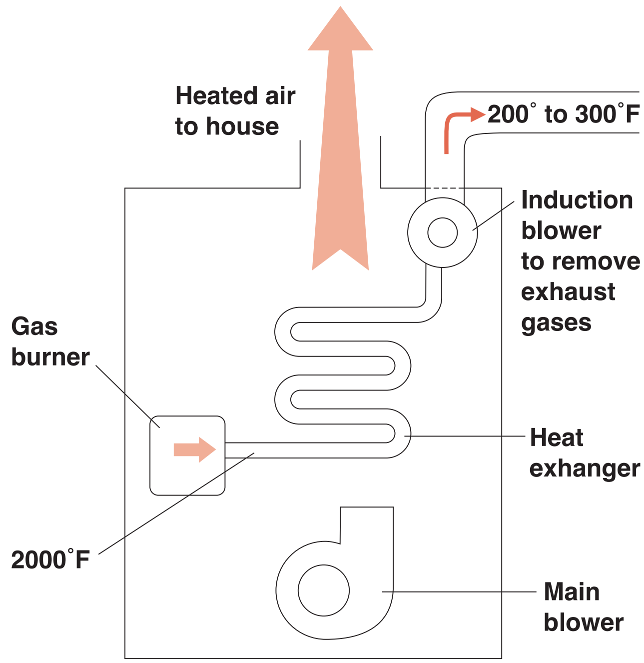

Figure 5-2 - Typical mid-efficiency gas furnace

Gas furnace technology has progressed by leaps and bounds during the past decade. Efficiencies have jumped from about 65% to as high as 95%. Efficiency of a heating system can best be defined as how effective the system converts fuel into useful heat.

Most gas furnaces have the same basic components: A gas burner where fuel is burned, an ignition device to start the fire, one or more heat exchangers where the heat from combustion gases is transferred to the house air, a circulation blower to circulate air to and from the house, and (on modern units) a small second induction blower to draw flue gases through the furnace and assist in bringing combustion air to the unit.

As the hot exhaust gases from the gas burner pass through the heat exchanger, they are cooled by the circulating house air, which carries the heat throughout the house.

The road to high efficiency

To achieve high efficiency, manufacturers designed special heat exchangers which squeeze as much heat as possible from the hot combustion gases before venting them out of the house. For example, in "mid-efficiency" furnaces (78% to 83%), the exhaust gases are cooled to about 250°F before exiting the furnace. To attain even higher efficiency, manufacturers install a second heat exchanger which further cools the exhaust gases to as low as 65°F. At that temperature, the gases are so cool that water vapor (one of the products of combustion) condenses out of the flue gases and is drained through a plastic tube to the sewer or floor drain. These ultra-high efficiency furnaces, called "condensing furnaces", have efficiencies ranging from 90% to 97%.

Condensing gas furnaces first appeared on the market in 1983 and are now available from literally every major furnace manufacturer. Because the exhaust from a condensing gas furnace is so cool, it can be vented through regular schedule #40 plastic PVC pipe (there is no need for a metal or masonry chimney).

Oil furnaces

Oil furnaces are similar to gas furnaces and share many of the same high efficiency features. The most important difference is in the firing apparatus. Oil furnaces have power burners that atomize the fuel oil, mix it with combustion air, and force it through the combustion chamber.

Condensing oil furnaces, with efficiencies above 90%, are available but are not as common as condensing gas furnaces.

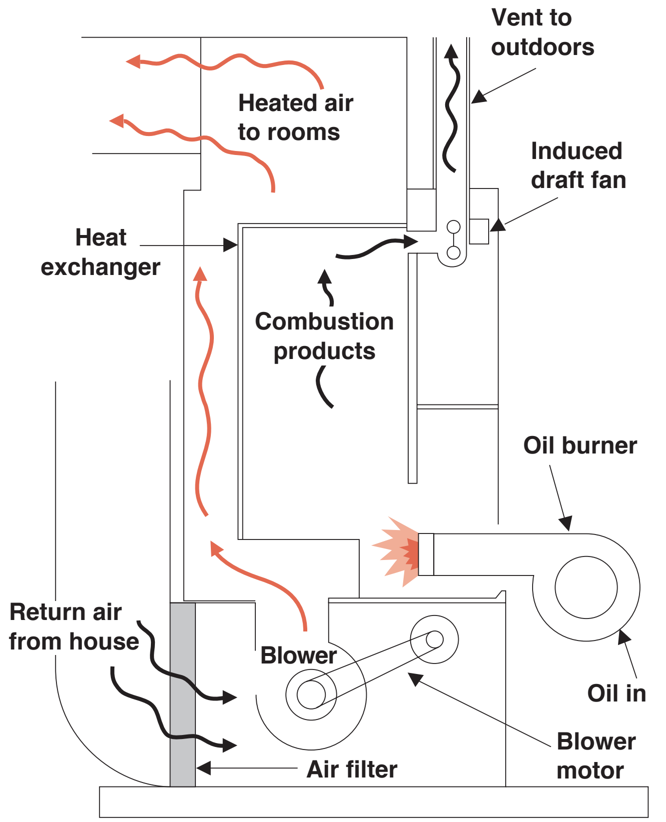

Figure 5-3- Schematic of typical oil-fired furnace

Electric furnaces

Electric furnaces contain an electric resistance heating coil that simply converts electricity directly into heat. The coil is mounted in a cabinet with a circulation blower. Except for a small amount of heat loss through the cabinet, nearly all the heat from the coil is transferred to the circulating house air. The efficiency of an electric furnace is close to 100%. Electric resistance heat, however, is generally the most expensive type of heat available and is not recommended - see "Know Your Btus" in Chapter 1.

Electric heat pumps

Heat pumps work on a completely different principle than electric furnaces. Instead of just converting electricity into heat, a heat pump uses an electric compressor that "pumps" heat from one place to another.

Heat flows naturally from hot to cold, never from cold to hot. Water flows naturally from a high level to a low level, never uphill. Just as a water pump moves water from a low level to a high level - against the direction of its natural flow -

a heat pump moves heat from a cold area to a warm area.

Refrigerators, air conditioners, and heat pumps are all basically the same. In a refrigerator, heat is pumped from the cold freezer and refrigerator compartments out into the warmer room. In an air conditioner, heat is pumped from the cool interior of the house into the hot outdoors. In a heat pump, heat is pumped from the cold outdoors to the warm interior of the house.

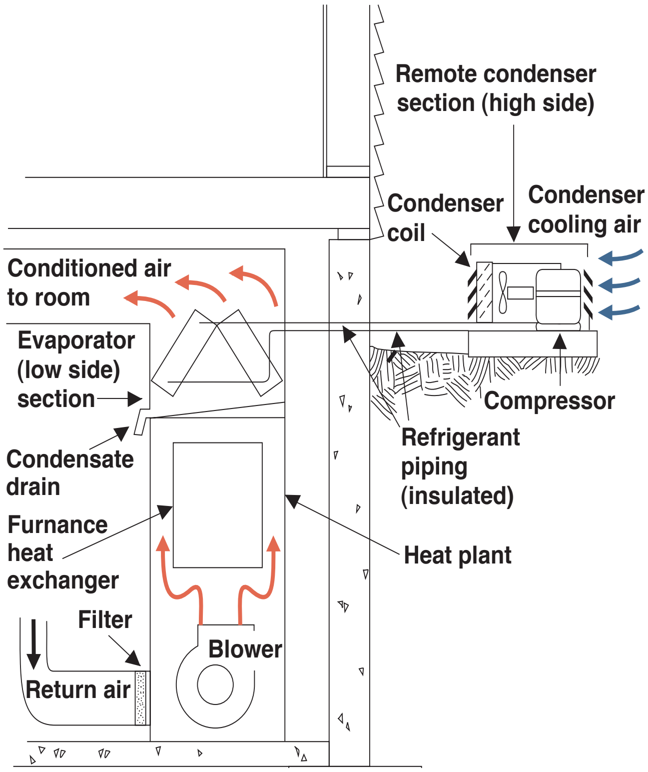

Figure 5-4 - Schematic of air-to-air heat pump

In fact, heat pump/air conditioner combinations use the same equipment for both jobs, using a flow control valve to change the direction of heat pumping from summer to winter. This ability to use the same basic equipment for heating and air conditioning is a prime advantage of heat pumps.

A heat pump makes much better use of electricity than an electric resistance furnace. For each Btu of energy that comes into the heat pump from the electric power line, it can pump one or two more Btu's from the outdoors. In this way it delivers two or three times more heat than an electric furnace for the same electric input.

All heat pumps have the same basic components: a compressor which does the actual "pumping", an indoor coil which heats or cools circulating house air, an outdoor heat source which supplies heat or cooling to the system, and copper tubing that circulates high pressure refrigerant fluid between the indoor and outdoor units.

Residential heat pumps can utilize heat sources down to 20-30°F to heat indoor air up to 80-100°F.

Heat pumps can also be used for water heating: See Chapter 6.

