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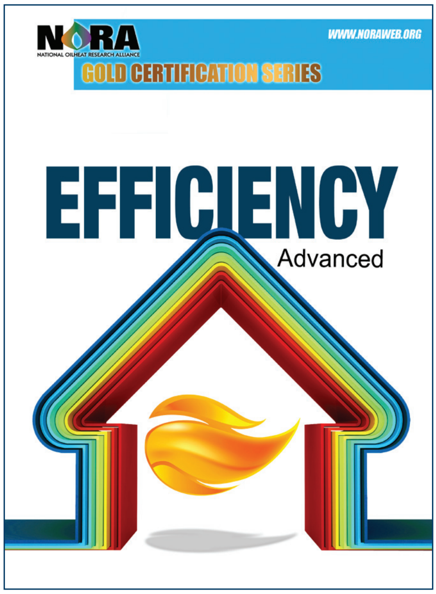

This publication is designed to serve as a training guide and to be used in conjunction with a course taught by a qualified instructor.

The reader should use local codes and equipment manufacturer's specifications and instructions in setting up and maintaining equipment.

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Chapter 1
The Science of Oil Heating

Introduction
The purpose of this book is to help Oilheat Technicians:

- Maximize customers' heating systems efficiency without sacrificing safety, reliability, or comfort
- Understand how heating systems and buildings lose energy
- Understand basic building science
- Understand how the HVAC system and the building interact
- Understand measurements of efficiency
- Maximize the efficiency of the existing system
- Evaluate energy conservation investments
- Reduce Oilheat's environmental impact

Oilheat Technician—Energy Expert
One of a service technician's most important responsibilities is to see that their customers' heating systems are operating as safely and efficiently as possible. According to the Energy Information Agency, as much as 58% of the total energy use in the home in the Northeast and Mid-Atlantic States is for space heating and 17% is for water heating. This means that Oilheat Technicians are responsible for maintaining up to 75% of the energy used in a home. Efficient Oilheat equipment is more reliable, safe, clean and economical than ever. Customers with efficient, modern heating equipment are more satisfied with their service provider and with Oilheat.

Service procedures are critical to performance and a furnace or boiler that is not set up properly will waste fuel. Properly calibrated combustion test equipment must always be used to adjust the burner for peak efficiency. Otherwise, the full efficiency of the boiler or furnace will not be reached and Oilheat's customers will not realize its full advantages.

The Science of Oil Heating
Understanding the terminology and the science of heat is vital in helping technicians to install and service heating equipment properly.

Comfort
Oilheat systems help make homes comfortable. Comfort is affected by:

- Air temperature
- Air velocity
- Relative humidity
- Radiant environment
- Activity level of the occupants
- The insulating value of the clothing worn

Air temperature has a big impact on comfort. The higher the temperature of the room, the slower heat will be lost from the body. The colder the temperature, the more quickly heat will be lost. This is a basic law of heat transfer. People are most comfortable in the winter when the heat transfer from their bodies to the surroundings is minimized.

People also lose heat from direct contact by sitting or lying on a cold surface. The heat leaves the body and goes to the colder surface, making the person feel cold. Drafts blowing cool air over skin also carry away heat. Skin temperature is about 91°F. If the air blowing over the skin is colder than that, the person feels a chill. Heat radiates from the body to colder surfaces nearby, and people also lose heat from evaporation. As perspiration evaporates, it cools the skin. The dryer the air, the faster evaporation takes place and the cooler people feel.

Heat Transfer

Heat is energy in transit. Put another way, it is energy transfer due to temperature difference. Heat always travels from something hot to something cold. Heat given up by one object must equal the heat gained by the other. For one object to warm another, actual contact is not needed. Heat can travel by conduction, convection and radiation and it continues to travel until the temperatures are the same.

Heat and Air Travel

The basic rules of how heat and air move are:

- Heat flows from hot to cold.
- High pressure flows to low pressure
- Airflow carries heat through the walls and roof.
- Airflow carries water vapor into the building envelope.
- Hot air rises through cold air.

Air Pressure

Air pressure is created by the weight of the atmosphere. There are over seven miles of air above the earth. The weight of this air is called atmospheric or barometric pressure. It is a little over 14 pounds per square inch at sea level. The higher the elevation above sea level, the lower the pressure.

Barometric pressure is not constant. It changes with the weather, altitude and the dynamics of hot air rising through colder air. Fans also mechanically change air pressure. High-pressure air moves toward low pressure. Outdoors, this airflow is called wind. Indoors, it is called draft.

Conduction

Conduction transfers heat by molecular vibrations and the movement of electrons. If one end of a silver teaspoon is placed in a cup of hot coffee, it does not take long for the handle of the spoon to get hot, too. Heat is transferred by conduction from one end of the spoon to the other. Figure 1. Neither the spoon nor the coffee move, only the heat moves. Conduction is the flow of energy through a material. It is also the flow of heat from one thing to the other if they are in direct contact.

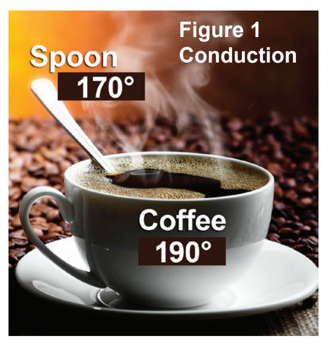


Figure 1
Conduction

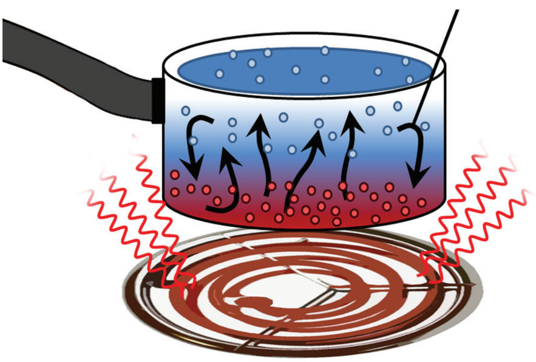
Metals such as silver, copper, steel and cast iron are good conductors of heat, while most non-metals (plastic and air) are poor conductors. Electricity and heat are both energy in motion. Good conductors of electricity are also good conductors of heat. Materials that are poor conductors, such as plastic or air, are considered insulators. Generally, good electric insulators will also be good heat insulators.

Convection

Air and water are heat sponges. They suck up and hold a great deal of heat. If they are moving, they will carry the heat with them as they move. Convection depends on motion of a fluid (liquid or gas) from one space to another, carrying heat with it.

When a fluid is heated it expands, becoming less dense, causing it to be lighter. As a result, if will rise through cooler fluid. When the

Figure 2
Convection



water in a pot is heated at the bottom, a natural flow from the bottom to top of the water column is created by differences in density caused by thermal expansion. As air or water moves, it heats the air or water it is moving through. This is called free convection or gravity flow. Old gravity warm air and gravity hot water systems depend on natural convection to circulate the air or water. (Figure 2).

A pump circulating the water in a heating system, or a fan circulating air in a furnace and ducts, causes forced convection flow. As that water or air moves, it warms the water and air it moves through.

You can feel convection taking place when air flows over your skin. As cooler air passes over your skin, it draws heat from your body and you feel cool. If warmer air flows over your skin, you draw heat from the air and feel warm.

Radiation

Radiation is transfer of heat by electromagnetic waves of energy. These waves may be visible light, infrared or ultraviolet.

Heat from the sun travels through space to warm the earth. The heat travels in the form of electromagnetic waves. Every warm object gives off this type of heat, and cool objects absorb these waves of radiation. Figure 3.

Waves of heat travel in a straight line. This is why when facing an open fire, your face will be warm and your back will be cold. You have to be able to see the heat source to receive radiant heat from it.

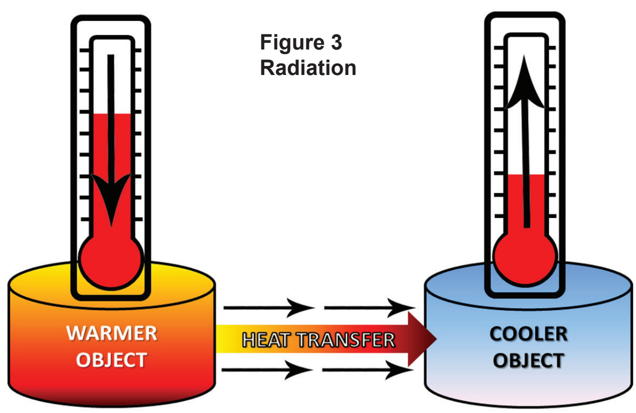


Figure 3
Radiation

Radiative heat transfer involves the production of heat at a source, its movement through air or space and subsequent absorption by another body. When you stand in front of a cold window, you radiate heat to the window and you feel cold, even though the room is warm.

If all bodies emit radiant energy continuously, why don't they eventually radiate away all their energy and cool down to absolute zero? The answer is they would if their energy wasn't being replaced in some way. All the bodies around them are also radiating energy. Some of this radiated energy is intercepted and absorbed. The temperature of the body determines the rate at which it radiates energy. The rate at which it absorbs energy depends upon the temperature of its surroundings. When a body is hotter than its surroundings, its rate of emission is greater than its rate of absorption. There is a net loss of energy. When a body is colder than its surroundings, the rate of absorption is greater than the rate of emission and the body's temperature rises.

Slowing Heat Transfer

Insulators are used to slow conductive heat transfer. Pan handles are made of plastics or wood because they are good insulators, thus keeping the handle cool.

To slow convective heat transfer (movement of hot air or water), the movement must be physically blocked. Windows in your house prevent the warm inside air from mixing with the cold outside air.

Measuring Heat

In the United States, heat is measured with the British Thermal Unit (Btu). A Btu is the quantity of heat needed to raise the temperature of one pound of water (about one pint) one degree Fahrenheit. A thermometer does not measure heat. It measures temperature.

Solid, Gas, or Liquid? Latent Heat

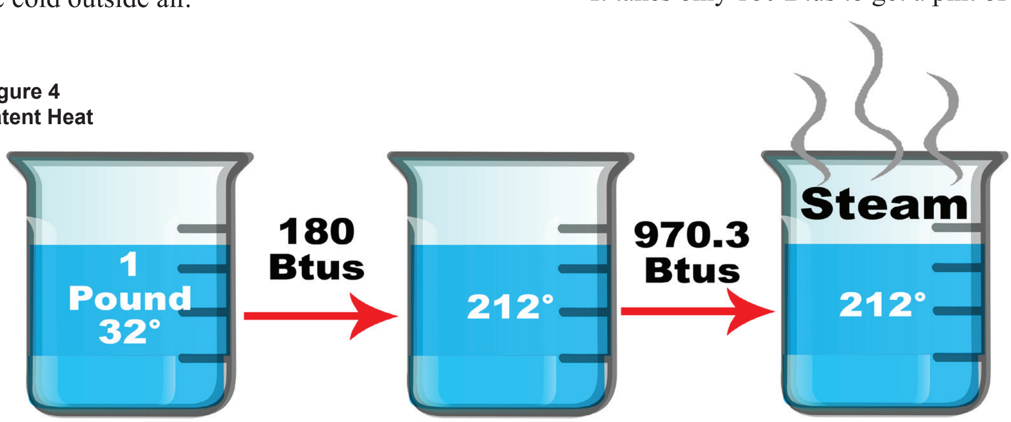
Water is an important ingredient to many heating systems. Water (H_2O) can exist in any of three states: liquid, solid or gas. When water is solid, it is called ice, and when it is a gas, it is called steam.

Moving from a solid to a liquid and a liquid to a gas are called phase or state changes. Changing phases requires a tremendous amount of energy compared to only changing the temperature.

When water changes phases, it absorbs or releases heat. To raise one pint of 32°F water (water can exist as a solid or a liquid at 32°F) to 212°F, 180 Btus of heat must be applied to the water. That would yield one pint of water at 212°F—but not steam (water can also exist as a liquid or a gas at 212°F). To get that pint of 212°F water to change state and become 212°F steam, an additional 970.3 Btus of heat must be applied. This 970.3 Btus of energy now in the steam is called the latent heat of vaporization.

It takes only 180 Btus to get a pint of water

Figure 4
Latent Heat



to rise from 32°F to 212°F, but it takes more than five times the heat (970.3 Btus) to get it to move from 212°F water to 212°F steam. There is no change in temperature, but there is a big change in the energy content of that steam. Figure 4.

The boiling point of water will vary depending upon atmospheric pressure. Water boils at a higher temperature in a hydronic boiler that is pressurized to 12 pounds than in a steam boiler open to atmospheric pressure.

Boiling is a reversible process, like freezing and melting. When heat is removed from the steam at boiling temperature, the steam returns to a liquid phase. This is called condensing. When water condenses, the same amount of heat that was needed to turn the water into steam will be released or transferred.

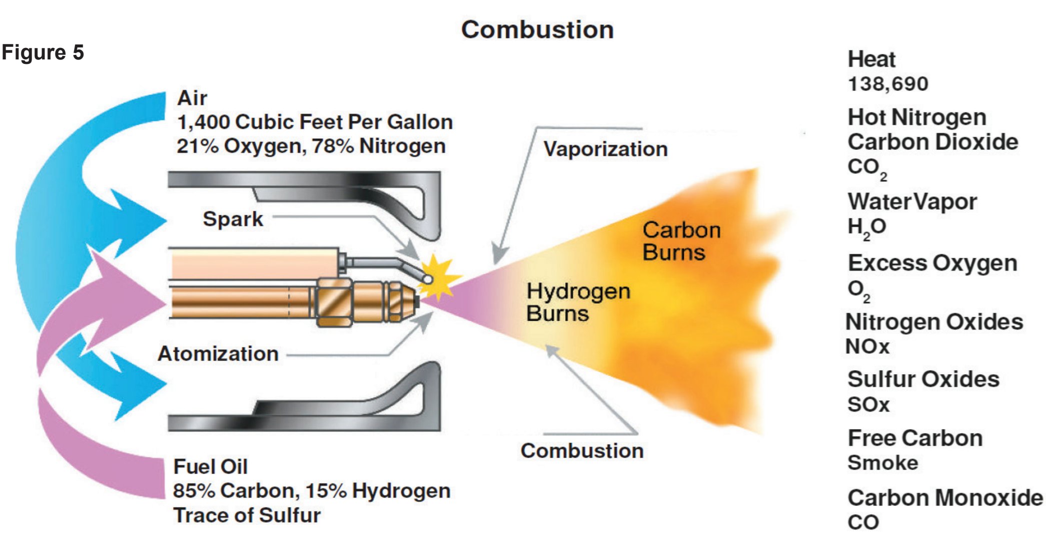
When heat is added slowly to water, the water will either change temperature or change state. For example, once the water reaches 212°F, it will stay at that temperature until all of the water turns to steam. At that point, the temperature can begin to rise again. As a result, since there is always some liquid in a steam system, the temperature of the steam in a residential steam boiler is always the boiling temperature of water (212°F at sea level) when it is making steam.

Steam heating systems use the boiling-condensing process to transfer heat from the boiler to the radiators. Since each pound of water that is turned into steam has absorbed 970 Btus of heat, the steam transfers that latent heat (970 Btus) to the radiators as it cools and moves through the system.

Lost Heat—The Steam in the Combustion Gases

When oil is burned, the hydrogen in the oil mixes with the oxygen in the air to create water. There is enough hydrogen in heating oil to create about one gallon of water for every gallon of oil burned. This water is created in the form of steam and it carries the latent heat with it as it exits the building with the rest of the combustion gases. Approximately seven gallons (59 pounds) of water are created per million Btus, which means 6.5% of the energy in the oil goes up the chimney as latent heat in the water vapor.

Figure 5



Oilheat Combustion

Oilheat Combustion is a controlled chemical reaction. All matter has potential energy and different substances have different energy levels. Every gallon of heating oil contains about 139,000 Btus of potential heat energy. When heating oil is burned, the heat energy in the fuel is discharged as it combines with air and creates water and carbon dioxide, Figure 5. Essentially, oil's carbon and hydrogen atoms' high energy is converted to water and carbon dioxide using little energy. And since energy cannot be gained or lost, the energy difference is given off as heat.

What Happens when Heating Oil Burns?

Heating oil is 85% carbon and 15% hydrogen. When heating oil burns, the hydrogen in the fuel reacts with the oxygen in the air to produce water vapor (H_2O). The carbon in the fuel combines with the oxygen to create carbon dioxide (CO_2). Since oil burners operate in widely variable conditions, there is some incomplete combustion and a small amount of carbon monoxide (CO) and free carbon (smoke and soot) may also be produced.

Every two hydrogen atoms in heating oil need one oxygen atom from the air and every one carbon atom needs two oxygen atoms for the conversion to take place. Only 21% of air is oxygen; the remaining 79% is nitrogen. This means a lot of air must move through the burner to provide enough oxygen for the fire.

Every gallon of heating oil contains 6.3 pounds of carbon and .9 pounds of hydrogen. With perfect combustion, the fuel mixes with 1,305 cubic feet of air and produces 23 pounds of CO_2, eight pounds of water and 78 pounds of nitrogen! All that nitrogen that came in with the oxygen will now absorb a great deal of heat and go up the chimney.

Time, Temperature, Turbulence

Oil burners and heat exchangers use time, temperature and turbulence to maximize their effectiveness.

Time—As the oil and air are injected into the combustion area, the mixture must stay in the area long enough to burn. However, new fuel and air are also being forced in and if the gases are moving too fast, the oil in the combustion area may be forced out before it has time to burn, creating smoke and carbon monoxide.

Flame retention burners use high static pressure to create additional time for the oil to burn through recirculation. This recirculation is created by the drop in pressure in the center of the air swirl, like the eye of a tornado. The lower pressure pulls some of the hot flame gases toward the burner head. These hot gases add heat to the fuel droplets coming out of the nozzle, speeding up their vaporization and burning rates. This yields a nice, clean, stable fire close to the burner head. Although it seems contradictory, the higher air velocity and pressure blowing out of the burner causes the flame to burn closer to the burner head.

Temperature—Oil will burn when the temperature in the combustion area is above the ignition point (about 600°F).

Turbulence —Turbulence is critical to combustion. As oil moves into the combustion area, it must be thoroughly mixed with oxygen or it will not burn. Burners subject the oil to high pressures to break it up into small particles, then swirl it with the air in the combustion area. This turbulence ensures that each droplet of oil is surrounded by enough oxygen to guarantee combustion.

In high-pressure atomizing burners, several factors control the quality of air-oil mixing.

The spray pattern of the oil droplets must match the air pattern created by the burner. Flame retention burners use high speed burner motors and air pattern shaping to create the high static air pressure required to form the high velocity air swirl and internal recirculation needed for clean, efficient combustion.

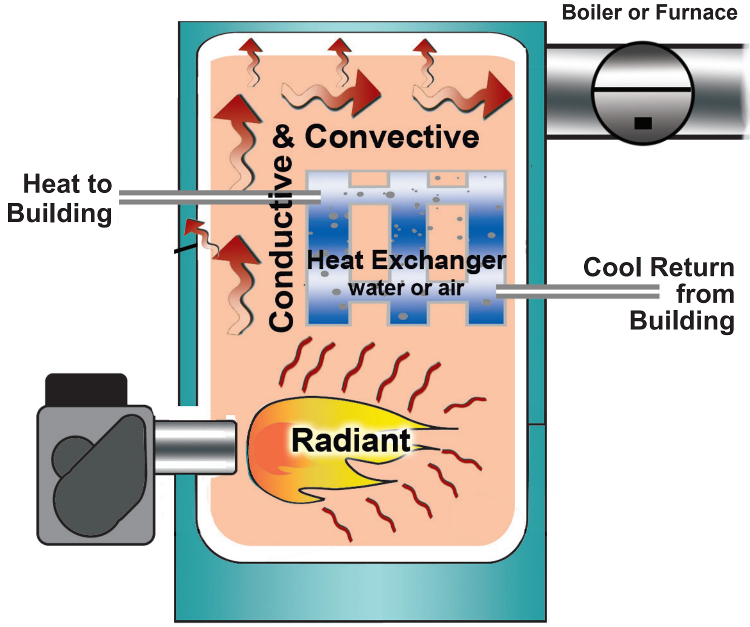
Heat exchangers also need time, temperature and turbulence. The more time the combustion gases spend in the heat exchanger, the more heat will be transferred to the living space. The hotter the temperature of the gases, the quicker the heat transfer will take place, and the more turbulent the flow of the gases through the exchanger, the more they will sweep the walls of the heat exchanger, providing better heat transfer.

Excess Air heat loss is a function of the temperature and volume of the combustion gases. As the volume of combustion gases increases, the speed at which they travel through the heat exchanger increases. The faster they travel, the less time the heat exchanger has to strip heat from the gases. The more excess air we add to the flame–the more combustion gases will flow through the heat exchanger. To do this requires the gases to flow quickly, reducing the time they are in contact with the heat exchanger. As a result, more hot gases go up the flue raising the net stack temperature and losing more energy. This lowers the steady state efficiency. All the excess air is taking heat that could be used in the house and sending it up the chimney. Air that enters the burner at 65°F from the building leaves the top of the chimney at anywhere from 200 to 600°F.

The less air up the chimney, then, the better the efficiency. That is why sealing up all excess air leaks into the heat exchanger and proper air adjustment of the burner are so important for improving efficiency.

It is also why draft regulators need to be properly adjusted. Only -.01 to -.02"wc over the fire draft is needed—just enough to slowly move the combustion gases through the heat exchanger. Over fire draft higher than -.02"wc dramatically increases both on and off-cycle losses. In some buildings, the chimney suction is so strong, two draft regulators are required to get the over fire draft down to -.02"wc. Draft regulators are a compromise. It is true that air is being pulled from the building up the chimney, but that is much better than pulling the gases through the heat exchanger too quickly. A little lost air at room temperature is a lot better than losing 300 to 600 degree combustion gases. Figure 6.

Figure 6
Heat Transfer in a Boiler or Furnace



Chapter 2

What is Efficiency?

What is Efficiency?

This chapter covers the various ways heating systems lose heat and defines the different efficiency terms used to describe heating system operation.

The purpose of oil-powered heating systems is to release the energy contained in the fuel and convert that energy into useful heat in the building. No heating system can operate without some heat losses. Part of the energy contained in the fuel is lost before it can be delivered as useful heat to the radiators or registers. The efficiency of the heating system is simply the percentage of the fuel's energy that is delivered to the living space of the building—the lower the heat losses, the higher the system's efficiency.

Many heat losses occur in a typical heating system, starting when the pump delivers the fuel to the burner up until the heat reaches the living area. Some of these depend on the design of the burner, furnace, boiler or water heater, the venting system and distribution system. Additionally, how the system is installed, adjusted and maintained will also affect the efficiency. Finally, how well the building envelope is sealed and insulated determines how long the heat created by the heating system stays in the building.

Efficiency

The actual efficiency of an oilheating system is affected by the following:

- The efficiency of the burner-boiler or burner-furnace
- Chimney design and upgrades
- Installation practices, including: boiler or furnace sizing, boiler water or furnace air operating temperatures, piping or ducting design, sealing, and insulation, and source of combustion air
- Service procedures, such as: barometric damper setting, sealing air leaks into the boiler or furnace, burner adjustment (excess air and smoke), cleaning boiler or furnace heat transfer surfaces as needed, and proper nozzle sizing
- Other factors that affect efficiency: building design and construction, location of unit in the building, chimney draft, zoning of the distribution system, and the domestic water heating system

Types of Heating System Heat Loss

Heating systems lose heat in five ways, Figure 1:

1) on-cycle flue heat losses (losses that occur while the burner is running)

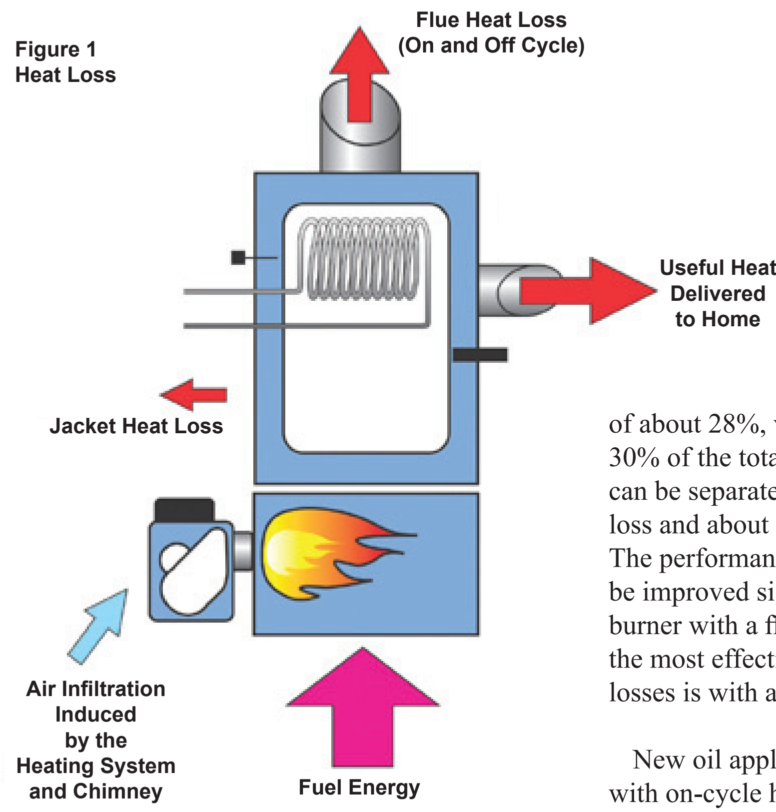
2) off-cycle flue heat losses (losses that occur when the burner is off)

3) jacket heat loss from the boiler, furnace, or water heater casing

4) distribution heat loss from the steam or water pipes and air ducts

5) infiltration heat loss from cold outdoor air being drawn into the building as a result of the operation of the furnace, or boiler.

Figure 1
Heat Loss



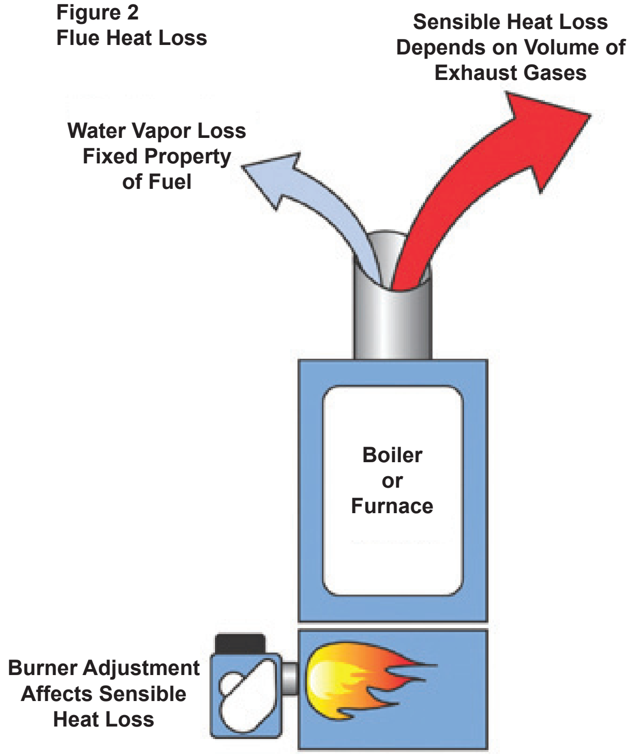
Flue Heat Loss During Burner Operation (On-cycle Losses)

One of the largest heat losses in a building is the heat that goes up the flue while the burner is running. The oil flame produces hot gases that pass through the heat exchanger and up the chimney, Figure 2. Most of the heat contained in these gases is transferred to the heating system water or air that is then transferred to the living space. Combustion efficiency tests measure flue loss. Flue losses that occur when the burner is running are divided into two parts: water vapor heat loss and excess air (sensible) heat loss. This is the heat carried out of the building with the hot exhaust gases.

On-cycle heat losses for oilheating units vary depending on heating equipment design and servicing. Studies show average on-cycle losses (as measured by CO_2 and net stack temperature) for burners installed before 1980 of about 28%, with a typical range of 20% to 30% of the total heat content of the fuel. This can be separated into 6.5% from water vapor loss and about 20% from excess air heat loss. The performance of many older systems could be improved significantly by replacing the burner with a flame retention burner. However, the most effective way to reduce excess air losses is with a new boiler or furnace.

New oil appliances operate very efficiently with on-cycle heat losses ranging from 9% to 14%. Combustion air normally enters the

Figure 2
Flue Heat Loss



burner at basement air temperature (usually about 63°F). The exhaust gases at the breach are normally between 350° and 600°F. The heat in the gases that go up the chimney is heat loss. Some loss is unavoidable, but heat loss can be reduced by better burner air adjustment, clean heat exchanger surfaces, or equipment replacement. New equipment uses much less combustion air and some units do not need a draft regulator, hence less heat is lost up the flue.

Water Vapor Loss

The water vapor (latent heat) loss is covered in Chapter 1. It is fixed and cannot be altered except through use of a condensing furnace or boiler covered in Chapter 4. The only way to reclaim this energy is to lower the combustion gas temperature to a point where the water would condense (turn from steam into water) and the latent heat would be released. This can only be done in specially designed boilers or funaces.

Excess Air (Sensible) Heat Loss

Excess air or sensible heat loss (also called chimney loss) is the amount of energy that leaves the building along with the combustion gases. The chimney must be heated in order for it to operate. The larger the temperature differences between the combustion gases and the outdoor temperature–the stronger the draft. The combustion gases that must be removed from the building include: carbon monoxide, smoke, sulfur oxides, nitrous oxides, steam and carbon dioxide. The size of this heat loss varies from unit to unit and is determined by the volume of gases that must be removed. The more gases–the higher the stack temperature and the lower the efficiency is.

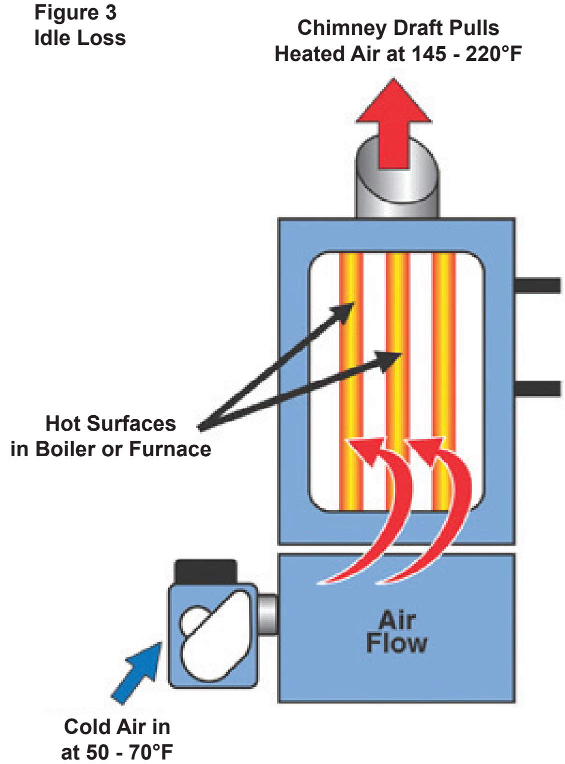
Off-cycle Heat (Idle) Losses

Off-cycle heat losses, also called idle losses, occur when the burner is not running. Oil burners do not operate continuously; they cycle on and off in response to demand. Because most boilers and furnaces are oversized, the typical residential or light commercial burner operates between 15% and 20% of the time during the heating season—less than 900 hours a year.

Idle losses are caused because chimneys continue to draft even when the burner is not operating. Whenever the air inside the chimney is hotter than the air outdoors, the chimney will create negative draft. When the burner is off, this draft will pull warm room air into the burner air intake, across the hot heat exchanger and up the chimney. It will also draw warm from the room into the draft regulator and up the chimney. If the appliance has any leaks, the chimney will also pull air through those leaks and up the chimney.

The air that goes through the heat exchanger is a particular problem. The room temperature air will be heated as it goes through the heat exchanger. Remember, heat goes from hot to cold and in the winter the heat exchanger will be warmer than the room it is in, Figure 3. This heated air flowing up the chimney will warm the chimney and continue the cycle of losses. The best way to demonstrate this loss is to place a thermometer in the flue pipe after the unit shuts down. Watch how long it takes for

Figure 3
Idle Loss



the temperature to drop to room temperature. The whole time it stays high, energy is being taken from the heating system and the building.