Air-to-Air Heat Pumps

The most common type of residential heat pump is an "air-to-air" heat pump which uses outdoor air as the heat source. Heat is extracted from the air by an outdoor unit that contains a heat exchanger and fan.

The main disadvantage of air-to-air heat pumps is that they lose efficiency and output at cold (less than 35°F) outdoor air temperature. When this happens, operating cost increases and indoor comfort decreases because the air from the heat pump is not very warm. While this is a troublesome problem in colder regions of the country, it is not a severe problem in most regions of Virginia.

Air-to-air heat pump systems are usually set up with a "two-stage" thermostat. As long as the temperature in the house remains within a few degrees of the thermostat setting, the heat pump operates normally. If the indoor temperature drops too low, the heat pumped by the compressor is supplemented by electric resistance heat and the heat pump's efficiency drops considerably. For a typical home with a heat pump, the electric resistance heat comes on during two conditions: when the outdoor temperature drops to about 15-25°F and when the heat pump is turned on suddenly when the house is cold.

When outdoor air temperatures are below about 40°F, air-to-air heat pump outdoor coil temperature may be below freezing. Moisture in the outdoor air then forms frost on the outdoor coil. If too much frost builds up, the heat transfer to the coil is restricted and heat pump output and efficiency drops. To avoid this, heat pumps have a "defrost" cycle that uses energy from the house to warm the outdoor coil and melt the frost. Frost is not a problem with air conditioners since you never cool your home to 40°F.

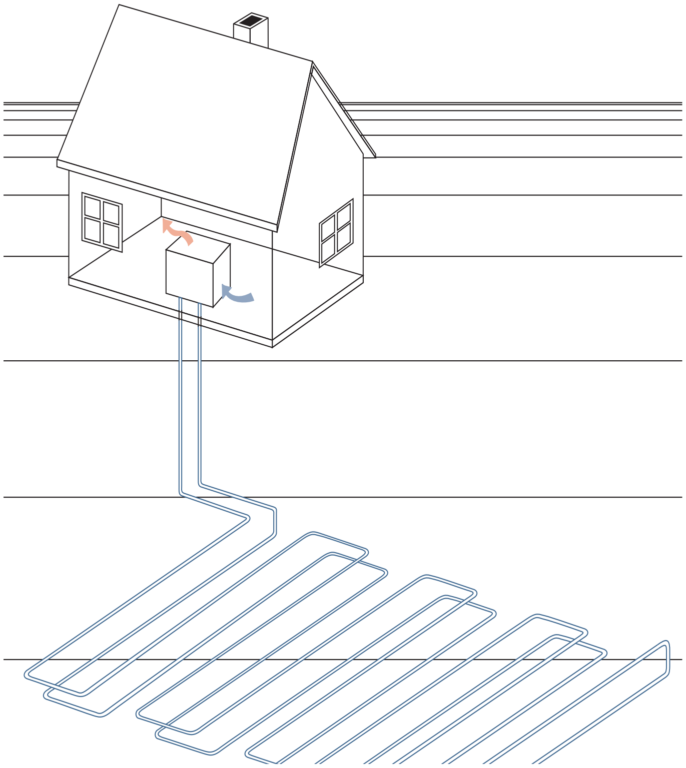

Figure 5-5 - Ground source heat pump

Geothermal Heat Pumps

"Geothermal" or "ground source" heat pumps (GHP) use the ground as the heat source. Heat is extracted from the ground by water circulating in a closed-loop pipe. This pipe is placed either in trenches or down specially drilled wells. Ground source heat pumps are generally more efficient than air-to-air heat pumps because the deep-ground temperature stays constant all year round. Just as the power required for a water pump increases as it pumps water farther uphill, the power required for a heat pump increases as it pumps heat over a greater temperature difference. Since GHPs pump heat from the relatively warm ground instead of the cold winter air, they pump heat over a smaller temperature difference. As a result, they use 25-50% less electricity than conventional heat pump systems.

GHPs can also operate as air conditioners, where they have the advantage of pumping heat into the relatively cool ground instead of into the hot summer air.

GHPs are quieter than conventional systems and they improve humidity control. GHPs tend to be more durable, require less maintenance, and have a lower environmental impact due to their increased efficiency.

GHPs have a higher installation cost, but because they are more efficient and save money in the long term, they can represent a good investment. The cost effectiveness of a GHP for a particular location depends, in part, on soil conditions and site layout since these affect the cost of the necessary excavation.

Hydronic heating systems and radiant floor heating

A hydronic heating system uses heated water to distribute heat from a central boiler to each part of the house. The distribution system may include any combination of baseboard heaters, radiators or sub-floor "radiant" heaters.

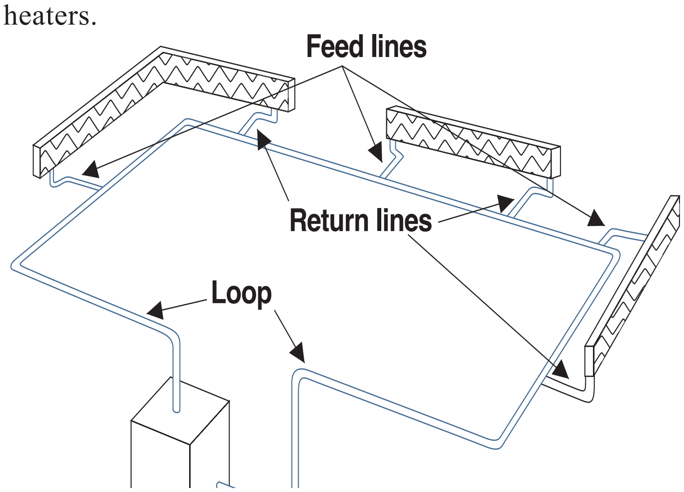

Figure 5-6 - Hydronic heating system

As with furnaces, boiler technology has advanced during the past decade although few boilers attain the impressive efficiency of condensing gas furnaces. Several gas- and oil-fired boilers are available with efficiencies up to 87% and condensing gas boilers are available with efficiency over 90%.

One very effective type of hydronic heating system is radiant floor heating. Radiant floor heating has been used for centuries and operates on the premise that people are most comfortable when their feet are warm and the air they are breathing is relatively cool. Radiant floor heat allows even heating throughout the whole floor and not just in specific areas like space heat and forced air systems. In hydronic floor heating systems, tubing is laid in a pattern underneath the floor and heated water is pumped from a boiler through the tubes. The temperature in each room is controlled by regulating the flow of water through each tubing loop through a system of zoning valves or pumps. A hydronic radiant floor system can save 20 to 40% per month on heating bills depending on the heat source, is very quiet to operate, and has virtually no air leakage as a result of there being no forced air distribution system.

Some radiant heating systems use electric resistance mats that are build into the floor. They provide the same comfort as hydronic radiant floor heating, but because they use the same basic technology as electric furnaces, they are expensive to operate.

Hydronic heating systems are not very common in Virginia. One reason is that most new homes have central air conditioning which requires a ducted distribution system. It's hard to justify a second distribution system when you could just as easily use the cooling ducts for forced air heating.

Energy Efficient Space Heaters

There are several types of energy efficient, direct vented, sealed combustion space heaters on the market. These heaters, which normally can use natural gas, kerosene, or propane as their fuel source, are direct vented through the wall - eliminating the need for a chimney.

They are sealed combustion, which means they bring in outside air for combustion. This helps to eliminate air infiltration due to an unsealed combustion system that sucks air from inside the house to provide combustion air, which in turn can force air to be drawn from outside the house. Their efficiency ratings run from 82 to 90% and they are generally equipped with programmable thermostats, which can maximize efficient operation.

The BTU output can range from 10,000 to 40,000 and they can heat one room or a 2,000 square foot house.

Many older houses have vented space heaters without sealed combustion. These units are less efficient than good sealed combustion heaters because the combustion gases leave at high temperatures and because they use indoor air for combustion. The best of these units, however, are fairly efficient. They must be vented through a metal or masonry chimney, and care must be taken to ensure they have adequate draft.

Unvented space heaters claim high efficiency, but can produce hazardous indoor pollutants. See "Unvented Heating Systems" at the end of this chapter.

Cooling Systems

There are basically three types of air conditioning systems available: room air conditioners, central air conditioners, and heat pumps.

Room air conditioners provide cooling to rooms rather than the whole house. These units can be installed in a window or mounted in a wall, but in both cases the compressor is outside. Room air conditioners generally range from 5,500 BTU per hour to 14,000 BTU per hour. They can normally be plugged into a 115- volt household circuit although larger units may need their own dedicated circuit. National appliance standards require new room air conditioners to have an Energy Efficiency Ratio (EER) of 8.5 or greater. If you replace an older unit that has an EER of 5 with one that has an EER of 10, you will reduce your energy costs by 50%.

Central air conditioners cool the entire house. They are normally a split system unit with the compressor and condenser outside and the evaporator inside. The cool air is distributed by a forced air duct system that pushes air into individual rooms through a supply system and then returns the used air back to the air conditioner through a return system. National minimum standards require a Seasonal Energy Efficiency Ratio (SEER) of 12 for central units but there are units on the market with SEERs reaching 17.