Restriction of air flow through the burner can reduce heat loss. Generally, older burners were designed with open combustion heads that provide very little restriction to off-cycle airflow. In contrast, the restricted air passes in high-speed flame retention head burners reduce off-cycle airflow, thereby reducing heat loss.

Oil vent dampers are a way to reduce off-cycle losses on older boilers and furnaces. They are a motorized damper installed in the vent pipe between the draft regulator and the chimney. They must be installed with a blocked vent safety switch to keep the burner from running if the damper fails to open on a call for heat.

Most new equipment uses low mass ceramic fiber combustion chambers that store less heat than high-density firebrick materials used in older equipment. Thus, they will have lower off-cycle losses. Small low mass boilers store less heat than their older heavier counterparts and will have lower off-cycle losses.

Heating system sizing is another important factor that affects on-off cycling. Oversized heating units will have longer off periods and off-cycle losses will increase. A heating unit that is closely matched in size to the building's heating requirements will provide the lowest off-cycle heat loss and highest efficiency.

Jacket Heat Loss

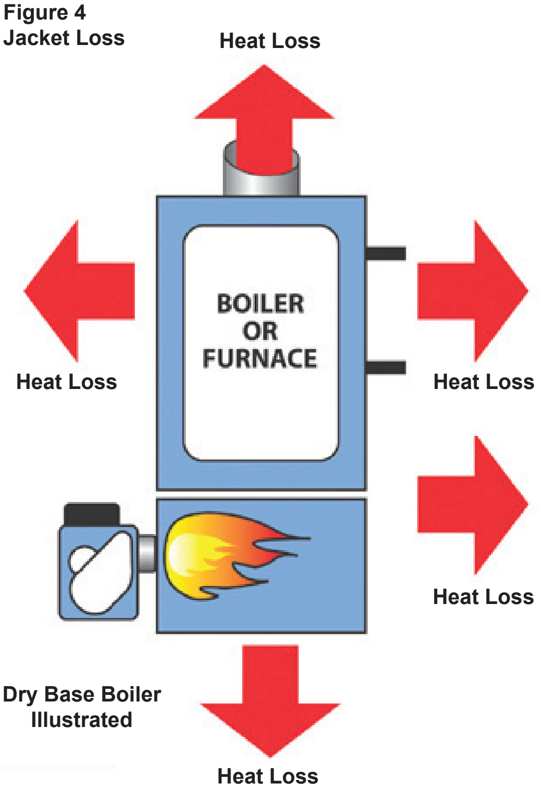
Jacket heat loss is the heat that is lost through the jacket or casing of the appliance. It reduces the amount of heat delivered to the building and lowers system efficiency, Figure 4. Jacket losses are affected by the location of the appliance. If the unit is located in a closet off the kitchen, then most of the heat goes into the house; however, some of that extra jacket heat may go up the chimney as off-cycle losses. Outdoor units must be very well insulated to reduce jacket loss to acceptable levels.

Off-Cycle Heat Loss

The main factors contributing to off-cycle heat loss are:

- **Burner design** (Retention head burners allow less off-cycle air flow.)
- **Heat exchanger design** (The tighter the heat exchanger passes and the higher the draft drop of the exchanger–the more it resists air flow.)
- **Heat storage capacity of the appliance** (High mass units retain heat longer and have greater off-cycle losses.)
- **Chimney height and construction materials**
- **The operating temperature of the boiler** (water temperature)
- **Air leaks in the appliance**
- **Frequency and length of off and on-cycles** (the shorter the cycles, the greater the losses).

Figure 4
Jacket Loss



Based upon Brookhaven National Laboratory testing, jacket losses from appliances can vary from less than 1% to more than 10%. This loss is highest while the burner is firing. Typical flame temperatures of approximately 2,000°F drive heat through the chamber wall and then through the jacket. Furnaces and dry base boilers that do not have water surrounding the combustion area tend to have higher jacket losses than wet base boilers in which the water backed heat exchanger extends around the combustion area to the floor.

One way to capture some of the jacket losses from a boiler or furnace installed in a basement is to seal up the air leaks into the basement and insulate the basement walls down to a level below the frost line. This results in the jacket losses heating the basement and the basement ceiling (the floor of the first floor).

Distribution System Losses, Pipe and Duct Heat Loss

The heat from a central boiler or furnace is transported to the home through pipes or air ducts. Heat loss that occurs between the heating unit and the living space causes system inefficiency, Figure 5. The level of loss depends upon how and where the pipes or ducts are installed, the size of the distribution system and the amount of thermal insulation. Uninsulated pipes and ducts that run through unheated areas have large heat losses. A properly designed and installed heat distribution system can operate with very low duct or pipe losses. Heat losses from steam or water pipes and air ducts are not measured in appliance efficiency ratings by the government (AFUE-Annual Fuel Utilization Efficiency). They do not appear in the AFUE rating and vary widely from building to building.

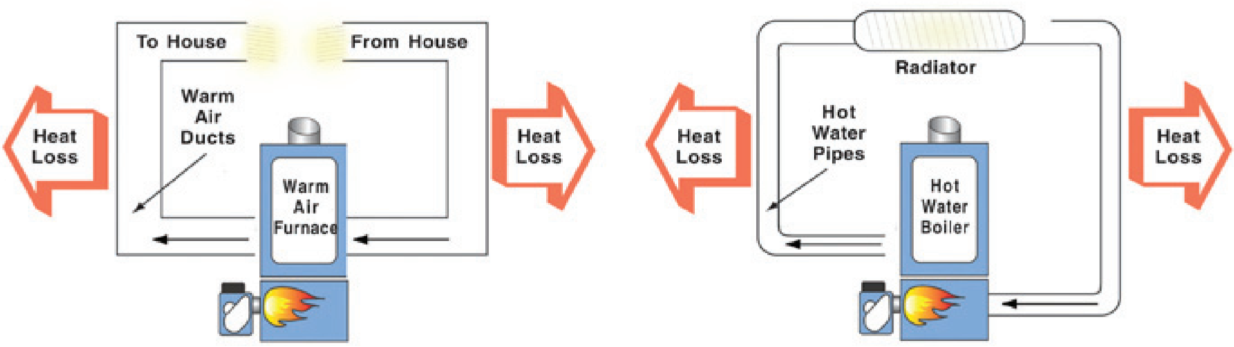
Outdoor Air Infiltration

All fuel-burning heating units consume air for combustion and for off-cycle draft. The air that passes out of the house through the chimney must be replaced by cold outdoor air drawn into the home. When the cold air is brought into the house, it goes through the living space and is heated. The energy required to heat this cold air is the infiltration loss.

In most cases, a burner operating in an unconfined space of a conventional building will receive adequate combustion air supply from air leaks into the building. But if the burner is located in a confined space, such as a furnace or boiler room, the enclosure must have one permanent opening into the rest of the building near the top and one near the bottom of the enclosure to let in combustion and draft relief air. If the burner is located in a tightly constructed or properly sealed building, outside air should be supplied for combustion.

The size of air infiltration heat loss depends upon on-cycle airflow through the heating unit,

Figure 5
Pipe and Duct Loss



the draft regulator and installation factors including the location of the heating unit within the building.

Air infiltration loss is greatest for heating appliances that operate with large quantities of excess combustion air, or units that have large off-cycle airflows. Efficient boiler-burner or furnace-burner combinations will operate with low air infiltration losses.

The best solution for air infiltration loss is isolated combustion, whereby outdoor air is piped directly to the burner air intake. Figure 6. Infiltration losses from new units with isolated combustion air that require no draft regulator can be almost zero.

Types of Efficiency

There are many types of heating systems and many different definitions for efficiency. The most commonly used efficiencies we deal with in heating are as follows.

Fuel-Conversion Efficiency

This is the percentage of the fuel that is converted to heat in the flame. If the burner is set for zero smoke, then all the fuel has been burned and the fuel-conversion efficiency is almost 100%. There are no unburned hydrocarbons left in the combustion gases.

Combustion Efficiency or Steady State Efficiency

Combustion efficiency includes fuel conversion efficiency, the amount of excess air used and the efficiency of the heat exchanger. It is the test technicians perform in the field, when the burner is firing at steady state.

After testing the burner, a smoke test is performed. At that point, the amount of excess air is determined by testing for carbon dioxide or oxygen and the net stack temperature (gross

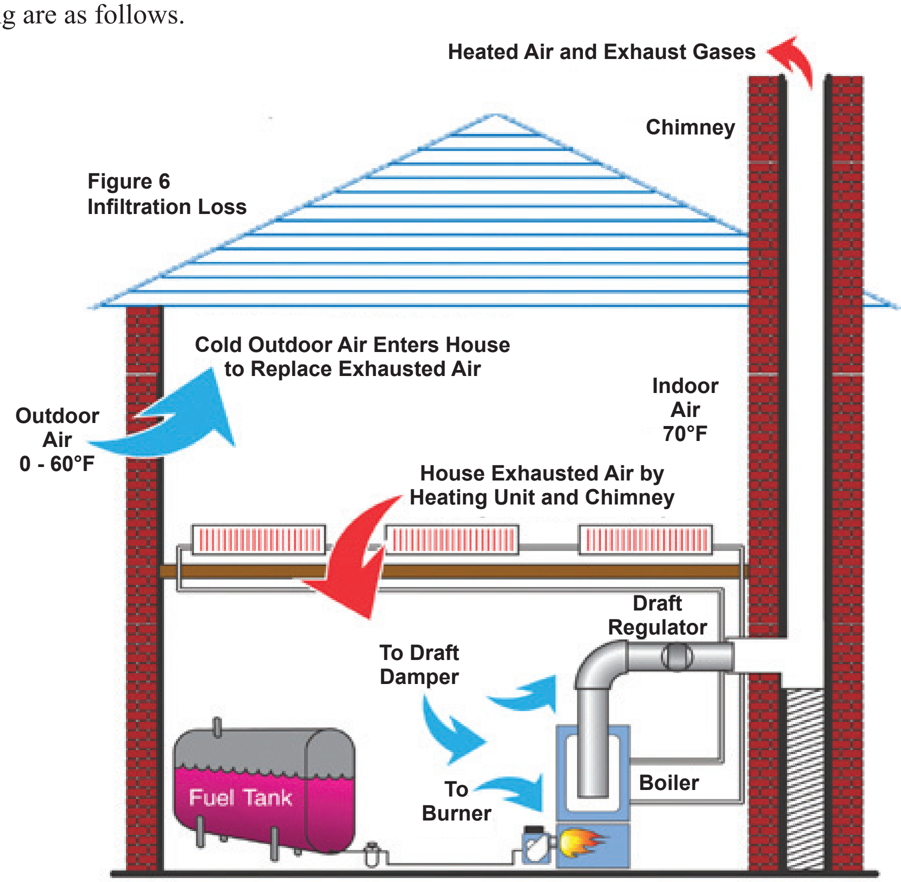


Figure 6
Infiltration Loss

stack temperature minus the temperature of the combustion air) is calculated. An efficiency calculation is done to relate the stack temperature to the excess air and arrive at an efficiency percentage, or combustion efficiency. When using digital test equipment, the smoke test is done first.

Combustion efficiency describes the appliance when adjusted at its maximum reliable efficiency. Combustion efficiency only describes on-cycle losses. It does not include jacket losses, off-cycle losses, distribution losses, or outdoor air infiltration losses.

It is possible in some older units to adjust the firing rate to get the combustion efficiency above 80%. But that number will ignore jacket losses that could be 8%, off-cycle losses of at least 15% and infiltration losses that could be 10%. The true efficiency is probably 30-40 percent lower than the combustion efficiency indicated.

Annual Fuel Utilization Efficiency (AFUE)

This is the US Government Department of Energy's attempt to provide a rating for boilers and furnaces. It is based upon standardized testing and calculation procedures developed by the DOE in the 1980s.

Manufacturers must perform these tests on every model of residential boiler or furnace they sell. These AFUE results are printed on a yellow label that must be affixed to the unit. They are also listed in several heating equipment directories. Unfortunately, equipment manufactured before 1985 does not have an AFUE rating and cannot be compared to today's equipment without further analysis.

The objective of the AFUE labeling program is to supply consistent efficiency information to help consumers select and install high efficiency equipment. While there are some serious flaws in this procedure, it is the only consistent information available for comparing units.

AFUE indicates the efficiency of the burner-boiler or burner-furnace combination for a standard set of operating conditions. The test procedure approximates on-cycle heat loss and cool-down characteristics and then calculates off-cycle and infiltration losses for "standard" conditions. There are many real world cases where off-cycle and infiltration losses are significantly different that those predicted by AFUE.

AFUE is used to rate the overall efficiency of new furnaces and boilers over an "average" heating season for "typical" operating conditions. While the AFUE test cannot and does not try to take all factors that determine efficiency into account, it does give a way to compare the

Heating System Efficiency vs. AFUE

Factors that cause the heating system efficiency to vary from the AFUE:

- Location of the boiler or furnace (Do the jacket and distribution losses help heat the living space or not?)
- Chimney Draft (The chimney height, what the chimney is made of, and the air temperature all affect on and off cycle losses.)
- The source of combustion and draft relief air
- Burner design and operating pressure
- Boiler or furnace sizing and firing rate relative to the heat load
- The zoning of the distribution system
- Pipe or duct design and installation
- Source and consumption of domestic hot water
- The mass of the boiler or furnace
- Boiler or furnace control system

It is also affected by air leaks and insulation of the building envelope.

relative efficiencies of the average new furnace or standard space-heating-only boiler. Boilers or furnaces made before 1985 do not have AFUEs, so comparing a new boiler or furnace to a much older boiler cannot be done with AFUE.

AFUE also does not apply to water heaters that may also be used for heating. And the overall efficiency of a boiler that provides heat and hot water is not accurately measured by AFUE.

Heating System Annual Efficiency

Heating System Annual Efficiency is the true efficiency of the system. It is the difference between the number of BTUs the customer bought and the number of BTUs they use to heat the building and domestic hot water.

It involves all of the energy losses and system interactions measured over the course of the year. It is a function of the gallons of oil used, the temperature of the outside air, solar gain, exposure to wind, the temperature of the inside of the building, the number of occupants and their lifestyle, as well as the amount and temperature of the domestic hot water they used. Unfortunately, there is no standard way to measure the heating system efficiency and each building has a different efficiency.

Combustion Efficiency vs. AFUE vs. Annual Heating System Efficiency

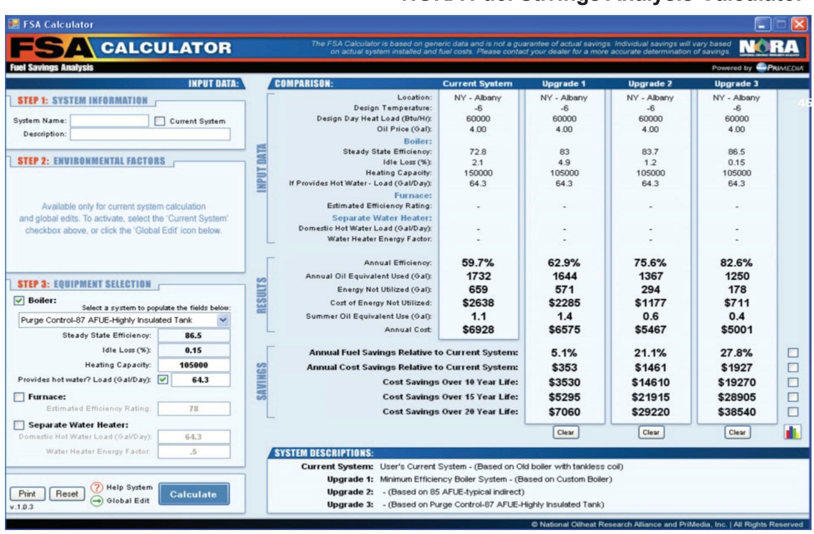
For years technicians have measured Steady State Combustion Efficiency and used that number to characterize the heating efficiency. It is like highway mileage for a car. The engine is warmed up and the car is cruising down the interstate in high gear.

Heating System Annual Efficiency is more like city mileage, with stop and go traffic and idling at red lights. The problem in helping our customers save fuel is that Combustion Efficiency does not factor in all of the losses of the heating system. A unit with a combustion efficiency of 81 percent will be much less efficient and if we could measure AFUE on that unit it might be in the 60s or lower. But if a customer compares 81 to an AFUE of 87, he will not understand how much better off he would be if his equipment were upgraded.