Heat pumps operate like central air conditioners except a heat pump can reverse the cycle and provide heat during the winter months. Heat pump effectiveness is expressed by using the term Heating Season Performance Factor (HSPF) and this as well as EER and SEER will be discussed later in the chapter.

Air conditioners use the same operating principles as a refrigerator. An air conditioner cools with a cold indoor coil called an evaporator. The condenser is a hot outdoor coil that releases the collected heat outside. The evaporator and condenser are copper tubing surrounded by aluminum fins and a pump called the compressor moves a heat transfer refrigerant between the evaporator and the condenser. The compressor forces the refrigerant through the circuit in the tubing and fins. The refrigerant evaporates in the indoor evaporator coil drawing heat out of the indoor air and cooling the house. The hot refrigerant gas is pumped outdoors in the condenser where it returns back to a liquid releasing its heat to the air flowing over the condensers tubing and fins.

Evaporative Coolers

Evaporative coolers are air conditioning systems that are most effective when the outside humidity is low, in dry areas of the country like the Southwest. They operate by blowing air over damp pads, so that the evaporation of water cools the air. The cooled, humidified air is then blown into the house.

Evaporative coolers are not effective in a humid climate like Virginia's. Although they reduce air temperature, they result in uncomfortably high indoor humidity.

Variable-speed systems — comfort with efficiency

One of the most noteworthy new developments in both heat pumps and air conditioners is the introduction of new "variable speed" systems. A variable speed air conditioner has the capability of varying its cooling capacity to match the needs of the house. Thus when a house needs little cooling, the system runs at a low speed, which not only saves energy, but is also extremely quiet. During very hot or humid weather, the system can switch to a higher speed to match the increased load.

Another advantage of variable speed air conditioning is enhanced humidity control. During very humid weather, some variable speed air conditioners can lower the indoor coil temperature to squeeze extra humidity out of the circulating house air.

All in all, a variable speed system gives the homeowner a combination of maximum comfort and energy efficiency.

How To Make Your Heating And Cooling Systems More Efficient

Change your filter regularly

The filter in your forced air system is intended to protect the blower and coils from dust. As dirt builds up on the filter, less air can pass through. The reduced air-flow reduces the capacity and efficiency of your heating system and increases the power draw of your air conditioner.

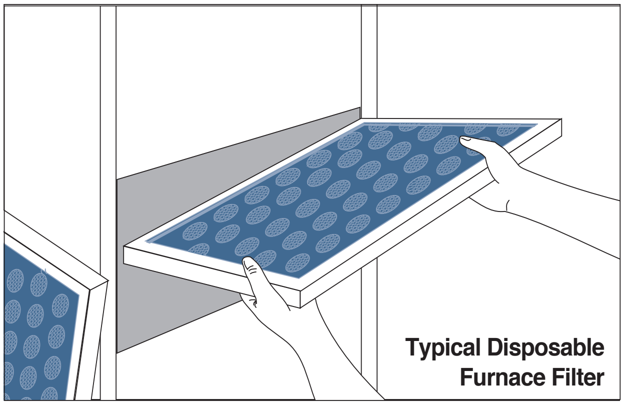

Figure 5-7 - Furnace filters should be replaced every one to three months, depending on conditions.

Depending on how dusty your home is, you should check the filter every one to three months and change it whenever visible amounts of dirt accumulate on the surface.

Eliminate duct leakage in forced air systems

One of the worst culprits in forced air heating and cooling systems is duct leakage. Duct leakage can account for 35 to 40% of heating and cooling energy loss in the home, particularly if the ducts are located in unconditioned areas like attics or crawlspaces. Since the air in your duct system is under high pressure and temperature (low temperature in summer), any leakage in the duct system results in high energy loss. Sealing leaky ducts is one of the most cost-effective improvements you can make to your forced air system.

A duct system consists of supply ducts and return ducts. A central heating or cooling system contains a fan that pushes heated or cooled air into the supply ducts that provide this air into each room of the house. The fan that is

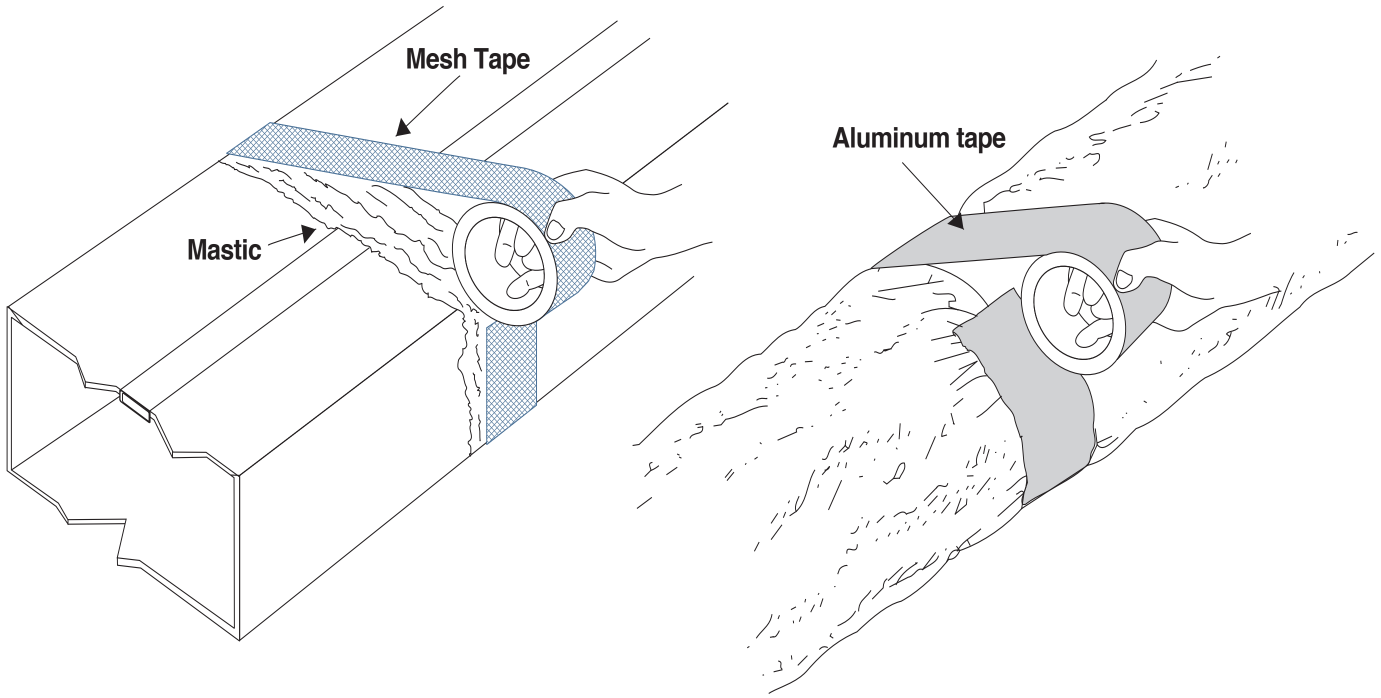

Figure 5-8 - Sealing ducts against air leakage

pushing the air gets its air supply through the return ducts that are located in the house. Ideally each room of the house should have a return register so that the system is balanced, but it is more common to have one return register for each floor of a house.

Leakge hurts duct system performance. If the supply side is leaky then two things can happen. First you will lose heated or cooled air and secondly the replacement air that is needed will be drawn in from outside due to the negative pressure that is being created by the leakage (infiltration). If the return side is leaky then unconditioned air is being pulled into the return system. This makes the furnace work harder because it must now heat or cool air that is not conditioned within a sealed return system. The positive pressures that return leakage cause within the living space will also force the conditioned air to be forced out of the house (ex-filtration). Return leakage can also create significant health hazards within the living space by pulling indoor pollutants into the system and by causing the combustion appliances to back-draft.

Sealing ducts is very important and can be relatively straightforward. But it is imperative that the system be tested by a professional - before and after sealing - to insure that repairing duct leaks has not unbalanced the system thus creating the types of problems discussed above.

Always seal ducts using duct-sealing mastic. Never use duct tape. The seal must be permanent and only mastic provides this long- term application. Duct tape does not last nor does it provide a proper seal. Make sure that your combustion appliances are drafting properly before and after any duct sealing is done.

A professional can test the duct system for leakage and also insure that your furnace is drafting properly. A blower door or air flow measurements can be used to test and diagnose duct leakage (Chapter 1) and draft testing is discussed in (Chapter 2). If you're hiring a professional to work on your duct system (affecting your energy bill, your health, and your safety), be sure he or she is well-qualified:

• Use someone with a reputation for good work. Talk to your friends and neighbors for recommendations. Check with your local Better Business Bureau or contractor licensing department for complaints. Ask for references and contact them.