Technicians must understand Annual Heating System Efficiency (city mileage) and all the factors that go into efficiency. The NORA Fuel Savings Analysis Calculator is a step in really understanding the true efficiency of the unit, Figure 7. Brookhaven National Laboratory, New York State Energy Research and Development Authority and NORA have developed a way to predict the actual savings for replacing an old boiler or furnace. It is called the Fuel Savings Analysis Calculator.

NORA has created a video to explain how to download and use the Calculator. Go to noraweb.org and watch video 14. This calculator is always being improved, so make sure you use the latest version.

Figure 7
NORA Fuel Savings Analysis Calculator



Chapter 3

Improving Efficiency and Minimizing Environmental Impact

Minimizing Oil Burner Air Emissions

When heating oil is burned, it creates nitrogen (N), carbon dioxide (CO_2), water (H_2O), oxygen (O_2), sulfur oxides (SO_x), oxides of nitrogen (NOx), carbon monoxide (CO), hydrocarbons (smoke) and particulate matter. Nitrogen, oxygen and water vapor have no negative direct impact on the environment. However, using too much extra air in the combustion process reduces efficiency and increases the amount of oil burned. This increases emissions of the other components.

The Oilheat Industry is transitioning heating oil to ultra-low-sulfur diesel (15 parts per million of sulfur) while blending with 5 and 20 percent biodiesel. This will dramatically reduce the impact on the environment from Oilheat.

Oilheat equipment manufacturers are making great strides in producing burners, boilers, furnaces and water heaters that are more efficient and cleaner burning. Oilheat dealers install this new equipment and maintain it to run as cleanly and efficiently as possible. As a result, the average Oilheated home in the USA uses over 500 gallons less oil a year than it did in the 1970s. This has dramatically reduced Oilheat's impact on the environment.

Carbon Dioxide Emissions

Carbon dioxide is a greenhouse gas that contributes to global warming. When oil burners are running properly, 10 to 13% of the combustion gases are CO_2. At zero smoke, oil burners create 3.2 pounds of CO_2 for every pound of oil burned. The only way to reduce Oilheat's CO_2 emissions is to help Oilheat customers burn less petroleum through increased efficiency. The less oil burned–the less carbon dioxide released into the air.

Sulfur Oxide Emissions

The sulfur in fuel results in sulfur dioxide being released into the atmosphere when it is burned. During combustion in residential heating systems, roughly 99% of the sulfur in the fuel is oxidized to form sulfur dioxide (SO_2) and is emitted from the stack. The remaining 1% of the sulfur is converted to sulfur trioxide (SO_3) in the flame. The SO_3 mixes with the water vapor in the combustion gases to form sulfuric acid. The dew point for sulfuric acid is about 200°F. When it condenses, the acid is sticky and it adheres to the heat exchanger, flue pipe and the walls of the chimney flue. It damages the chimney liner and the flue pipe and forms scale buildup in the heat exchanger, reducing its efficiency. Figure 1.

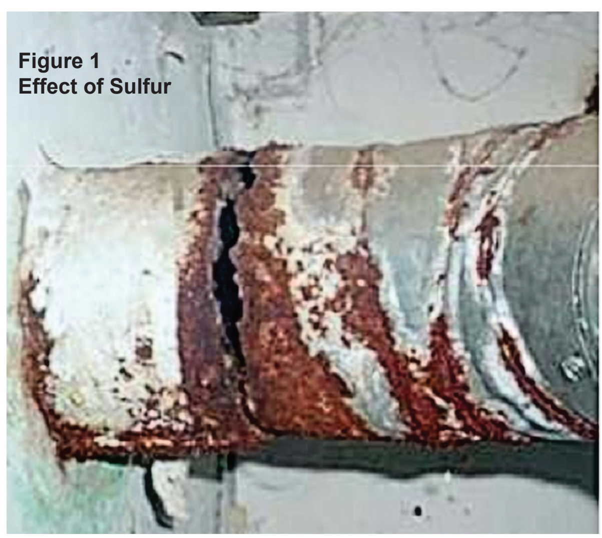


Figure 1
Effect of Sulfur

Research by the US Department of Energy at Brookhaven National Laboratory, the Canadian Clean Energy Technology Center and others has shown a direct relationship between the sulfur content of home heating oil and the fouling deposit buildup on heat transfer surfaces. As the percentage of sulfur in fuel is reduced, the rate of heat exchanger fouling drops and the need for vacuum cleaning decreases. Research in Germany indicates that the use of ultra-low-sulfur fuel improves efficiency over the heating season by 1 to 2 percent.

The advantages of low-sulfur fuel are:

- Reduced service costs through less frequent vacuum cleaning of heating equipment
- Lower air pollutant emissions, including sulfur oxides, nitrogen oxides and fine particulates, improved fuel stability and lower environmental impacts.

Hydrocarbon Emissions (Smoke and Soot)

When properly adjusted, oil burners produce very few unburned hydrocarbons (smoke and soot). Oil burners should be over 99.99% clean burning. However, older, non-flame-retention burners are not this clean and an improperly adjusted new burner can also produce smoke. Burners must be adjusted for zero smoke. If this is not possible, they should be replaced.

Bioheat®—New Carbon Doesn't Count

Bioheat® is a blend of heating oil (ASTM D396) and biodiesel (ASTM D6751). Biodiesel is a non-toxic, biodegradable, renewable fuel derived from natural vegetable and animal oils. Current feedstocks for the creation of biodiesel are soy, canola, sunflower, mustard and rapeseed oils, as well as waste cooking oil and grease, including trap grease, tallow and animal fats such as fish oil. Since all of these feedstocks are "new" carbon that is currently in the carbon cycle, they do not contribute to climate change. Only carbon that has been captured underground, locked up in petroleum for many years, subsequently brought to the surface, burned and released into the air increases the amount of carbon in the cycle and contributes to climate change.

The US Environmental Protection Agency recently confirmed biodiesel as an "advanced biofuel" that meets the demands of the EPA's Renewable Fuel Standard. It enjoys the highest energy balance of any renewable fuel. For every unit of energy produced, biodiesel returns 5.54 units of energy. The vegetable oils and animal fats used for biodiesel feedstocks are not produced specifically for biodiesel—they are minor byproducts of food production—therefore, they do not suffer from the fuel-from-food stigma, as do other biofuels such as ethanol.

Adjusting Oilheat Equipment for Maximum Efficiency

Installing and adjusting heating equipment for maximum safety, reliability and efficiency is very important. Even the best equipment can waste fuel if it is not installed and adjusted properly. Older oil boilers and furnaces are less efficient than newer units. However, there are some steps covered in this chapter that can increase older equipment's operating efficiencies.

Air Leaks

Air leaks into the heat exchanger should be sealed. Locations for air leaks are:

- The space between the burner air tube and the combustion chamber opening
- The seam between the combustion chamber and heat exchanger on furnaces and dry base boilers
- The space between sections of cast iron boiler
- Flange seals
- Loose fitting clean out and flame inspection doors.

Sealing these air leaks (Figure 2) with furnace cement will reduce off-cycle airflow and heat loss. To test for air leaks into the heat exchanger, compare the excess air levels over the fire and at the breech. They should be the same. If there is more excess air at the breech, this indicates there are heat exchanger leaks.

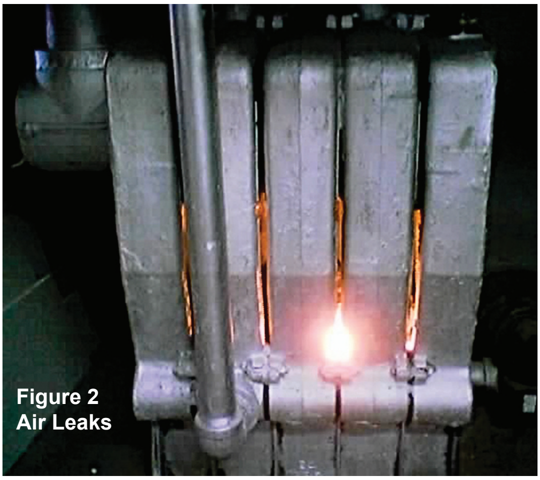


Figure 2
Air Leaks

Flue Gas Temperature

The flue gas temperature (net stack temperature) is directly related to combustion efficiency. As the flue gas temperature rises, more heat goes up the chimney and the furnace, boiler, or water heater captures less heat.

The lower the flue gas temperature–the higher the efficiency. Typical net flue gas temperatures for modern heating equipment are between 350°F and 450°F.

It is good practice to be sure the net stack temperature at the breech is about 350°F to insure that the flue gas temperature at the top of the chimney is above 200°F (the point where sulfuric acid starts to condense). In most installations, a 350°F temperature should keep the sulfuric acid in the flue gases from condensing in the chimney. As sulfur levels in the fuel are reduced, this is less of a concern.

If the net flue gas temperature at the breech is above 450°F, too much heat is going up the chimney and efficiency is lowered. Check for the following conditions and take corrective action as needed.

Soot and Scale Accumulation on the heat transfer surfaces—Soot and scale are great insulators and will prevent the heat exchanger from working efficiently. Brush and vacuum-clean these surfaces and then determine the cause of the soot.

Too high a firing rate—The heat exchanger does not have time to extract the useful heat because there is too much heat being produced in too short a time period. Overfiring causes the burner to short-cycle, causing many problems. A common cause of overfiring is increasing pump pressure without reducing the nozzle size. Increasing pump pressure increases firing rates. When raising the pump pressure, downsize the nozzle.

Excessive draft through the heating unit—If the draft is set too high, excessive amounts of air enter the heating unit through the burner and secondary air leaks. These leaks lower the combustion temperature, which reduces the rate of heat transfer. Because there are more gases flowing through the heat exchanger, they must also flow more quickly and the heat exchanger has less time to remove the useful heat. The result is an increase in the net stack temperature and lower efficiency. Adjust the draft regulator and seal secondary air leaks.

Outdated heating unit—Older boilers, water heaters and furnaces designed to operate with low static pressure burners cannot effectively transfer heat from the combustion gases to the water or air. The result is higher flue gas temperatures and reduced efficiency.

Outdated equipment gives both low carbon dioxide readings and high flue gas temperatures. The effect on efficiency is devastating. Common fixes, such as bricks, baffles and turbulators in the heat exchanger, will slow down the flow, but replacing the old, inefficient boiler or furnace is a better choice.

The Periodic Preventative Maintenance Tune-Up

Periodic cleaning and adjustment of all

heating systems assures the highest level of efficiency, safety and fewest service calls. All combustion systems operate best when they are serviced on a regular basis. Good service procedures save fuel and prevent equipment breakdowns.

Typical savings from a tune-up are about three percent for systems that are regularly adjusted. If a heating system has not been tuned for several years, or is out of adjustment due to equipment malfunction, then the fuel savings will be higher. Always follow burner-manufacturer-recommended burner adjustments to maximize efficiency.

Reducing Nozzle Firing Rate

Excessive firing rates cause problems for boilers and furnaces. Firing rates that are higher than the heating requirement of the building increase off-cycle loss. Heat loss varies with the off-period time and large firing rates produce long burner-off times.

The solution is to reduce the nozzle size, but not below manufacturer recommendations and not below what is necessary to keep the net stack temperature above 350°F. Selecting the correct nozzle size is an important part of proper service procedures. With fixed head burners, it may be necessary to change the combustion head if you are reducing nozzle size.

The two exceptions to reducing firing rates are steam boilers and units with tankless coils. In these two cases, the units should be fired to their maximum rating. New units that are properly sized for the load should be fired to the manufacturers' recommendations.

Since most older heating systems are oversized, reducing the firing rate improves efficiency in three ways:

• The net stack temperature goes down because the smaller flame produces fewer gases, therefore the gases spend more time in the heat exchanger. This gives the heat exchanger a chance to pull more heat from them.

• Off-cycle heat losses are reduced because the burner run-times increase, reducing the time the unit is off.

• Cycling losses are reduced. Overfired burners make heat faster than the heating system can absorb it, causing the burner to cycle on and off on the high limit. The burner never reaches steady state. This increases deposits on the heat exchanger and reduces efficiency.

An average oil burner only operates about 15% to 20% of the time during the heating season. Heat losses during the off-cycle for older oversized units can be significant. New properly sized boilers and furnaces will not benefit from reducing the firing rate because the off-cycle losses for these units are already very low.

The perfect nozzle size is the lowest firing rate that will:

- Heat the building adequately on the coldest day of the year
- Produce enough domestic hot water
- Produce a clean, smoke-free flame with high combustion efficiency
- Ensure net stack temperature is adequate

Pipe and Duct Insulation

Steam pipes, hot water pipes and warm air ducts often waste large amounts of energy when they are not insulated. These losses reduce system efficiency and increase fuel consumption. Duct leak sealing and the use of thermal insulation will prevent unnecessary heat loss. All heating system distribution lines that run through unheated spaces should be adequately protected against heat loss.

Boiler Pipes

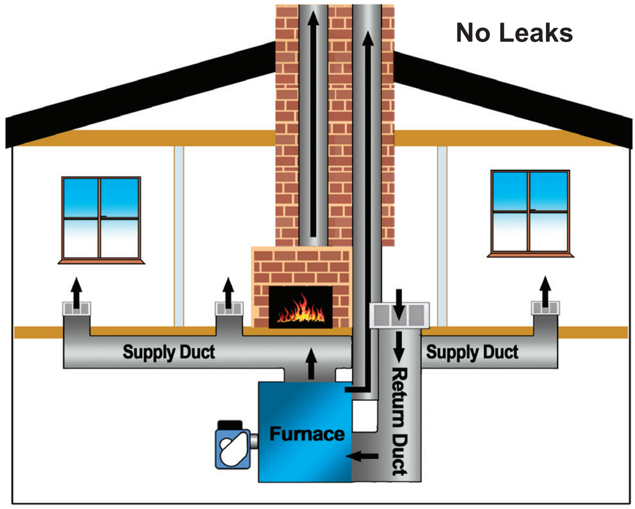
The heat loss from the piping system depends upon several factors:

- Temperature of the hot water or steam within the pipes
- Length of piping system and the amount of insulation
- Temperature of the air surrounding the pipes

Warm Air Ducts

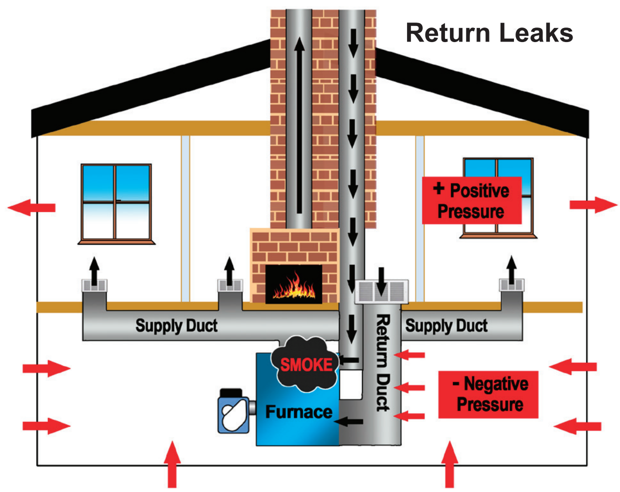
Ducts that distribute heated air to the house lose heat in two ways:

- Heat flows from the heated duct walls to the colder surroundings
- Heated air escapes from leaky supply duct joints and cold air is drawn into leaking return ducts.



Both of these losses reduce the useful heat delivered to the house and increase fuel consumption. Warm air is lower in temperature than hot water, but the duct surface area is much larger. The large duct area and air leaks contribute to relatively high distribution system losses for warm air systems. Additionally, many warm air ducts pass through unheated areas, such as attics or crawl spaces. Because of the cooler surroundings, heat loss into these areas is large. Inspect all warm air ducts to determine if there are leaks that can be sealed.

Properly sealed and insulated ducts can reduce cooling cost by up to 15% and heating by 20%! The furnace fan (blower) moves 1,200 cfm. Return leaks in the furnace room are a problem because the blower is strong enough to backdraft the burner.