• Ask questions about home energy use: How do leaky duct systems lose energy? How can leaky duct systems create health hazards? How can you test the ducts to determine that they leak? How will you fix the leaks and what material will be used to make repairs? How can the duct system cause combustion appliances to backdraft? A qualified professional should be able to answer such questions clearly and correctly.

Balance air distribution system

For optimum performance, an air distribution system should supply the proper amount of air to each room. A large bedroom, for example, requires more air flow than a small study. When the duct system is designed, duct and register sizes should be selected to provide adequate air flow to each room. System sizing, however, can only control air flow approximately. Once a system is constructed, air distribution can be fined-tuned by adjusting the flow-control dampers in each register. This fine-tuning is called "system balancing."

In large commercial buildings, the engineers who design the air distribution system specify the correct air flow to each register. Once the building is finished, specialized "Testing and Balancing" (TAB) contractors adjust the system to provide correct air flow. In residential air distribution systems, design is often approximate and the correct air flow to each register is often not specified. Nevertheless, residential systems can benefit from proper balancing.

When systems are not properly balanced, one or more rooms can be uncomfortably warm or cold. To keep these rooms comfortable, the whole house may have to be overheated or over-cooled, making other rooms uncomfortable and wasting energy. In the worst case, the only way to keep the whole house comfortable may be to keep some windows open while the heat or air conditioning is on!

One way to balance your system is to have a qualified contractor do the work. Since you probably do not have design drawings for your house specifying correct air flows, the contractor must calculate the air flow required for each room (based on size, use, and exposure to the outdoors) and balance the system to his calculated flows. The contractor should also ask you what rooms are uncomfortable, and take your preferences into account.

You can also adjust the balance of your air distribution system yourself. If you have a room that doesn't get enough air (too cold in winter and too warm in summer):

• Check if the damper to the room is fully open. If not, open it further.

• If the damper is already fully open, slightly close all other dampers on the distribution system to force more air into the room in question.

Getting all your rooms comfortable may take some experimentation. Adjust some dampers, see how the occupants like it, and then try again if they're still not comfortable. Be careful not to close dampers off any more than necessary, since closing too many dampers hurts system efficiency and generates noise.

Remember: your house is a system, and you are part of the system. If you aren't comfortable, the system isn't working right!

Insulate ducts and hot water distribution pipes

Insulating your duct system, particularly if ducts are located in unconditioned areas (attic, crawlspace, unheated basement), is usually very cost effective and can save significant money on your heating and cooling bill. Insulation will keep the heated air inside the duct warm and the cooled air inside the duct cool. Be sure to use the appropriate type of insulation and if there is any doubt, consult a professional. Obtaining the services of a professional is always a good idea because insulating the duct system must be done correctly.

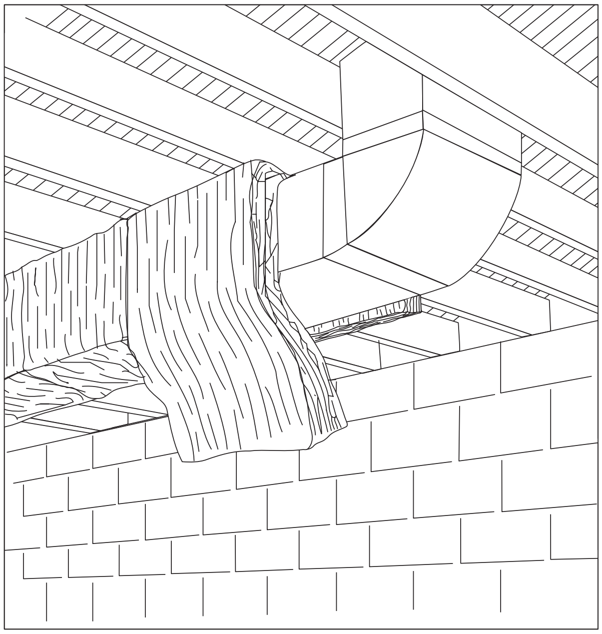

Figure 5-9 - Ducts and pipes that run through unheated spaces should be insulated. Special insulation is available for both types of systems. Keep in mind that duct insulation is not a good air seal. Have your ductwork sealed against air leakage before wrapping it with insulation.

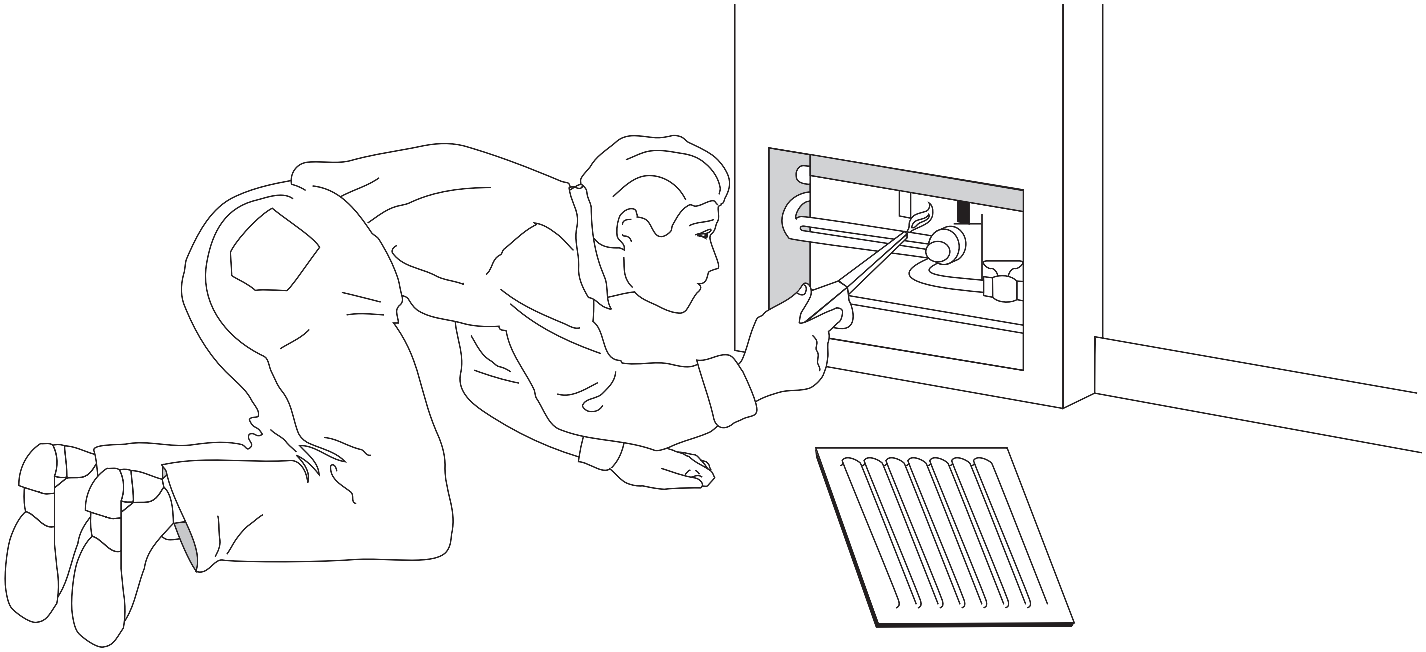

Figure 5-10 - Gas Furnace service

Make sure that all leaks have been repaired and tested before insulating the duct system.

Have your system inspected, cleaned and tuned up by a professional service contractor

Regardless of the type of system in your home, you should have your heating and cooling system inspected and maintained on an annual basis. Professional cleaning and maintenance will not only assure optimum efficiency, but will also extend the life of the appliance and insure the health and safety of the occupants.

Gas furnaces and boilers

Your service contractor should check the combustion efficiency of your gas furnace or boiler by measuring flue gas temperature, oxygen, carbon monoxide, and draft. He or she should also check the heat exchanger for dirt buildup or leaks. Dirt buildup on the heat exchanger can significantly reduce efficiency, particularly with high efficiency condensing gas furnaces, which have two heat exchangers. See Figure 10.

Oil furnaces and boilers

Oil-fired appliances are more complex than gas systems and generally require more frequent maintenance. Your service contractor should check the operation of the oil-burner and make any necessary air and fuel flow adjustments to produce the proper flame. He or she should also clean the burner nozzle and heat exchanger. After servicing the system, your contractor should perform an efficiency check by measuring stack gas temperature, oxygen reading, carbon monoxide, draft test and smoke levels. If the efficiency cannot be brought up higher than 70%, you should consider installing a new burner or even replacing the heating system itself with a higher efficiency, Energy Star unit. Modern “flame retention” burners provide much higher efficiencies than the conventional burners found in most older furnaces and boilers.

Make sure that the contractor inspects your vent pipes and chimney for dirt, obstructions, disconnects, and whether the chimney is lined properly. If your contractor is doing these tests with no testing equipment other than a cigarette lighter and a flashlight, then you are not getting the professional service that your system needs.

Your furnace should be inspected by a qualified professional every year.

Heat pumps and air conditioners

Of all residential mechanical systems, heat pumps and air conditioners can benefit most from professional maintenance and servicing. In addition to the usual problems resulting from normal wear and tear, many heat pumps function very poorly simply because they were installed incorrectly. Field studies have shown that heat pump and air conditioner efficiency can be commonly improved as much as 30% through proper tune-up and repair. At a minimum, regular inspection is recommended every two to three years but an annual check up is a good idea as well.

Make sure your outdoor unit is properly ventilated and shaded

The outdoor unit of your air conditioner should have at least two feet of clearance on all sides for proper airflow. Some installers and homeowners try to hide the outdoor unit by placing it under a deck or by surrounding it with bushes. This is not a good idea because if the air circulation to the unit is restricted, it cannot reject heat efficiently and system performance will be degraded.

The outdoor unit should also be elevated to keep the coils free of snow and other debris such as leaves. In Virginia, code requires that units be elevated at least 3" above grade, but more elevation may be desirable in areas with a lot of snow.

If possible, the outdoor unit should be shaded from direct sunlight in summer so that it may run cooler and reject heat more efficiently. Ideally, it should be located so that it is shaded in summer, but exposed to sunlight in winter to improve wintertime heating performance. Don't place the unit directly under a roof pitch that might dump snow onto the unit in winter.

If your outdoor unit is improperly located or protected, consult with your service contractor about having it relocated.

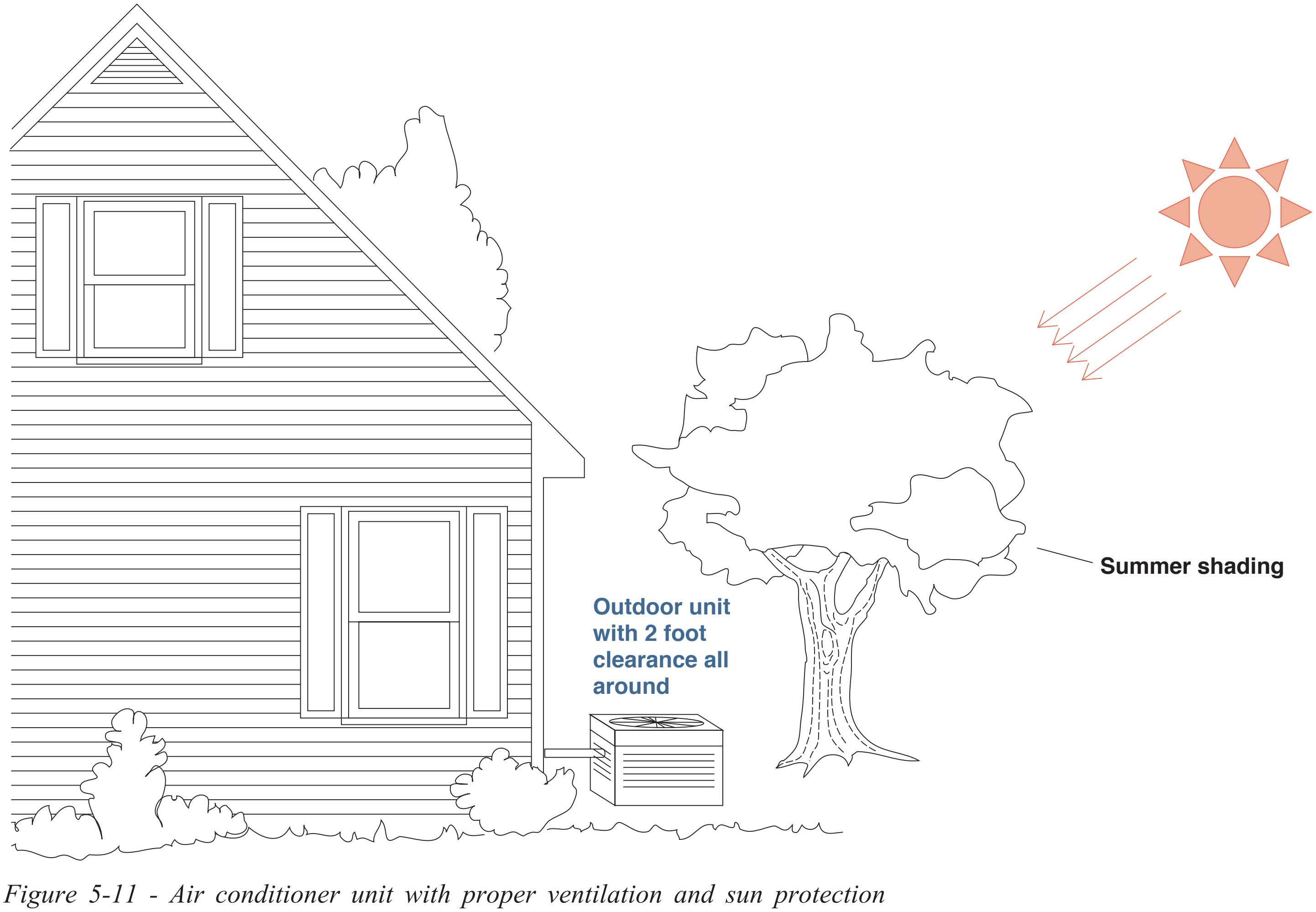

Figure 5-11 - Air conditioner unit with proper ventilation and sun protection

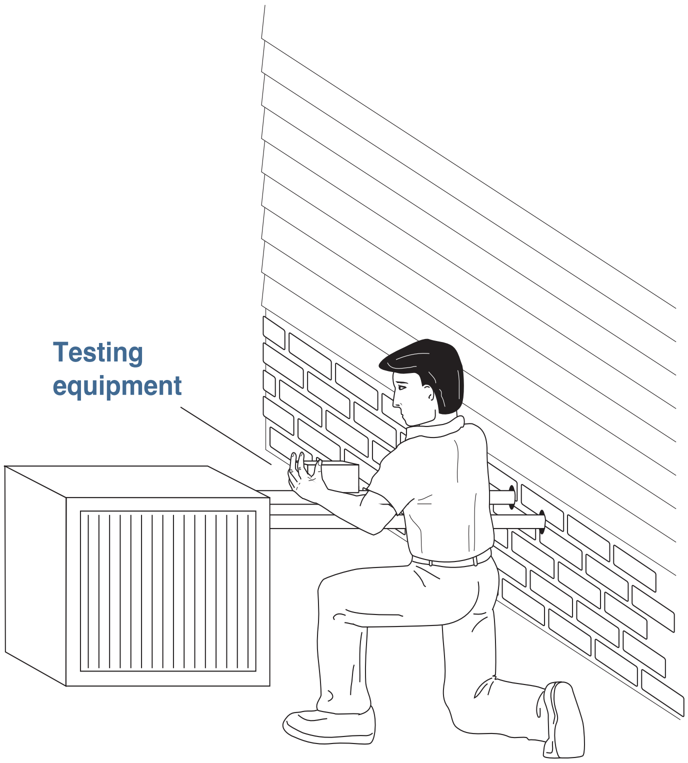

Figure 5-12- Service person should check refrigerant charge as part of routine inspection.

Call for a service inspection and maintenance

Have your service contractor perform all the following inspections and maintenance procedures.

1. Inspect and clean both indoor and outdoor coils

The indoor coil in your air conditioner acts as a magnet for dust because it is constantly wetted during the cooling season. Dirt buildup on the indoor coil is the single most common cause of poor efficiency. The outdoor coil should also be checked and cleaned if necessary.

2. Check the refrigerant charge

The circulating fluid in your heat pump or air conditioner is a special refrigerant gas that is put in when the system is installed. If the system is overcharged or undercharged with refrigerant, it will not work properly. Have your service contractor check the charge and adjust if necessary.

3. Check the airflow over the indoor coil

All residential air conditioners are designed for a specific volume of airflow across the indoor coil — typically about 400 cfm per ton of cooling (A "ton" of cooling equals 12,000 Btu/hr - the amount of heat necessary to melt one ton of ice in a day.)

Low airflow can be caused by dirty filters, dirty blowers, dirty coils, closed supply registers, or (most commonly) by improper duct sizing. Although the remedy to this problem may not be simple, it could significantly improve system performance.

Upgrading to High Efficiency Heating and Cooling Equipment

When to replace your existing system

Deciding when to replace an old system is not easy. Unless your present system is old and in very poor working condition, it may be hard to justify a new high efficiency system on energy savings alone.

The most important information comes from your service contractor. If a heating system's steady state operating efficiency is lower than 70%, you should consider a new unit. Particularly for a large home with a high heating load, the annual dollar savings from installing a new system may pay for the new system in a short time.

Ask your contractor to do a load calculation to determine the proper sizing of your system. If your system is undersized or oversized, this may be an additional reason to replace the existing system.

For heat pumps and air conditioners, the situation is not as straightforward since it is not easy to measure the efficiency. If your system loses cooling capacity or if the compressor fails completely, you may want to take the opportunity to move up to a high efficiency system rather than just replace the old compressor. Sometimes a failed compressor is just the first of many component failures that may end up costing you more in the long run.