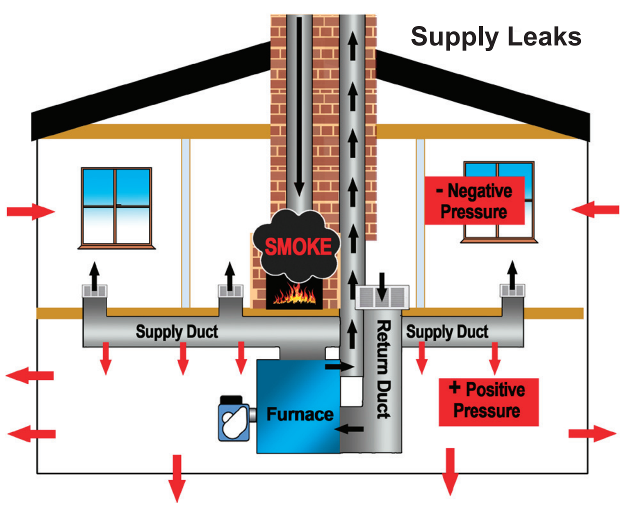


Water Heating

The heat losses associated with direct-fired water heaters are the same losses any boiler suffers: On-cycle losses, idle (off-cycle) losses up the flue, infiltration losses, piping losses, jacket losses.

The efficiency measurement for water heaters is the Energy Factor (EF). Energy Factor tells how effectively the heat from the energy source is transferred to the water and quantifies standby losses (the amount of heat lost per hour from the stored water compared to the heat content of the water) and cycling losses.

The primary losses for oilfired water heaters



are idle losses. The Energy Factors for new oil direct-fired water heaters range from .5 to .68. This means that 50 to 68 percent of the potential energy in the fuel is converted into hot water and stays in the hot water until it is used. Water heaters are also rated by the First Hour Rating. This indicates how many gallons of hot water that can be produced by the water heater in one hour of operation.

To understand the efficiency of indirect water heating (where boiler water is used to heat domestic water) requires an understanding of the efficiency of the boiler. The secondary considerations involve heat transfer and storage. There is no government or industry-wide sanctioned way to measure the efficiency of indirect water heaters.

Integrated Space and Water Heating Systems

Many boiler manufacturers offer an integrated system, featuring an external plate-type heat exchanger and storage tank or hot-coil water heater. They use a low, or at least lower, mass boiler combined with a control system. Systems that are designed to do both space and water heating offer efficiency that is far superior to any of the other systems.

Water Heater Energy Conservation Strategies

Insulate the pipes

Insulating hot water pipes can save energy. Savings depend upon the location of the tank and pipes in the building. If the tank and pipes are located in the living area, then any heat they lose helps heat the building. However, in the summer, they are making the air-conditioning work harder.

Installing heat traps on the inlets and outlets of non-circulating water heaters and tanks reduces buoyancy-induced flow (hot water rises) of hot water through the piping, where it loses heat to the building interior. These simple pipe loops reduce unintended hot water circulation for a small installation cost, with typical paybacks of less than a year. Heat traps are already built into many high-efficiency water heaters and the addition of external traps is redundant. Also, insulating the cold water intake piping next to the water heater connection reduces losses from the hot water heater conducting heat to the cold water pipe.

Recommend Water Conditioning

Hard water is very tough on any water heating system. Hard water causes lime (calcium) deposits on heat exchanger surfaces, in lines and valves. The lime will cause reduction in performance and can lead to insufficient hot water and wasted energy. This calcium build up must be removed periodically.

Over time, calcium will build up and it is necessary to flush the sediment out of the bottom of the water heater tank. To eliminate the need for coil cleaning, recommend that customers with hard water install water softeners. Acidic water will attack pipes and tanks. In such cases, you should recommend acid neutralizers to customers.

Hot Water Conservation

Low-flow showerheads and faucet aerators, cold-water rinse cycles for the washing machine and fixing leaking faucets can save significant amounts of hot water.

Which water heater is best?

For a furnace or large hot water demand relative to the heat load, the best option is the high-recovery, direct-fired, oil-powered water heater. If the customer has a reasonably efficient boiler, they are better off with a storage-tank-type indirect water heater because there is only one burner heating both the space and the water.

The best system of all is an integrated boiler with an indirect water heater and a storage tank system.

Chapter 4

Efficiency Improvements with New Oilheat Technology

Oil Burners

The oil burner makes or breaks the efficiency of a heating system. Today's oil burners convert 99.99% of the energy in the fuel into heat. The challenge is to be sure the heat exchanger of the boiler, furnace, or water heater transfers as much of this energy to the living space or domestic hot water as possible and the venting system safely removes the combustion gases from the heat exchanger and the building.

Flame Retention versus Conventional Burners

The main difference between conventional (pre-1972) and flame retention (post-1972) burners is the way combustion air and fuel are combined. The flame retention burner has a specially designed combustion head (end cone) and a high-pressure fan that produces more recirculation within the flame for better fuel-air mixing. The swirling air pattern increases the contact between the fuel droplets and the air. In addition, a recirculation zone is formed within the flame.

Flame retention burners operate with less excess air than older burners' designs. Flame retention burners require 20 to 30% excess air; older burners need 50 to 100% excess air to achieve low smoke numbers. Lower flue heat loss for these burners translates into a fuel savings of more than 10%.

The static pressure increase with flame retention is dramatic. Static pressure is needed to overcome the restriction in the heat exchanger, and the increase in static pressure allows furnace and boiler manufacturers to make more restricted heat exchangers, which are more efficient.

High static pressure burners push against the increased restrictions in the heat exchangers for clean, quiet, and efficient oil combustion. To ensure the new burners produce the necessary static pressure, make sure the air handling parts are clean. It is also important to be sure the air guides, gaskets, and blower wheels are installed properly.

Fourth Generation Flame Retention Oil Burners

Flame retention burners have continued to improve since their introduction in the early seventies. The result is today's burners are much better than those manufactured even as recently as the 1990's.

Today's flame retention head burners produce more effective fuel-air mixing than outdated designs. This reduces the amount of excess combustion air required for clean burning, produces higher flame temperatures and increases boiler and furnace heat transfer rates. All this results in lower heat losses and improved efficiency.

Because they require less excess air, the air intake on the new burners is not as open as on older burners. This dramatically reduces off-cycle airflow through the heating system. The result is much lower on-cycle and off-cycle losses and greater efficiency.

These burners often burn so clean that almost no combustion residue builds-up over the heating season. This means that the efficiency does not go down through the season like it does with older burners. Not only do the new burners use less oil, thanks to the PSC motors, igniters and interrupted ignition they use dramatically less electricity.

Venting

Venting combustion gases reduces the efficiency of the heating system, but it is important to remember that in trying to make the venting more efficient, ensure all the combustion gases are safely removed is the top priority.

Draft regulators allow heated air from the building to flow up the chimney. However, many chimneys produce such a strong draft that it affects the fire. NFPA 31 states that a draft regulator should be installed on all units unless the manufacturer specifically says not to in their installation instructions. Several boiler and furnace manufacturers recommend draft regulators not be installed on their units

Chimney lining and insulation can improve the performance of oversized or worn out chimneys, reduce chimney heat loss rates, and produce more stable chimney draft. Upgrading the chimney allows for the use of higher efficiency boilers and furnaces without worry about condensation and serious reductions in chimney draft caused by lower flue gas temperatures.

New Boilers and Furnaces: *The Best Investment a Building Owner Can Make*

When replacing a boiler or furnace, customers gain all the advantages of the new burner and also gain large reductions in off-cycle losses. These off-cycle losses are the big difference between the old and new furnaces and boilers. Some new boilers on the market have almost zero off-cycle losses compared to the 5 to 12% off-cycle losses from older boilers. The appliance manufacturers have done this by tightening up the flue passes in the heat exchangers and reducing the mass of the heat exchangers. These changes have dramatically reduced heat losses and increased efficiency.

Older heating units are inefficient and oversized. New high efficiency oil boilers and furnaces have Annual Fuel Utilization Efficiencies (AFUEs) between 83% and 97%. Replacing old and outdated heating units will cut fuel consumption and increase customer satisfaction. Typical savings for installing a new furnace or boiler is between 20% and 30%.

High Mass or Low Mass?

High mass units have lots of iron and water and rely on a small but constant fire. These units need significant mass to absorb the heat and hold it for the heat distribution system to do its job. They feature low firing rates, long burner run times, with long burner off times in between. They are well-insulated to reduce off-cycle losses.

The alternative is low mass. The first low mass boiler was the System 2000 from Energy Kinetics. It is made of steel with less than three gallons of water in the boiler. Control strategies and design enable cold start and cold finish, resulting in almost no heat being left in the boiler when it is off. That means there are virtually no stand-by losses.

Be sure to consider how the entire system is operating and make any needed changes that minimize heat loss. Don't forget to use combustion test instruments when installing the new unit. It is the only reliable way to reach the highest possible operating efficiency.

Consider the Heating System Factors

The following heating system factors affect overall efficiency:

- Proper boiler or furnace sizing
- Chimney draft
- Source of combustion air
- Burner design and static air pressure
- Zoning of the distribution system
- Pipe and duct insulation and air duct leakage
- Source of domestic hot water.

Boiler Water Temperature Reset, and Electrically Commutated Magnetic Motors

The ideal heating system would operate continuously, supplying only the heat needed to replace the heat lost through the building envelope. The room temperature would never change. However, heating systems provide short bursts of heat followed by periods of no heat. As a result, room temperatures go up and down.

Manufacturers have developed a number of strategies to try to keep the house at a fairly uniform, comfortable temperature. Electrically Commutated Magenetic Motors (ECM) on blowers and circulators vary the speed the air or water moves through the heating system, better matching the heat delivered to the room to the heat lost through the envelope.

Temperature Reset is a control strategy that adjusts appliance water temperatures to provide more heat when it's colder and less heat when it's warmer. There are two types of boiler temperature reset controls available today: indoor and outdoor.

Outdoor reset controls adjust the temperature in the boiler based on the outdoor air temperature. As the outdoor temperature rises, the control lowers the boiler water temperature to meet the reduced space heating demand, lowering off-cycle heat losses for most of the heating season.

Indoor reset controls adjust the boiler temperature to meet the actual heating needs of a home, based on how cool the water from the radiator pipes is when it returns to the boiler.

Fuel saving for temperature modulation controls depends upon the initial off-cycle heat loss and the degree to which the boiler temperature is reduced. Typical savings of 10% are expected for older burner-boilers with large heat losses when automatic controls are applied.

Thermal Purge Controls

Thermal purge controls anticipate the end of a thermostat call and keep the zone valve open to send the energy left in the boiler to the building or domestic water heater, similar to the way the fan on a furnace continues to run after the thermostat shuts off the burner.

These controls are most effective with boilers with low water volume, as they have very little energy left to purge when the thermostat is satisfied. This greatly reduces both off-cycle losses and losses caused by oversizing.

Laboratory studies show that this type of integrated operation can save 20% to 40% over boilers that do not thermally purge. Although thermal purge is very efficient with new equipment, it may not be right for many existing boilers. Cast iron and higher water volume steel boilers may cause excessive heating during thermal purge operations. Also, some boilers are not designed to sit cold during idle periods, which may result in leaking gaskets and the possibility of thermal shock.

Automatic/Manual Thermostat Set-Back

The thermostat is the single best device homeowners can use for energy conservation because the temperature the rooms are heated to has a big effect on how much energy is needed. The greater the difference between the inside and outside temperatures, the greater the heat loss.

Living with slightly lower thermostat settings can reduce energy use. For every degree the thermostat setting is lowered over a 24 hour period, the heating bill drops by as much as 3%! Routinely setting the thermostat lower once or twice a day when additional heat is not needed because no one is in the building or everyone is in bed can save significant money.

When temperatures outside are very cold, a setback may lead to the system being off for too long. In that period, some of the radiator pipes in outside walls may freeze, which could lead to water damage or the house getting too cold. Set-back thermostats should not be used on radiant heat, steam heat or hot water systems with large radiators. It works best on furnaces, hydro-air systems, and fin-tube baseboard.

Thermostat set back can be accomplished manually or automatically. The new digital set back thermostats are very reliable and easy to use.

Condensing Boilers and Furnaces

Venting large amounts of exhaust gases results in significant loss of energy as the steam in those gases has absorbed a great deal of energy. To recapture this energy and use it in the home, manufacturers have developed condensing appliances. These units have larger heat exchangers.

The heat exchangers cool the combustion gases down to the point that the steam in the combustion gases condenses back into water vapor and then into water, thereby returning this latent heat to the heat exchanger. For the water in the boiler to condense; the water from the radiator pipes must be below 120°F, Figure 1.

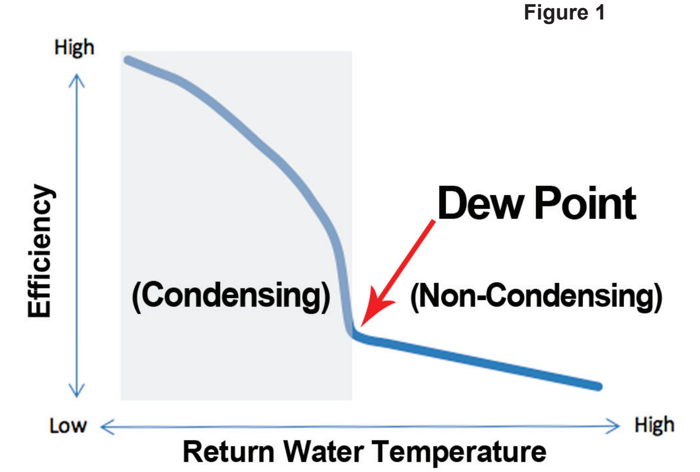
When considering whether a condensing boiler will work in a home (Figure 2 on following page), ensure that these low water temperatures will provide sufficient heat.

Combining Efficiency Improvement Options

Many equipment upgrade and replacement options are available, and many of them solve the same problem.

In assessing savings from multiple improvements, it is important to understand savings cannot be determined by simply adding to-

Figure 1



gether the savings for each individual modification, because some of them affect the same losses.

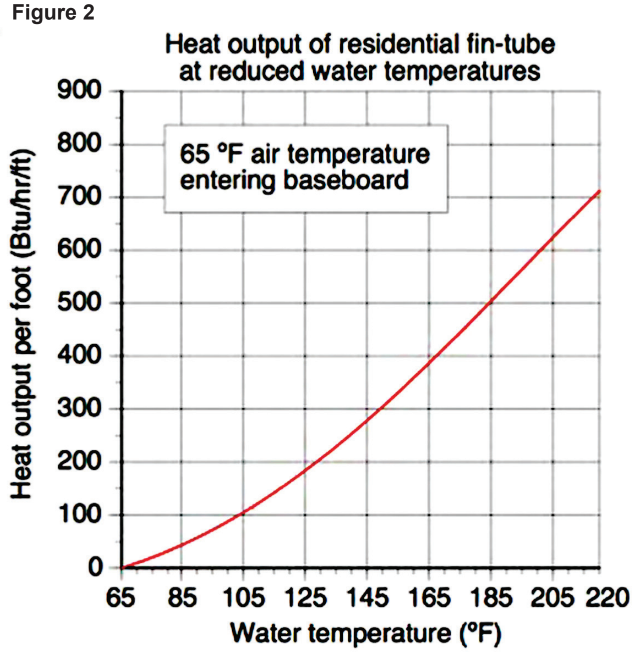
The most economical first cost retrofit is the one that saves the most fuel for the lowest cost. Additional modifications cost more and the added fuel savings often are less.

Maximize the Savings

In order to be certain customers enjoy the full potential savings from their new high-efficiency equipment, be sure to do the following:

- Size the boiler or furnace properly.
- Minimize heat loss from other heating system factors.
- Use combustion test equipment to properly adjust the burner for maximum safety, reliability and efficiency.

Figure 2



System Upgrades

Replacing the boiler or furnace should be part of a general system upgrade. The following are some of the things that should be included in an upgrade:

- Replace the oil lines, especially if they are unprotected lines buried under concrete. Convert from two pipes to one pipe if possible. Follow local codes when replacing oil lines. If they must be under concrete, be sure they are sleeved in protective conduit or are double wall lines built for this purpose.
- Replace the flue pipe. Be sure the new pipe is well secured and strapped so it cannot fall down.
- Replace any questionable heat distribution parts, like zone valves, expansion tank, and circulator.
- Consider bringing in combustion air from outdoors. Check to see where combustion and draft relief air are coming from. A newer home with good air sealing and several exhaust fans may need isolated combustion.
- Install a quality oil filter. If there is already a filter, replace the element.
- Check the oil tank for water and remove accumulated water. If excessive, find out why.
- If the oil tank is accessible, inspect the tank and fuel lines. Are there any provisions for keeping the oil lines outdoors insulated? Is the tank on a stable foundation? Is the outside of the tank rusty? The best time to replace an old tank is before it leaks—when replacing the boiler or furnace.

Chapter 5

Home Performance and Building Science

Building Science is the study of how a building keeps the heat generated by the heating system within the building when it is cold outside, and how it keeps the heat from outside out of the building when it is hot outside. Home performance is how well the building does at keeping the heat in during the winter and out during the summer.

Home Performance is a comprehensive, whole-house approach to improving energy efficiency and comfort in a building. Home performance contractors do energy audits to find air leaks in the building and evaluate the quality of the insulation. They also seal air leaks and improve insulation.

The Building is Part of the Heating System

The building itself is critical to the efficiency of the heating system. The part of the building that keeps the indoors from being outdoors is called the envelope. It includes the walls, roof, floors, windows, and doors. The building envelope's job is to separate the warm and comfortable indoor environment from the weather outside.

The building operates as a system. All of the elements of the building—the envelope, mechanical systems, and occupant activities—affect each other and the result affects the performance of the building as a whole. Figure 1.

For example, reducing air leaks through the envelope makes the building less drafty and more comfortable. It helps protect the envelope from moisture damage. However, it will also increase the moisture level inside the building caused by occupant activities, such as cooking and bathing, since less water vapor escapes. This leads to increased condensation on the windows. Sealing up leaks can also starve combustion appliances such as the oil burner of needed combustion air. Any change to one component of the whole building system can have an immediate and often negative effect on other components.

The building design and construction determines the heat load that the heating system

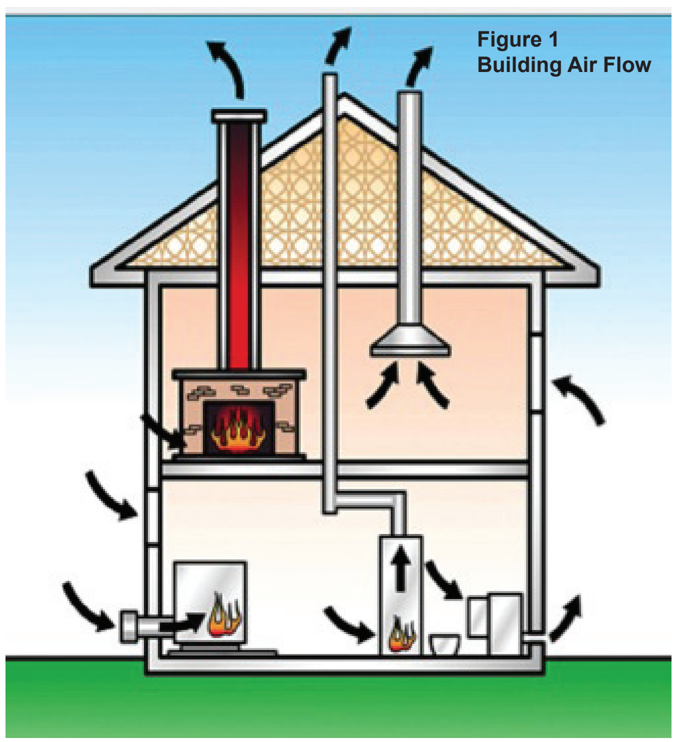


Figure 1
Building Air Flow

must meet. Several factors affecting overall efficiency and energy consumption are:

• The various exhaust fans (attic, bath, and kitchen) and atmospheric (fireplace) and power vented appliances (clothes dryers) that can pull warm air out of the building and cold air in. A kitchen exhaust fan can remove all the warm air from a building in one hour of steady operation!

• Draft regulation devices, such as draft hoods and draft regulators, draw air out of the building envelope during and after appliance operation.

• The height of the building (number of floors) affects exposure to wind and heat loss as well as chimney height and draft.

• The insulation of outside walls and window areas and their construction dramatically affect heat loss.

• Air leakage into the house around doors, windows, and into the basement affects air infiltration rates and energy consumption.

The location of the heating appliance and the distribution system affects efficiency.

If the boiler and piping are all within the living area, then jacket and piping losses are not losses; they are gains in the winter. However, jacket losses from water heaters and boilers in the conditioned space will increase the cooling load in the summer.

A Princeton University study found that 60% of the heat in a typical home comes from the heating system, 15% is from solar gain. If the building occupants manage the solar gain by opening the drapes to let the sun in, then closing the drapes at night, the solar gain can be even greater. Twenty percent of the heat comes from the lights and appliances and five percent of the heat gain is from the body heat given off by occupants and their pets. People radiate between 300 and 420 Btuh, and pets radiate up to 300 Btuh.

All of these building construction factors interact with the heating unit to produce overall heating system efficiency for the building/chimney/heating unit combination. While some of these interactions are beyond an Oilheat technician's control (Figure 2), by understand-

Figure 2
Where the Heat Goes

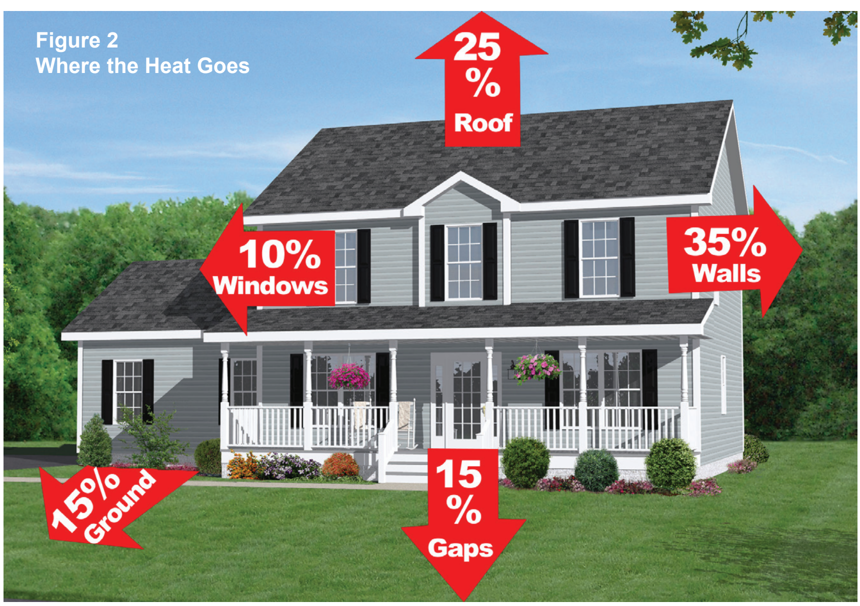
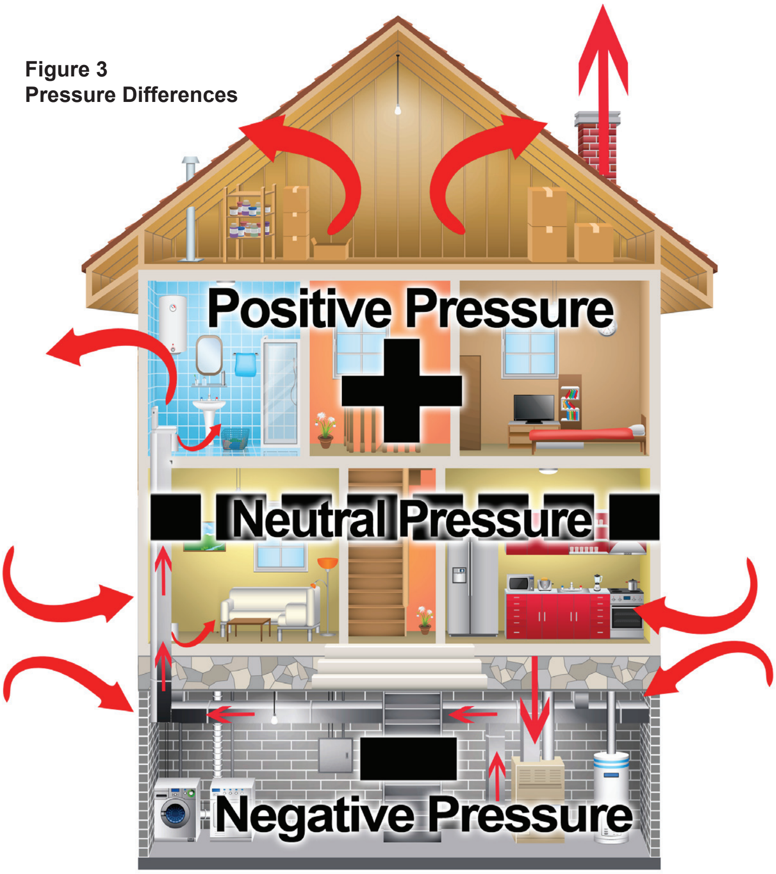


Figure 3
Pressure Differences



ing them, he or she can make better decisions, and be a more valuable source of information for Oilheat customers.

The Building Shell as an Energy System

As mentioned in the beginning of this chapter, to understand home performance it helps to think of the building as an envelope or shell. Remember, its function is to keep the inside air in the building and the outside air from entering the building. All of the components of the shell—walls, windows, doors, floors, ceilings and roof—comprise the envelope, which has two parts: the air barrier and the thermal barrier. The air barrier stops the flow of air through the envelope and the thermal barrier stops the flow of heat. Parts of the building are inside these barriers and parts can be outside the barriers.

The flow of air through the envelope is affected by and affects the HVAC systems, the operation of the other appliances and the actions of the people in the building. That's why building science also involves the study of the interactions in the building. It is a struggle to compromise between undesirable air leakage and the proper ventilation and moisture control needed to maintain a healthy environment in the building and the durability of the building components.

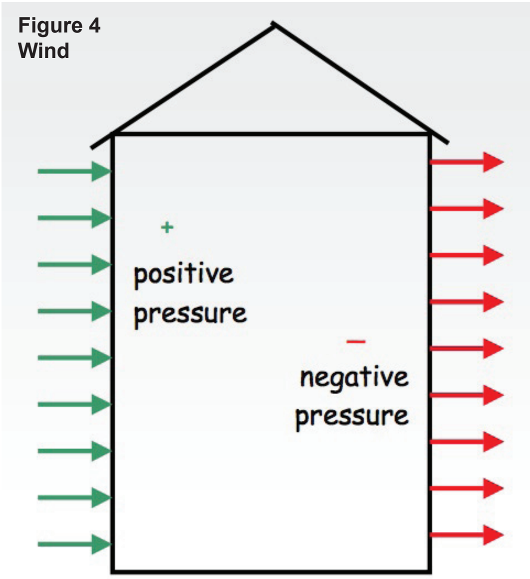
The Building Envelope

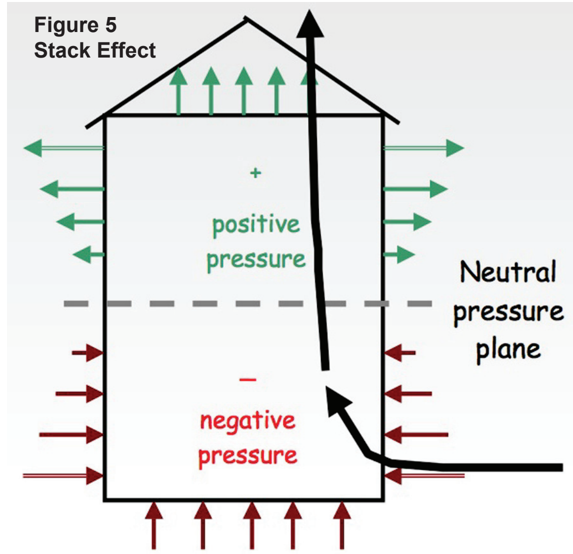
Four basic principles of physics dictate how the envelope works.

- Heat flows from hot to cold.
- High-pressure air flows to low-pressure.
- Airflow carries heat through the walls.
- Airflow also carries water vapor into the envelope.

Airflow is caused by pressure differences caused by wind, the stack effect, the air for combustion and exhaust fans. These factors combine to create air pressure in the top of the building that is higher than atmospheric pressure outdoors and pressures less than atmospheric low in the building. Somewhere in the middle is the neutral pressure plane where the pressure indoors and outdoors are equal. Figure 3.

Wind blowing on the building forces air into the upwind side and sucks air out of the downwind side (Figure 4). The Stack Effect (Figure 5) is hot rising and cold air falling in the building. The stack effect makes the air pressure higher than atmospheric pressure in the top of the building and below atmospheric pressure lower in the building. Air drawn into the burners for combustion and combustion gases vented from the building cause the pres-





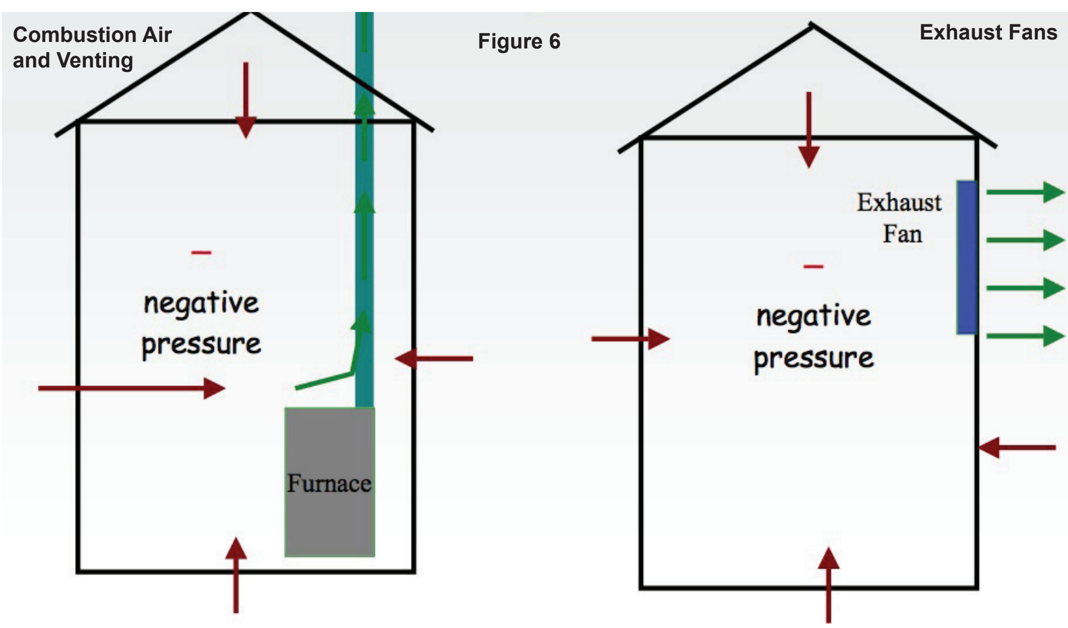
sure to drop inside the building. Exhaust fans that suck air out of the building also lower the pressure in the building and suck air in from outside. Figure 6.

Measuring Pressure

Oilheat technicians measure air pressure using inches of water column. One inch of water column is the pressure difference required to draw water one inch up a straw. Home performance contractors use Pascals (Metric Standard). One Pascal equals the weight of one Post-it Note and 248 Pascals = 1" WC (American Standard) so 2.5 Pascals = .01" WC.

The Building Envelope

Energy efficient homes are wrapped in a continuous "building envelope" that con-



nects the two aforementioned barriers: the Thermal Barrier and the Air Barrier.

The Thermal Barrier is composed of good insulating materials that resist conductive heat loss. Air is a heat sponge. If it is prevented from moving, it will hold the heat in the building. Insulation has many air pockets that trap air and prevent the flow of heat. The building also needs a pressure or air barrier, otherwise the pressure differences from wind, and other factors changing the air pressure will cause the air in those loose pockets in the insulation to flow, carrying the warm air out of the building.

The Pressure (Air) Barrier is the shell of the house. It should not have air leaks and should stop air under pressure from pushing through insulation, cracks and holes in the building. If there is a big pressure difference between inside and outside, a tiny hole can have a huge impact. Think how quickly a small nail hole in a tire can create a flat. The Home Performance goal is to have the thermal barrier always in contact with the air barrier and form a continuous, leak-proof wrap around the building. In the northern parts of the country, the air barrier is installed inside the thermal barrier.

Inside, Outside, or In-Between?