Shopping for efficiency

Discussing efficiency of home heating and cooling appliances can sometimes turn into alphabet soup - AFUE, EER, SEER, HSPF, are all common terms for expressing how well a system uses energy to heat or cool the home. Despite the apparent complexity, the basic concepts are relatively simple. Be sure to look for Energy Star certified

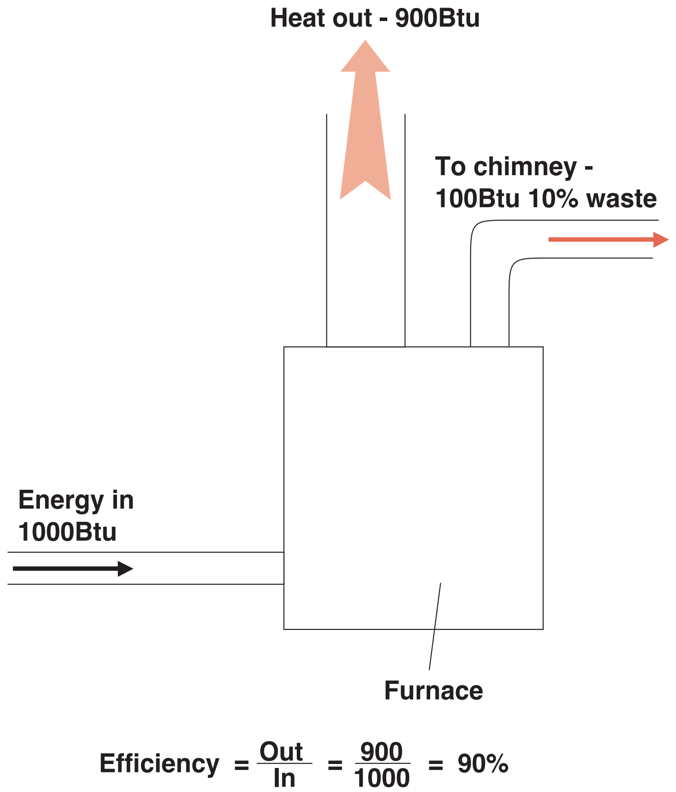

Figure 5-13 - Efficiency is defined as "heat out" divided by "energy in".

equipment. They will always rank in the highest classifications of AFUE, EER, SEER, and HSPF.

"Efficiency" is defined simply as "heat output" divided by "energy input"

Let's look at a gas furnace. It uses the chemical energy contained in natural gas (the energy input) to deliver warm air into the house (the heat output). If the furnace delivers 900 Btu of heat per cubic foot of gas (which contains 1000 Btu), then the efficiency is 90%. The other 10% is lost up the chimney.

As another example, consider an electric space heater that converts electric energy into heat energy. Because it is located in the heated space and has no flue losses, it delivers exactly 3413 Btu of heat for every kWh of electricity consumed (1 kWh = 3413 Btu). Electric space heaters are always 100% efficient. Since electricity costs much more per Btu than gas, however, this doesn't translate into low energy costs.

Many modern fuel-burning appliances have efficiencies above 90%, but old poorly maintained units are sometimes as low as 50%.

The AFUE denotes furnace and boiler efficiency over an entire heating season

Furnaces and boilers are rated according to their "Annual Fuel Utilization Efficiency" or AFUE, which is a measure of efficiency over an entire heating season. Heating equipment may have a different efficiency at part load (cool weather) than it does at full load (very cold weather). AFUE gives the average efficiency for a typical winter, using a formula developed at the U.S. Department of Energy. (USDOE)

Heat pump efficiency is measured by the HSPF

Heat pumps do more than just convert electricity into heat; they pump heat from outdoors to indoors (see description above). The heat output is almost always more than the input.

Since the performance of a heat pump depends on outdoor temperature, we use the term "Heating Season Performance Factor" (HSPF) which is the total heat output over a typical heating season, measured in thousand Btu's, divided by the total electric input in kilowatt hours. Typical HSPF for modern heat pumps ranges from 6.8 to around 10.0. Like the AFUE for furnaces and boilers, the HSPF is calculated using a formula developed by USDOE.

Since lower outdoor temperatures decrease heat pump efficiency, heat pump HSPF depends on climate. If you live in a cold area, the performance of a heat pump will be lower than the HSPF for a typical season; if you live in a warm area it will be higher.

Air conditioners are rated by EER or SEER

Air conditioner performance is expressed as the "Energy Efficiency Ratio" (EER) or "Seasonal Energy Efficiency Ratio" (SEER). The EER is the amount of heat energy removed from the house when the air conditioner is running, measured in thousand Btu's, divided by the amount of electricity used, measured in kilowatt hours. EER is always listed for window air conditioners, but is usually not listed for central air conditioners or heat pumps.

High efficiency window air conditioners have EER ratings of 10.0 or above.

SEER is the seasonal efficiency of an air conditioner, essentially the average EER over a typical summer. It is calculated as the amount of heat removed from the house over an entire cooling season, in thousand Btu's, divided by the electricity consumed, in kilowatt hours. SEER is always listed for central air conditioners and heat pumps.

High efficiency central air conditioners have SEER ranging from 10.0 to as high as 17.0.

The Federal Standards

The National Appliance Energy Conservation Act (NAECA) sets minimum efficiency standards for all home heating and cooling equipment. All new equipment for sale must meet NAECA standards. You can save money and energy, however, by buying equipment that exceeds the minimum NAECA standards.

The Federal Energy Management Program (FEMP) lists recommended efficiencies and the efficiencies of the best equipment currently available. The FEMP recommended efficiency is also the minimum efficiency allowed for Energy Star labeling.

Consider your fuel options

When replacing your existing heating or cooling system, you may want to consider switching to a different fuel. The best fuel for you may not be immediately obvious.

When selecting fuel type, you need to consider both efficiency and cost (and of course availability).

Which fuel is most expensive? That depends on both purchase price and the efficiency of your heating system. Together they determine the delivered cost of energy to heat your home.

Table 5-2 lists the purchase price per million Btu for the common residential fuels used in Virginia. Notice that electricity is more than three times as expensive as natural gas. But this doesn't mean that electricity is always the most expensive fuel to use.

Table 5-3 lists the delivered energy cost for various types of heating systems and fuel types. Notice that a high efficiency electric heat pump (9.0 HSPF) is less expensive to operate over a typical heating season than an oil or gas furnace. In colder climates heat pump HSPF decreases while furnace AFUE stays fairly constant, so the relative cost of heat pump and furnace operation may change.

Table 5-1 – Recommended and Best Available efficiencies for heating and cooling appliances according to the Federal Energy Management Program.

Equipment	Performance Units	Recommended	Best Available
Air Conditioners			
Window < 20,000 Btu/hr	EER	10.7	11.7
Window > 20,000 Btu/hr	EER	9.4	10.0
Central Split-System	EER SEER	11.0 13.0	14.6 16.5
Central Unitary	EER SEER	10.5 12.0	12.2 16.0
Heat Pumps			
Air-Source Split-System	HSPF EER SEER	8.0 11.0 13.0	9.6 14.9 17.4
Air-Source Unitary	HSPF EER SEER	7.6 10.5 12.0	8.3 12.0 15.6
Ground-Source Closed Loop	EER	14.1	25.8
Ground-Source Open Loop	EER	16.2	31.1
Furnaces			
Gas and Oil Furnaces	AFUE	90%	97%

Table 5-2 - Fuel prices in Virginia

Fuel type	Cost per million Btu purchased(2000 average prices)
Electricity	$22.04
Propane	$17.34
Natural gas	$9.64
Fuel oil	$9.47
Coal	$3.12

Table 5-3 - Delivered energy costs with various types of heating systems.

System type	Cost per million Btu delivered (1993 average prices)
100% electric space heater	$22.73
80% oil boiler	$10.25
78% natural gas furnace	$9.52
9.0 HSPF heat pump	$8.44
93% natural gas furnace	$7.99

NOTE To calculate the cost per million Btu of delivered energy at differing fuel prices, use the following equation:

Cost per million Btu ($) = (Unit fuel price) x 1,000,000 / (Btu per fuel unit)(Table 4)

Example: For electricity at $.06 per kWh:

Cost = ($.06) x 1,000,000 / 3413 Btu per kWh
= $17.58

Table 5-4 - Btu content in various fuel units

Fuel Type	Unit	Btu content
Electricity	kWh	3,413 Btu/kWh
Natural gas	ccf	100,000 Btu/ccf
Propane	gallon	96,000 Btu/gallon
Fuel oil	gallon	138,000 Btu/gallon
Coal	ton	27 million Btu/ton

For gas heating, consider a power vented or sealed combustion furnace or boiler

"Atmospheric vented" or "natural draft" furnaces and boilers, which rely on natural buoyancy to carry flue gases up the chimney, are sometimes subject to flue gas "spill-age" or "backdrafting" into the house. The cause of the problem is competition between the furnace and other exhaust appliances such as clothes dryers, central vacuum cleaners, range-top stove exhaust fans, and even bathroom exhaust fans. The negative indoor pressure created by those fans can reverse the flow in the chimney, drawing the flue gases back into the house.

Power vented furnaces and boilers have a small blower that pulls combustion air to the heating system, making them much thus less prone to spillage or backdrafting. Sealed combustion furnaces are also power-vented and use outdoor air for combustion, making them completely immune to the problem.

But in all cases, make sure that your vent pipes and chimney are code and manufacturer approved and that they are clean and unobstructed. Backdrafting or spillage can result from obstructed or improper venting.

Operating Your System For Maximum Efficiency

Never turn the thermostat up high for faster heating

Your thermostat is an on-off switch that simply goes to "on" whenever the temperature in the house passes the setpoint. Simple as it is, the way you use your thermostat can significantly affect your heating and cooling energy consumption.

Unlike a gas pedal in a car, pushing the thermostat higher does not usually make the house heat or cool any faster. It just makes the system run longer. The system runs at maximum capacity as long as the thermostat calls for heating or cooling. By pushing the thermostat farther, you may cause the house to overheat or overcool, thus wasting energy.

One exception to this is with heat pumps. Pushing the thermostat higher with heat pumps may bring on the auxiliary electric resistance heater. Although you will get more heat, it will be expensive due to the high operating cost of electric resistance heat.

Reduce your thermostat setting whenever the house is unoccupied

Thermostat setback in winter and setup in summer always saves energy. As a rule of thumb, you will save about 3% for each degree of setback. Keep the thermostat set as low as you can in the winter and as high as you can in the summer. A rule of thumb setting is 78°F in the summer and 68°F in the winter but this depends on different variables. The important thing is to understand that how you set or operate your thermostat can have a very significant impact on your energy bill. Your house is a system and even if your home is well insulated with an energy efficient heating and cooling system, this can all be minimized if you operate your thermostat inefficiently.

One possible exception is with heat pumps, which may resort to supplemental resistance heat to recover from setback. In general, there is little to be gained by manually setting back a heat pump thermostat unless it can be left set back for 24 hours or more.

Programmable thermostats can save as much as 10% on your heating and cooling bill by automatically setting the thermostat when the house is not occupied or when the occupants are asleep. Using a programmable thermostat allows you to adjust the times you turn on a heating or cooling system according to a pre-set schedule. Be sure to look for the Energy Star label if shopping for a programmable thermostat.

A few special programmable thermostats are made specifically for heat pumps. These thermostats start the heat pump early – before the heat is required – and then use electric resistance heat to warm the house only if the heat pump is unable to get the job done on time.

Use the sun wisely in both summer and winter

The primary source of cooling load in summer is solar heat gain through windows. By controlling sunshine into windows with interior shades, exterior shutters or yard plantings, you will make the house more comfortable and reduce cooling energy costs.

In winter, solar gain through windows can provide useful space heating energy.

On sunny days, keep window shades open on south-, east-, and west-facing sides of the house.

For more information on passive solar heating see Chapter 10.

Wood Burning Appliances

Wood heating appliances have changed radically over the past decade. Modern wood stoves are far more efficient and clean burning than their pot-bellied predecessors. The efficiency of new wood heating appliances ranges from 65% to 78% and averages about 72%. Although this efficiency is lower than that for gas or oil-fired furnaces, wood heat may still be the most economical alternative in areas where wood is plentiful and inexpensive.

Wood heat and the environment

Although wood heat is generally regarded as "environmentally friendly" since wood is a renewable resource, wood smoke contains a plethora of combustion products, many of which are potentially hazardous air pollutants such as carbon monoxide and "polycyclic organic material" (POM). In some regions with climatic temperature inversions, such as Juneau, Alaska and Denver, Colorado, local authorities have passed ordinances limiting the use of wood stoves and/or requiring special low-emission stoves.

In 1988, the U.S. Environmental Protection Agency (EPA) passed emission standards for new wood stoves and fireplace inserts. The regulations reduce the average smoke production from about 3 pounds per day, which is typical for most older wood stoves, to less than 1/2 pound per day from stoves that meet EPA standards. All new wood stoves manufactured after July 1, 1990, or sold at retail after July 1, 1992, must now be tested and certified to meet the new EPA standards.

Although the reason behind the new standard is to control outdoor air pollution, two side benefits are increased efficiency and safety (less creosote formation and thus less fire hazard).

To comply with the standards, manufacturers have redesigned appliances and added new technologies. The most common new component is the "catalytic combustors".

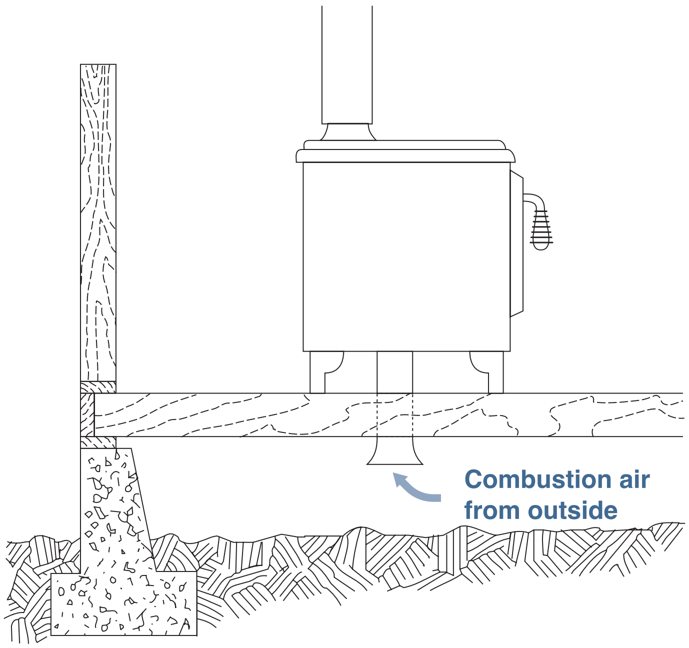

Figure 5-14 - Wood stoves should have outdoor combustion air intakes to avoid backdrafting and to reduce air leakage into the house.

A catalytic combustor is similar to the catalytic converter in a car. A metallic catalyst (usually platinum or palladium) on the combustor enhances smoke combustion at lower temperature so that more smoke is burned and less is exhausted up the chimney.

Catalytic combustors are now incorporated into many new wood stoves and can also be added to existing stoves using special retrofit devices. One possible drawback to stoves with catalytic combustors is that the catalyst has a limited lifetime that varies anywhere from 1 to 10 years. The combustors also require some special care to prevent clogging.

Not all certified wood stoves have catalytic combustors. Some manufacturers have improved their designs in other ways to meet federal emission standards without catalytic combustors. The advantage of these appliances is that they should not lose burning efficiency over time as do stoves with catalytic combustors.

Wood furnaces, wood stoves that connect to a duct system to heat the whole house, are exempt from most wood stove emissions regulations and therefore do not usually include catalytic converters. Separate catalytic converters can be bought and installed on wood furnaces, but care must be taken to ensure that the converter does not interfere with the furnace draft.

Selecting a wood stove

Wood stoves are available in a variety of styles, efficiencies, and heating capacities. The following are a few features to check when comparing models:

Sealed Combustion

Wood stoves need large volumes of air for combustion and to help induce draft. This means that large amounts of household air will be needed to make a woodstove burn and draft properly. When selecting a woodstove try to purchase a sealed combustion model or one that can be modified to provide combustion air sources from outside. This is especially important if you live in a mobile home or a house with small volume. Make sure the unit is mobile home approved and certified if you are installing it in a mobile home.

Cast iron versus steel

Some stoves are made from steel plates that are welded together; others are made from cast iron components that are bolted together. Cast iron stoves are typically heavier, take longer to heat up and hold their heat longer after the fire burns out. Neither type is inherently more efficient.

Soapstone

Soapstone wood stoves take advantage of thermal mass principles and stores heat in the soapstone brick. Then it slowly releases the heat long after the fire has gone out. These stoves are environmentally friendly because burning a hot fire for a short time is more efficient, and produces fewer emissions, than burning a low fire for a long time. Soapstone stoves, however, are very expensive.

Fireplace inserts

A fireplace insert is basically a wood stove designed to fit into a conventional open fireplace. Like conventional stoves, inserts may be made of cast iron or steel, and may come with or without glass doors. Some inserts have catalytic combustors, and there are some that burn pellets.

Inserts either fit in the opening of the fireplace or protrude onto the hearth. The latter position is more efficient because the sides, top, and bottom provide additional radiant heat. Some inserts have integral blowers that circulate room air through the heater, providing enhanced heating as well as increased efficiency. The blower may be either manually or thermostatically controlled.

In the past, most installers placed inserts in fireplaces without any chimney connections. This method, in some cases, allowed creosote to build up inside the fireplace, presenting a potential fire hazard. To prevent this, the National Fire Protection Association (# 211) now requires that inserts be installed with a connector between the appliance outlet and the first section of the flue liner. Fireplace inserts have one major drawback: they weigh over 400 pounds. This can be a problem when they need to be moved so that the chimney can be cleaned. However, the insert can stay in place if you install a full relining collar — a stainless steel pipe that connects to the insert and goes to the top of the chimney.