It is important to determine what parts of the building are inside and outside the air and thermal barriers. Generally, the unheated parts are outside: attic, garage, porches, and crawlspaces. All heated parts should be inside the barriers. Buildings also have rooms that are semi-conditioned. They are not heated deliberately, but heated by waste heat from appliances and passive solar heating. This would include basements, crawlspaces, sunrooms, and porches. Note that barriers can be installed to place crawl spaces, basements, and attics inside or outside the heated space.

The Air Barrier

The air barrier can be sheetrock (drywall), plastic, wood—in fact, any material impenetrable to air. It may even be the insulation itself (dense-pack cellulose and closed-cell foam are both a thermal and an air barrier). Doors and windows—the glass, weather-stripping, and the framework and trim—are also air barriers.

Air barriers should provide a continuous impenetrable surface or membrane surrounding the entire conditioned space of the house, in direct contact with the insulation. The air barrier is supposed to be a complete wrap with no leaks; however, in building the house, the air barrier is cut many times. Wires, pipes, chimneys, windows, bathroom vents, attic hatchways, electric outlets, and ceiling lights all create potential gaps in the air barrier. Figure 7 on following page. Finding and sealing these leaks is the most import energy conservation job home performance contractors do.

Barriers

The facings on fiberglass insulation are air barriers. They protect insulation, provide air and or vapor barrier, facilitate fastening, and hold it together. The effectiveness of a barrier depends on flawless installation and continuous, sealed seams. The facings can be made of Kraft paper, aluminum foil, or woven polyethylene (weather resistant— lets vapor escape).

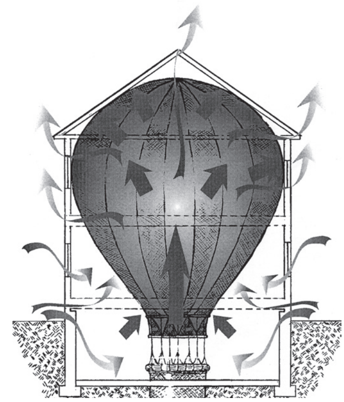
Air barriers can also be vapor barriers. Water vapor moves from inside to outside in the winter, and outside to inside in the summer. A vapor barrier is only suggested in rooms with lots of water vapor, such as the room with a shower. The vapor barrier should be on interior surfaces in the north, and exterior in the south. A vapor barrier is not strongly recommended because if it leaks it can allow water to flow into the walls or ceilings and trap it there, causing mold growth and the walls and ceilings to rot.

Air Leakage

Air leaks need air, a hole, and a pressure difference (driving force) between each side of a wall or ceiling. The bigger the hole or the greater the pressure difference, the more airflow. Reduce the size of the hole or driving force and airflow is reduced. Air sealing makes the air barrier as whole as possible.

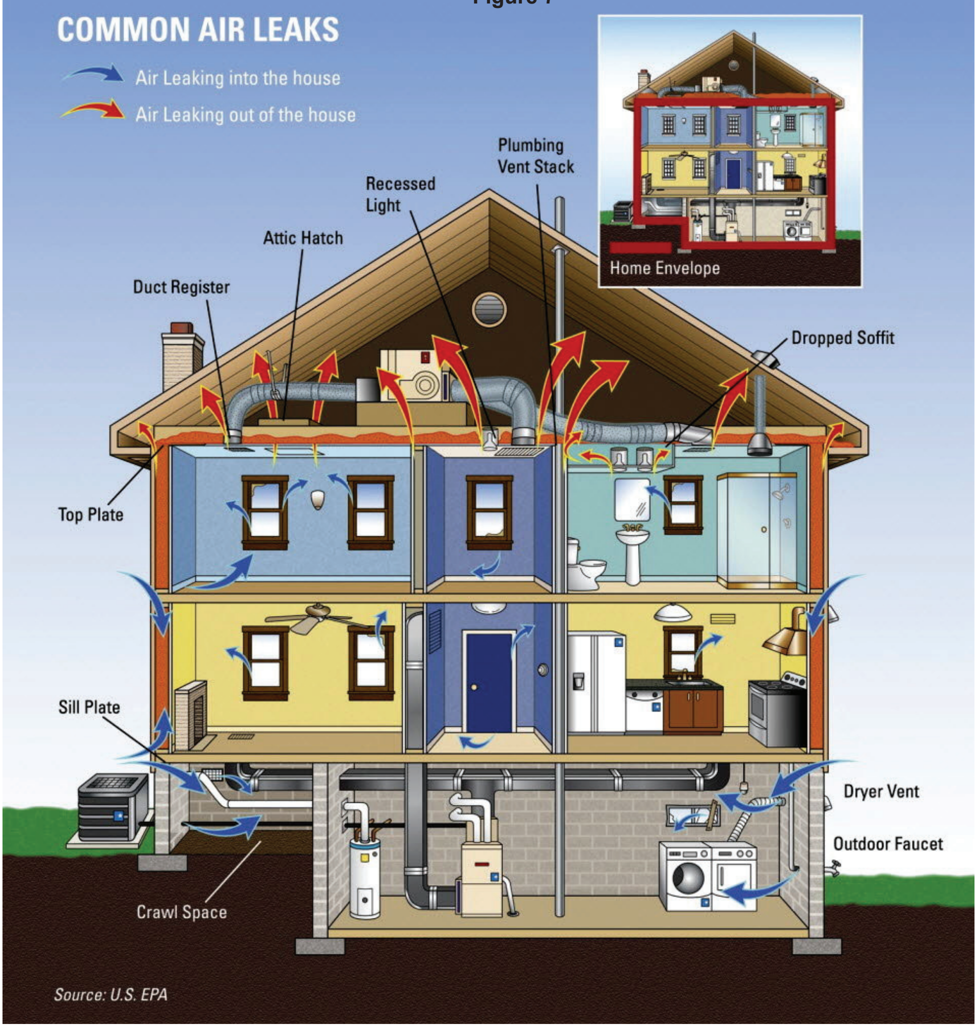
Top Priority—Air Sealing

Because of the Stack Effect, pressure differences are greatest at the ceilings and floors of the building. Basements and attics are also the most accessible for air sealing, and finding leaks in the attic should be the first priority. Leaks around windows and doors are common, so they should be inspected for leaks, especially between the garage and the house. Even if the basement is not in the conditioned space, sealing air leaks is helpful, and insulating to below the frost line to keep the heat exchanger, jacket, pipe or duct heat losses in the building is useful.



Over 35% of a home's energy is lost because of air leaks. Older homes with loose construction can lose all the air in the home twice in one hour. Infiltration loss is the energy required to heat up all the cold air

Figure 7



drawn into the building to replace the warm air that was lost through all the leaks. State-of-the-art sealed homes can have as low as one half an air change per hour. Additionally, air leaks create drafts that occupants may notice. After the heating system, finding and sealing air leaks should be the top priority.

Home Performance Contractors use a device called a Blower Door to measure and find air leaks, Figure 8. It is a large, variable-speed fan

Figure 8
Blower Door

they place in an open outside door. It draws enough air out of the building to make the pressure difference between indoors and outdoors 50 Pascals. By determining the cubic feet of area inside the air and thermal barriers, and the speed the blower has to run to achieve negative 50 Pascals, they can compute how big the leaks in the building are. When the building pressure is far below the outdoor pressure, the air leaks become obvious and are easy to locate. If there is a temperature difference between inside and outside, a thermal imaging camera will quickly identify gaps in the Thermal Barrier (Insulation).

Heat Flow is Dominated by the Weakest Link

It doesn't matter how thick the fiberglass is piled if there are gaps and missed spots. Gaps in insulation of just 5% in an R-40 attic will triple the heat loss! The typical leaky attic hatch accounts for about 5% of the surface area of the attic floor. A bypass is a place where air escapes the building thru chimney-like leaks. The effects of a by-pass are heat loss, moisture transport, and higher negative pressure in the building (sucking in more cold air). Typical by-passes: chimney and plumbing chase, tops of partitions and exterior walls, floor-knee wall transitions, and balloon frame construction.

Insulation

The most common way to describe insulation performance is R-value. R-value describes a material's resistance to conductive heat transfer. Materials with low resistance to heat transfer have low R-values: glass, steel, concrete, wood, and wallboard. Materials with higher resistance to heat transfer have higher R-values.

R-values for a wall or ceiling can be added but not averaged. They are like a sandwich. Each layer has a different R-value. To determine the total R-value of a square foot of wall, add together the R-values of all its layers. US-DOE minimum recommended R-values for existing homes in New England: Ceilings and attics:R-49; Sloped roof: R-38; Walls: R-19.

Insulation slows heat transmission

Air is a poor conductor. It is a heat sponge. It absorbs heat and carries it with it if it moves. Insulation's job is to trap the air and not let it carry heat away. Insulation also reduces radiation and air convection within cavities. It enhances comfort, reduces the size of heating and cooling system that is needed, prevents winter condensation, reduces noise, slows air leaks and water vapor transmission and improves fire resistance.

Dense-pack Cellulose

The newest and most cost effective insulation is dense-pack cellulose. It is made from recycled newspaper with fire retardant coating. It is blown-into the wall and ceiling cavities with a compressor. Because it is packed tightly into the cavity it has a very high R-value of about R-3.6 to 3.8 per inch. It is so densely packed that it allows no air to flow through. It is both a thermal and an air barrier. It is the preferred insulation for walls and ceilings. It should not be used in wet areas such as crawl spaces and basements.

Foam

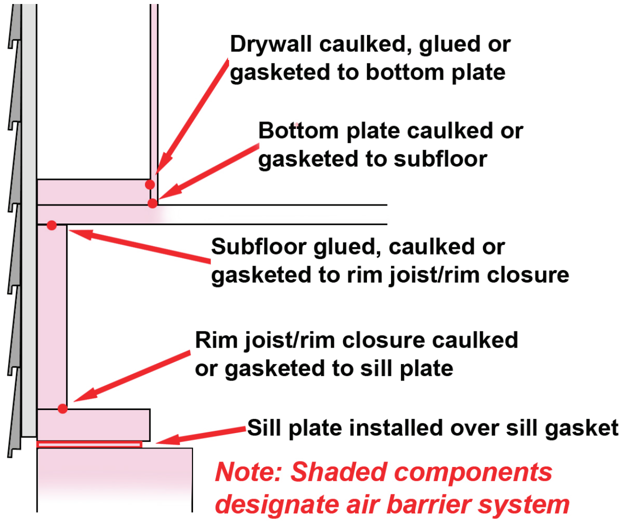
There are two types of foam insulation: High-density, closed cell- about R-7 per inch, and Low density, open cell- about R-3.5 per inch. Foam has excellent air sealing characteristics. It also offers excellent "fit", since it expands to fill spaces and glues itself to surfaces. Therefore foam serves as both an air and thermal barrier.

Foam also comes in rigid faced and unfaced boards. Foam is the best way to seal the band joist and sill plate in a crawl space or basement. It is also recommended to seal the basement walls down to below the frost line. The downside to foam is it is not fire retardant, and fireproof paint or foil facing must be applied to the foam on the basement walls.

Attics—Air Seal First, then Insulate

If the attic hatch is located above a conditioned space be sure it is insulated, weatherstripped, and closes tightly. It is an easily accessible major hole in the barriers. In the attic be sure openings for pipes, ductwork, and chimneys are sealed. Look for stains on

Figure 9
Sealing Band Joist and Sill Plate



the insulation to locate leaks. Air leaks carry dust and dirt from the house with them. If the edges of the fiberglass are stained a dark color it means air is leaking there, these are often referred to as ghost stains.

If there is no floor in the attic and the air leaks have been sealed it is easy to add more insulation: either loose fill or unfaced fiberglass batts. A foot (R38) of fiberglass or cellulose insulation is cost-effective in the attic floor. It is critical to install fiberglass batts properly.

If there is a lot of ductwork, or if there are air handlers for hydro-air systems in the attic, the best attic strategy might be to bring the attic indoors, that is, instead of insulating the attic floor and ventilating the space, insulate the attic roof. Alternatively, if it will be difficult to seal the ducts and air handlers properly, the air and thermal barriers can be installed over the top of the ducts and air handlers so they are beneath the insulation instead of outside of it.

Basements

The sill plate, the rim joist, and the foundation above frost line should be sealed and insulated (The insulation can be outside the foundation or inside.) Figure 9 above. Materials that could be damaged by moisture, such as fiberglass and cellulose, should not be used to insulate a crawl space or basement. Interior basement insulation should be foam installed against the basement walls. It must be protected with fire-rated covering—drywall, spray-on coating, or fire-rated foam. If there is cellar hatchway to outdoors, be sure it is sealed and insulated. Installing an air barrier between the hatchway and the cellar, such as a door, may be a good option.

Crawl Spaces

The crawl space should be sealed, NOT ventilated. (Think of crawlspaces as small basements). Dirt Floors are a source of moisture and should be sealed: eliminate the source of any standing water then use 6-mil thick polyethylene sheeting as a vapor barrier to cover the ground and seal tightly to walls and columns. Then seal and insulate the walls, rim (band) joist and sill plate.

Humidity

Humidity is important for comfort. Humidity affects the rate skin is able to discharge heat. In the winter, higher humidity is more comfortable, because the water vapor on skin will not evaporate and will not take the heat from the body making one more comfortable at lower temperatures. In the summer, perspiration and evaporation cool the body.

Humidity is water vapor in the atmosphere. The mass of water vapor per unit of air volume is called absolute humidity. Relative humidity is the ratio of the water vapor in the air compared to the amount of moisture the air could hold at that temperature. If the relative humidity is 100%, the air is saturated with water (it cannot hold any more water). If the relative humidity is 0 percent, then no water vapor is present. Clothes that are hung out to dry on humid days will dry more slowly than on dry days, because the air cannot absorb the water as quickly when it is mostly saturated.

Air saturation depends on the amount of water in the air or the air temperature. The saturation point is called the dew point. When the air cools at night, the relative humidity will rise until the air is saturated. At that point, water will begin falling and this results in dew in the summer and frost in the winter. The temperature at which the amount of water in the air and the temperature intersect to have water condense is called the dew point.

A number of household comfort and health problems stem from having either too much or too little humidity in the air. When the relative humidity indoors exceeds 50% on a continuing basis, usually in the summer, mold, mildew, and bacteria grow in furnishings, walls and ceilings. Windows and walls start to sweat and moisture condenses inside the walls and roof framing. This sets the stage for rot and allergies.

If the air in a building is too dry, it can cause problems. Not only do occupants feel cold, but also when relative humidity is 15 percent or less, throat and nasal passages get too dry due to rapid evaporation. Furniture joints come apart, bookbindings crack, paint may not hold to some surfaces, plaster cracks, and static electricity becomes a nuisance.

Both furnaces and boilers that are in the conditioned space that are not provided with outside combustion air will tend to lower the humidity of a house. Generally, people, animals and plants will increase humidity as the moisture in them evaporates. Similarly, boiling water, showers, and the dishwasher will also add water to the air. However, as the boilers and furnaces call for air for combustion, fresh cold and generally dry outside air will be brought into the house through air leaks. As this air is brought up to room temperature, it will seem even drier as the relative humidity falls.

Furnaces often make the problem even worse due to their use of circulating air to heat the home. Most rooms have supply registers, but only a few also have return registers. If the doors to the supplied rooms are closed the air pressure will rise, and warm air will be forced out of any air leaks in the room. The pressure in the room with the return register will be less than atmospheric pressure and dry cold air will be sucked into this room.

Water condenses on cooler surfaces. If those surfaces are inside the wall and ceiling cavities it can cause serious problems. In the summer, less than 60% humidity is comfortable; in the winter, humidity should be less than 40% to avoid condensation. Living in a home creates a great deal of water vapor; if the home is so dry it needs a humidifier, it probably has spectacular air leaks that should be fixed instead.

Water Solutions

Stop water from leaking into the building. Make the walls and roof watertight, fix plumbing leaks, keep water away from the building (gutters and grading), seal dirt crawl space and basement floors, install a sump pump to eliminate standing water, be sure exhaust fans are vented to the outdoors, and install or improve air/vapor barriers.

Ventilate with dry outdoor air to dilute more humid indoor air, and improve insulation to keep indoor surfaces warmer, resisting condensation. If the basement is wet, get rid of the water before sealing up the air leaks.

Determining the Heat Loss for the Building

Understanding Building Science helps understand heat loss. When replacing a boiler or furnace, always do a heat loss calculation for the building! Most units in the field are oversized. Many buildings have had home performance work done that decreases losses allowing for a smaller boiler or furnace.