Fan-driven heat exchangers

Many manufacturers supply stoves with fan-driven heat exchangers either as standard or optional equipment. These heat exchangers increase heat output and energy efficiency. Their disadvantages are that they make some noise and that they won't work in case of an electric power failure.

Heat reflecting glass doors

Many stoves come with glass doors and a few manufacturers now use special heat-reflecting glass that improves combustion efficiency by keeping more heat in the stove than with conventional glass.

Convenience features

There are a variety of convenience features available including a thermostat control that automatically controls combustion air, insulated handles for easy door opening without a pot holder, and a removable ash pan for easy ash disposal.

Pellet fuel

Pellet fuel is manufactured from a variety of materials compressed to resemble animal feed. The pellets may be made from sawdust, bark, wood shavings, cardboard, peat, or agricultural wastes like corn husks and rice hulls.

Apart from the fact that they both burn solid fuel, there are few other similarities between pellet stoves and wood stoves. In a pellet stove, the pellets are poured into a hopper, from which an auger, a corkscrew-shaped device, transfers the pellets into the fire chamber as needed. A mechanical blower provides combustion air and other fans distribute the heat into the living area. The rate at which the fuel is burned and the speed of the fans may be controlled by thermostats. Some pellet-burning appliances use elaborate electronic circuitry that does everything from controlling the circulation air to sounding a buzzer to let the user know the stove is low on fuel.

A major advantage of pellet stoves is that they need to be refueled less frequently than most wood stoves; refueling varies from once a day to only twice a week. Pellet stoves pollute very little and are highly efficient, with an average efficiency of 78%. The creation of creosote and ash is reduced or eliminated, depending on the type of pellet being burned. The flue gases are relatively cool and can be exhausted through a side vent in the wall to the outdoors. The exterior surfaces of the heater are also relatively cool, reducing the risk of accidental contact burns.

However, pellet-burning appliances also have disadvantages. The internal fans, which may require around 100 kWh of electricity each month, add to the total energy bill. Also, since the fans are necessary for operation, the stove will not function during a power outage. Because using pellets is a relatively new way to burn fuel, the fuel is expensive and often difficult to find.

Chimney safety

Studies have shown that house fires related to solid fuel heating appliances often originate around the chimney or stovepipe. The main causes of fires are insufficient clearance from combustibles, creosote build-up, use of a single-walled stovepipe as a chimney, and leaks and cracks in the chimney. Chimneys require some care and attention in order to reduce fire hazards.

All chimneys that service a wood-burning appliance should be lined with a code-approved liner. Chimney liners come in three main types: Clay tile, metal, and cast-in-place. Clay tiles are the most common and if kept clean they perform fairly well. But they can deteriorate due to moisture and crack because of expansion. They are not suitable for gas appliances and if cracked or in disrepair they should be replaced. Metal chimney liners, usually stainless steel or aluminum, are commonly used for upgrading and repairing existing chimneys. These liners are very safe and durable and if properly installed keep the flue gases hot, which promotes draft and inhibits creosote build up. They generally work best with an approved high temperature insulation installed on the outside of the liner. Metal liners work well with wood, oil, and gas and the aluminum liners can be used very effectively in certain gas applications. Cast-in-place liners are made of a light-weight cement product and are excellent for restoring the structural integrity to old chimneys. They are very durable and are suitable for all fuels. But they can also be very expensive to install.

An unlined chimney can have cracks, missing bricks and mortar that has deteriorated and is non-existing. This is not only a fire hazard but allows cool winter air to infiltrate the chimney and dilute the hot flue gases. This dilution will cool the hot flue gases and cause condensation that can lead to chimney deterioration and creosote build up, and will impede draft – cooler flue gas will be heavier and exit the chimney slower – which can effect the efficiency of your furnace and make back-drafting more possible.

Stoves and chimneys should be installed according to the manufacturer's instructions, and inspected by a local fire or building inspector. The chimney or stovepipe must be as specified in the installation instructions for the appliance, and if a chimney connector is required, it must be of the correct gauge (thickness). Chimney connectors should be kept at least 18 inches from stud walls, ceilings, curtains, or any combustible materials. Achieving proper clearances from combustibles is a critical safety measure in preventing residential fires. Consult your local building inspector, a licensed heating contractor, or a local fire marshal if you are unsure about clearance requirements. Chimney cleanouts should be installed to make soot and creosote removal easy, especially for woodstoves. Where the chimney exits from the roof it should be at least three feet taller than the roof, and two feet taller than any roof surfaces within ten feet.

In using the appliance, there are several things that can be done to prevent creosote build-up. Start each fire at a high burn rate for about 30 minutes to bring all surfaces up to operating temperatures. Short, hot fires are more efficient and produce less creosote than long, slow-burning fires. Avoid overloading the stove. Try to burn only dry and seasoned wood. Green wood is full of moisture, which will produce a cooler flame and flue gas and promote creosote formation.

Finally, chimneys should be inspected and cleaned if necessary at least once a year and stovepipe should be checked every few weeks. Be sure that the chimney and stovepipe are clean and show no signs of wear or deterioration. Creosote should be removed when it accumulates to one-eighth to one-quarter of an inch. Consider using the services of a professional chimney sweep on an annual basis to clean your chimney and provide a thorough safety inspection of your entire venting system. Be sure that the chimney sweep is qualified, experienced, and has references.

It is absolutely imperative that you have UL- rated smoke alarms and carbon monoxide detectors placed in appropriate places within the home – whether you use wood as a fuel or have any combustion appliance in the home. Consult your local building inspector or fire department if you need more information. Smoke alarms and carbon monoxide detectors are mandatory safeguards that save lives on a daily basis.

Un-vented Heating Systems

Un-vented combustion space heaters, which include natural gas, propane, and kerosene fueled free standing heaters, fireplaces, unvented gas logs and wall- mounted heaters are not recommended due to significant health and safety concerns. These systems are growing in popularity even though vent-free heaters have been banned for use in homes in five different states.

Unvented combustion heaters use indoor air for combustion and vent the combustion by-products directly into the living space. These by-products include nitrogen oxide, carbon monoxide, and large amounts of water vapor that can cause mildew, condensation, mold, and potential for rotting of walls and ceilings.

Unvented heater manufacturers claim that the systems are safe because they operate with maximum combustion efficiency. But this is only possibly true if nearby windows are cracked open and the system is installed correctly, properly maintained, and operated according to manufacturers specifications. Gas heaters are also required to have oxygen depletion sensors that will cut off the gas if the oxygen in the room is depleted below acceptable levels. These systems should never be used in a room where people are sleeping or where it will be unattended and should never be used in mobile homes or air-tight houses.

With all of the potential problems that exist, it is recommended to avoid the use and purchase of unvented heating systems.

Energy Tips and Recommendations

1. Reduce your heating and cooling load by treating your house as a system and recognizing that a well insulated, air tightened house with good energy decision making occupants will be a household that is much easier to heat and cool.
2. You may significantly improve the heating and cooling systems in your home by replacing them with more efficient units, by repairing and maintaining the units and the distribution system, by operating them more efficiently, and by making sure that the venting systems are safe and in good condition.
3. Be sure to consider all options before replacing your heating or cooling system. Obtain professional advice if necessary and always check the Annual Fuel Utilization Efficiency (AFUE) rating on furnaces and boilers, the Heating System Performance Factor (HPSF) for heat pumps, the Energy Efficiency Ratio (EER) for window air conditioners, and the Seasonal Energy Efficiency Ration (SEER) for central air conditioners. Make sure any new heating or cooling system you may purchase has an Energy Star label.
4. Change your furnace and air conditioner filters every one to three months or whenever necessary.
5. Be sure to have your duct system tested for air leakage by a professional. Duct leakage can account for significant energy loss and potential health and safety issues.
6. Make sure that your duct system is properly insulated – particularly if it is in an unconditioned space.
7. Get your heating and cooling systems inspected by a professional - preferably on an annual basis. The inspection should be thorough and include the use of testing and diagnostic equipment. All systems should be checked for efficiency and safety.
8. Use your thermostat to maximize the efficiency of your heating and cooling systems. Set your thermostat for 68°F in winter / 78°F in summer, don't turn it up high for faster heating, and (except for heat pump systems) set back the temperature when the house is unoccupied.
9. Use the sun to maximize solar heat gain in the winter and find ways to control that solar heat gain in the summer.
10. Make sure that all wood burning appliances are installed correctly and have adequate clearances from any combustibles.
11. All vent pipe and chimneys should be cleaned on an annual basis or sooner if needed. Be sure that all chimneys are properly lined and free of any obstructions.
12. Avoid using any unvented heating system, including portable kerosene heaters, unvented gas logs, unvented gas fireplaces, and unvented wall mounted heaters.
13. Install UL rated smoke alarms and carbon monoxide detectors in all recommended locations within the home.