Why Oversizing is bad: larger units cost more than smaller ones, the bigger the unit the greater the off-cycle losses, the heat input outruns the heat output, therefore the burner short cycles and never reaches steady state. This lowers efficiency by one to three percent as soot and scale deposits on the heat exchanger increase.

The best way to calculate heat loss is with heat loss software. To do a proper heat loss, a floor plan of the building and building construction information is needed, including: wall construction materials and insulation, window and door details, floor, ceiling, attic and basement details, and the building owner's desired indoor temperature (the Indoor Design Temperature).

Steps to Determine Heat Loss

- Determine the design temperature difference.
- Obtain dimensions of all heat loss surfaces, (any surface with heated space on one side and unheated space on the other).
- Determine Transmission Heat Loss Factors.
- Determine Infiltration Heat Loss Factors.

DTD—Design Temperature Difference

The DTD is the Indoor Design Temperature minus the Outdoor Design Temperature for

Typical Transmission Heat Loss Factors

Windows & Doors:
Single pane glass—1.14

Double glass—0.65

Storm windows—0.56

Walls not insulated:
Wood frame—0.24

Brick, cement—0.31

Walls insulated:
2" batts (R-7) —0.10

4" batts (R-11) —0.08

6" batts (R-19) —0.02

Ceiling:
Uninsulated—0.30

2" batts—0.11

4" batts—0.07

6" batts—0.05

8" batts (R-28) —0.03

12" batts (R-40) —0.02

Cold Floor:
Over cold basement
Uninsulated —0.15

2" —0.05

4" —0.04

Vented Crawl space:
Uninsulated— 0.36

2" —0.09

4" —0.06

the region of the country. The Outdoor Design Temperature is the temperature it will not be colder than for more than 2.5% of the time during the coldest month of the year for a specific location, so it is the average temperature on the coldest day of the year.

Transmission Heat Loss, Insulation

The transmission loss is the quantity of heat (Btuh) flowing through one square foot of wall, ceiling, floor, roof or glass for every degree temperature difference between inside and outside air. Transmission Heat Loss Factor is the rate of heat flow through the insulation and material that makes up the walls, ceilings, windows, and doors.

To determine the Transmission Heat Loss, find the Surface Area (square feet) of all the surfaces in the building that separate the heated space from outdoors and the unheated spaces in the building.

Multiply the square feet of surface area by the Heat Loss Factor for each surface. The heat loss factor is a number that describes how fast heat travels through the materials the walls, ceilings, and floors are made of.

The next step is to multiply the answer by the Design Temperature Difference. The better the insulation, the smaller the factor and the slower the heat loss. This equals the Transmission Losses.

Infiltration Loss—Air Leaks

Infiltration Heat Loss Factors measure the energy required for heating the cold air that infiltrates in through the walls and cracks around windows and exterior doors. It is the number of times each hour that the total cubic feet (volume) of air within the building is replaced by the infiltration of cold air.

The factors range from one-half air change per hour for few air leaks and heavy insulation to as much as two changes an hour for buildings with lots of air leaks and little insulation. The infiltration heat loss factor is one Btuh for every cubic foot of room volume for every degree difference between indoor and outdoor temperatures.

Multiply the Infiltration Factor times the Volume (cubic feet) of air in the building times the Design Temperature Difference to find the Infiltration Loss.

Infiltration Loss Factors

- Very tight, very heavy insulation, ½ air change per hour—0.009
- Tight, heavy insulation, ¾ air change per hour—0.011
- Standard construction and insulation, one air change per hour—0.018
- Older house, good condition, 1½ air changes per hour—0.027
- Loose construction, air leaks, 2 air changes per hour—0.036

Total Heat Loss

The total heat loss calculation is how many Btus per hour (Btuh) it will take to heat the building on the coldest day of the year.

The total Btus per hour that leak through every square foot of building surface that is heated on one side and not heated on the other at the Design Temperature Difference–add the total Btus per hour it takes to heat every cubic foot of cold air pulled into the building to replace the warm air that is leaking out– this equals the Total Heat Loss of the Building.

The total Heat Loss is also called the heating load. It is the total Btus needed per hour to heat the house on a design temperature day.

Boiler and Furnace Sizing

The total heat loss calculation provides the information needed to size the boiler or furnace to heat the building. Heat for warming the domestic water does need to be considered in the overall boiler sizing unless hot water is a primary load (for example, a commercial laundry or kitchen application).

Inspecting the hot water requirements however, is critical, especially for drain down tubs and high volume showers. The trick is to take care of the additional hot water demand by increasing the size of the storage tank. Most manufacturers recommend the same volume in storage as the largest demand. A 100-gallon bathtub requires a 100-gallon storage tank.

Hot water can be addressed with either firing rate or storage, or a combination of both. Something else to consider: as building heat loss gets lower and lower, hot water may become the primary design criterion instead of the heat loss in the future.

In the USA, boiler and furnace ratings are shown in Btus per hour. Manufacturers also often use the term MBH–1,000 Btus per hour. European equipment uses the Metric Rating—Kilowatts (kW). A kilowatt equals 1,000 joules per second, about 3,412 Btuh. Commercial and industrial boilers are rated in boiler horsepower. One boiler horsepower equals 33,446 Btuh (don't confuse this with brake horsepower used to rate motors).

To size a furnace, use the furnace output rating to select the furnace that is the closest higher number to the Total Heat Loss for the building. Use the Net Load Rating when selecting a boiler. The Net Load Rating includes a 15% pick-up factor that allows for heat loss from piping. Select a boiler with a Water Btuh Net Load Rating just higher than the heating load.

Chapter 6

Heating System Safety Tests

Home performance contractors are required by the Building Performance Institute (BPI) to perform preliminary and post-installation safety inspections of all combustion appliances whenever changes are made to the building envelope and/or heating system. The Safety Inspection includes a carbon monoxide test, then the following three tests to determine whether combustion appliances are venting properly:

- Spillage
- Draft
- Worst-case depressurization of the combustion appliance zone (CAZ). The CAZ is the room containing the boiler, furnace, or water heater. Trained heating technicians must act upon combustion safety test results appropriately.

Carbon Monoxide

Carbon monoxide (CO) originates from incompletely burned carbon. It is dangerous because it prevents the absorption of oxygen into the blood stream. Causes of CO formation are:

- Fuel-rich mixture
- Improper venting
- Premature cooling of the flame.

Sources of carbon monoxide are unvented kerosene and gas space heaters, leaking chimneys, furnaces, boilers, woodstoves, pellet stoves, fireplaces, gas stoves, dryers, other gas-powered equipment, an attached garage, candles, and smoking.

Carbon Monoxide Test

Carbon Monoxide is measured in parts per million (ppm). Most carbon monoxide test equipment calculates as measured and air free CO levels. For BPI testing energy auditors use as measured values.

Home performance contractors measure ambient CO levels (ambient means the air in the room). BPI certification requirements state that ambient CO shall be monitored upon entering the CAZ and during the test period for all appliances. An ambient reading over 35 ppm is considered unsafe and requires action.

They also measure CO in undiluted flue gases (the gases present in the heat exchanger before the draft relief air from the draft regulator is blended with them). The reading for the undiluted flue gases at steady state should not be higher than 100 ppm.

Unvented and “vent free” appliances are not recommended. BPI tells contractors to not test them. (You touch it. You own it.) Home Performance contractors are instructed to stop the audit as soon as they discover an unvented appliance and to tell the customer it is dangerous and should be removed. They will return to finish the audit once the appliance has been removed.

CO and Oil Burners: Combustion Air Supply Problems

An oil burner’s CO production can increase dramatically with incomplete combustion which can result from either insufficient combustion air or too much combustion air. Insufficient air will also create smoke, while too much air does not, but excessive air will create a yellow spot on the smoke test paper from unburned oil.

Because one of the major causes of CO events is insufficient combustion air in the

CAZ, this can be difficult to diagnose at first because when entering the CAZ, the open door allows the pressure to equalize, supplying fresh air to the room. This temporarily fixes the problem. Look for clues that the burner was starved for air when the problem occurred.

Some hints that there are air supply problems include:

- Odors or smoke in the building when the unit runs
- Carbon monoxide detector sounds alarm
- Soot or rust on top of unit, in burner air tube, and draft regulator
- Burner rumbles
- Soot streaks around inspection port
- Sooted-up cad cell and drawer assembly

A carbon monoxide problem in the building is caused by improper combustion and a venting failure.

Ambient CO

BPI certified contractors training states that when running combustion appliances for testing, the technician should monitor the ambient CO levels in the room in which they are working. If at any point the CO level in the room goes above 35 ppm, they are to turn off the appliances, open the doors and windows to provide fresh air and go outside until the CO drops to a safe level before returning to the CAZ. They are to inform the customer a heating technician must inspect and repair the system.

Carbon Monoxide Remedies

- Do NOT use unvented combustion appliances.
- Inspect and tune-up combustion appliances.
- Be sure all venting systems are operating properly.
- Be sure there are no holes in furnace heat exchangers or leaks in returns in the combustion air zone.
- Install a carbon monoxide detector on each floor.
- Bring in combustion air from outdoors.

Spillage (Back Draft) Test

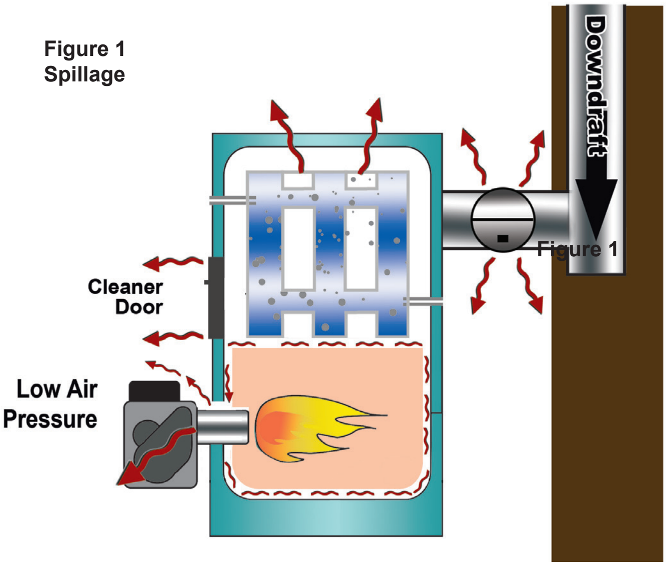
Spillage occurs when proper negative draft is not established in the venting system and flue gases spill from the appliance into the building. Spillage often leaves behind visual signs—rust and soot on top of the unit and on the floor around the unit.

To check for spillage, turn the unit on and use the back of your hand or a smoke stick. Check airflow around the draft diverter or draft regulator to be sure that within one minute of firing, the flow is from the building into the venting system. For induced draft heating units, check for spillage at the base of the chimney. Figure 1 on following page.

Spillage that occurs under normal building operating conditions should be addressed immediately. Spillage should also be checked under simulated worst-case conditions.

Draft Test

Take a pressure measurement in the flue pipe with reference to the combustion appliance zone. Draft should be measured in a hole in the flue pipe 12" from the draft diverter for gas



atmospheric pressure outside the house, the house is said to have "gone negative".

Fans can move significant volumes of air. The volumes of air measured in cubic feet per minute, that some common fans can draw are listed below:

- Clothes Dryers—200 cfm (often installed in the CAZ)
- Kitchen Range Hood Fans—200 to 1,200 cfm
- Bathroom Fans—25 to 90 cfm
- Open Fireplace dampers—500 cfm
- Fuel Burning Appliances without Sealed-Combustion—35 cfm.
- Blower on a warm air funace—1,200 cfm

Central vacuum systems and attic ventilation fans can also cause depressurization problems.

and between the breach and the draft regulator for oil. The test hole should not be in an elbow. Draft should be measured under steady-state conditions (after five to 10 minutes of operation.) Acceptable draft is dependent upon the outside temperature and the appliance.

A minimum of -2.5 to -5 Pascals (-.01 to -.02" wc) is required to pass the BPI Draft Test.

Worst Case Depressurization Test

The Worst Case Depressurization Test is a safety test to see if there are combustion air or draft problems. If all the windows are closed and all the exhaust fans are on, will the combustion gases still go up the chimney? The test determines how strong the negative pressure in the CAZ is with respect to outdoors and the rest of the building. Then it determines if the appliance vent will create negative draft under that condition and if so, how strong will the chimney draft be? Figure 2.

Fan Wars

There are a lot of fans in homes these days: bathrooms, kitchens, blowers for furnaces and air conditioners, and dryers. When they are all turned on, they create a large pressure difference between inside and outside the home. When the air pressure drops inside relative to

Depressurization Test Steps

Before doing the test, be sure there is no fire nor hot ashes in the woodstove or fireplace. The test will take the house negative, so air will be pulled down the chimney. This could rekindle the smoldering ashes and pull the sparks and smoke into the house.

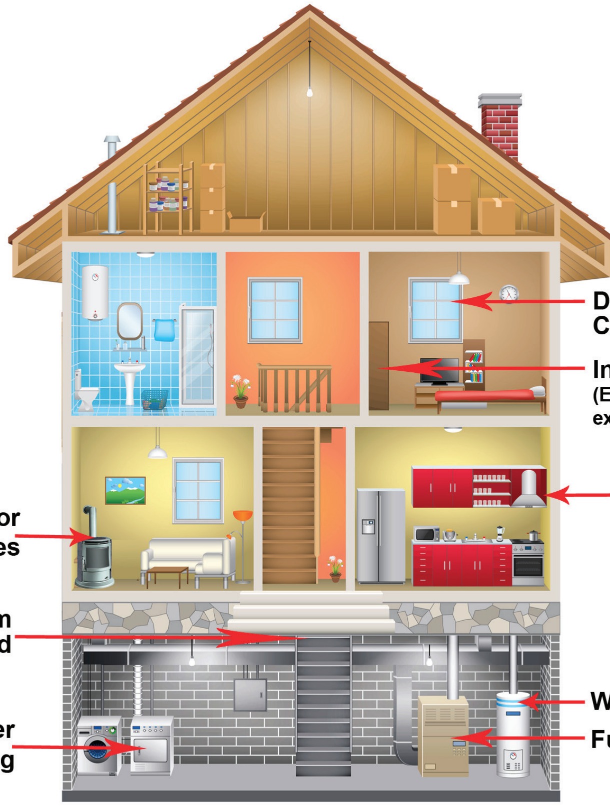
Close the attached garage door. There may be hazardous chemicals (cleaners, degreasers, insect repellents and poisons) in the garage as well as gases from the cars and other internal combustion engines and possibly even gasoline fumes). Do not suck fumes from any of these sources into the home.

Turn off all the combustion appliances, close all exterior doors, windows, and fireplace dampers.

With everything off, test the air pressure in the CAZ with reference to the outside pressure to establish a baseline pressure. Insert the probe from your manometer (digital draft gauge) through a slightly open window. A tester hose extension may be needed to reach the nearest window.

Then turn on all exhaust fans and the furnace

Figure 2
Worst Case Test



fan. Use your manometer to test the air pressure difference again between the combustion air zone and outdoors. Open or close interior doors to create worst-case depressurization (the highest negative draft possible) in the combustion air zone.

Once You Have Created Worst Case

Fire the water heater if it is a separate unit and test to be sure it is operating properly. Then fire the boiler or furnace and check the draft overfire and in the flue for all the combustion appliances for back drafting and spillage. Also check for CO ambient and in the undiluted combustion gases.

The results you are looking for are: -.02" wc (-5 Pascals) overfire draft, less than 35 ppm CO ambient, zero to trace smoke. If any appliance fails the spillage or draft test under worst case, repeat the test under normal conditions. If it still fails, determine the reason and fix the problem.

Fixes for Depressurization

If the building's air leaks are sealed and the fans are preventing sufficient air for the burner's combustion, outdoor air must be provided. This can be accomplished with a fan in a can, an air boot on the burner or an air box on the burner. The return air ducts should also be checked for leaks in the CAZ. If there are leaks, the furnace blower (the largest fan in the house) is pulling air out of the CAZ and sending it up into the building. The blower on the furnace is depressurizing the burner on the furnace!

The following are fixes for depressurization of the CAZ:

- Seal leaking ducts (especially leaking returns in the combustion air zone).
- Add point source ventilation for problem devices.
- Isolate combustion for burner.
- Install carbon monoxide detectors on every floor.
- Advise the customer to only run one big fan at a time and not to run fans if there is a fire in the fireplace or woodstove.

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