Off-cycle losses can be minimized by vent dampers, draft fans, and smaller heat-exchanger passageways that restrict off-cycle airflow through the heat exchanger and venting system. Room heaters have far less off-cycle losses than central heaters because most of the heat stored in the heat exchanger escapes into the room rather than out the vent.

Furnaces and boilers are designed to achieve their maximum efficiency at maximum output and load. When the heating load is less than the heater's output, then the furnace or boiler cycles on and off. Numerous, shorter cycles waste energy through greater off-cycle losses. However, longer cycles may overheat the building, waste energy, and cause discomfort. This is why selecting a furnace's or boiler's output correctly reduces waste caused by both off-cycle losses and overheating. This principle is more important with boilers than with furnaces because of the boiler's heavier heat exchanger and heating fluid.

Distribution losses — Distribution losses typically amount to 5% to 30% of the heat contained in the fuel being burned by a furnace or boiler. Distribution losses are partially reclaimed if the pipes or ducts run through heated spaces. If these distribution losses heat an unconditioned space, heat loss from the conditioned to the unconditioned space is reduced. However, central heating systems are designed to heat rooms through registers, radiators, or baseboard convectors. Usually, distribution losses are at least partially wasted — escaping from unconditioned spaces or overheating conditioned spaces.

Heat escapes the distribution system in two ways.

1. The heating fluid — air, water, or steam — escapes from the ducts or pipes.
2. Convection and radiation carry heat away from pipes and ducts.

Leaks in pipes and ducts are the most severe distribution problems. You can reduce convection and radiation by installing pipe or duct insulation.

If the distribution system is undersized or its circulator is functioning poorly, this reduces heat transfer at the central heater's heat exchanger. More of the flame's heat escapes up the chimney.

Combustion Safety and Efficiency

Combustion heaters are, statistically, among the most dangerous hazards found in residences. Fire and indoor air pollution are the most common problems.

Home-heating systems are more likely to be dangerous than those of multifamily buildings because of stricter multifamily safety standards and the home heater's closer proximity to residents. Room heaters are particularly dangerous, because of their location within the living space.

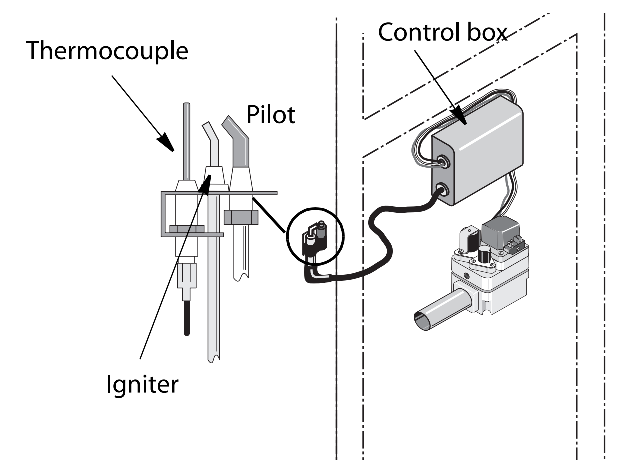
Ideally, a heating professional performs maintenance and safety checks annually for all oil-fired equipment. Gas furnaces and boilers burn cleaner and have less moving parts than oil, so they need service less often.

Combustion-safety Issues

CO is the greatest indoor pollutant threat from combustion heating. This colorless, odorless gas can sicken or kill the building's occupants. Other gases affecting health include nitrous oxide, water vapor, and sulfur dioxide. These gases can escape into the building's living spaces through cracked heat exchangers, backdrafting, and spillage. Combustion air is essential for safe operation of combustion heaters.

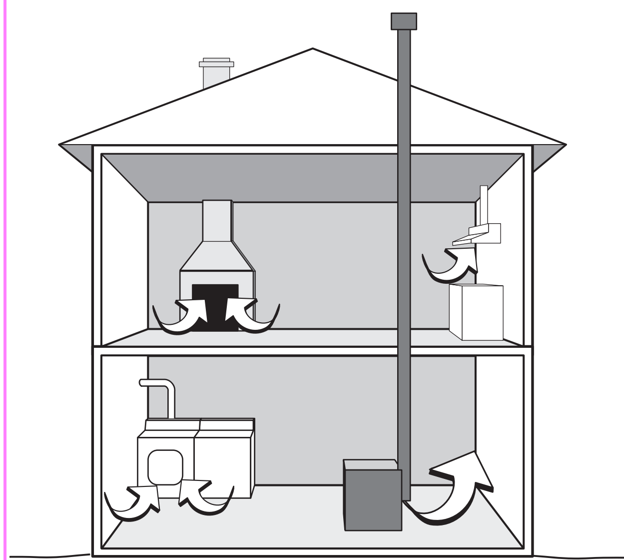
Flame-safeguard controls — Heaters are a major cause of fires. Combustible materials should be kept at a safe distance from hot components of the heater. Electrical components should be inspected for safety at least biannually. A smoke alarm should be located in or near the heater's space.

Intermittent Ignition Device (IIDs)



Pilot lights consume 3% to 5% of a furnace or boiler's fuel. IIDs eliminate that waste.

Back-Drafting with Depressurization



Appliances that exhaust air — such as dryers, fireplaces, and exhaust fans — create a suction that can cause the furnace chimney to back-draft indoors.

All combustion heaters should be equipped with a high-limit control to extinguish the burner in the event of overheating. The high-limit control is a bimetal element attached to a switch in the burner's control circuit. The high-limit is tested by disabling the circulator and measuring the fluid temperature (pressure, if fluid is steam) at which the high-limit control extinguishes the burner.

Flame-safety controls protect against fuel delivery to the combustion chamber without ignition. Oil, natural gas, or propane accumulation in the combustion chamber could lead to a fire or explosion. The three most common flame safeguards are the thermocouple, the photocell, and the flame rectifier.

A *thermocouple* is a small electric generator powered by heat from the pilot light of a gas appliance. The thermocouple's electric circuit powers a magnetic valve that remains open as long as electric current is flowing. If the pilot light goes out, the electric current stops, and the spring-loaded valve closes, shutting off the gas.

A *flame rectifier* uses the flame to conduct control current and to change it from AC to DC. Many modern furnaces use flame rectifiers, which both light and sense the flame with a single device.

A *photocell* produces a small electric current from the light emitted by a flame. This current holds the contacts of a relay (magnetic switch) together as long as the photocell senses the flame. If the flame goes out or fails to light initially, the photocell's relay interrupts electricity to the heater's power burner.

Cracked heat exchangers — Cracked heat exchangers are a safety problem specific to combustion furnaces and room heaters. Cracked heat exchangers can allow combustion gases to mix with air from the building. Rust, excessive heat, and weld failure are common causes of cracked heat exchangers. Technicians inspect heat exchangers for cracks visually and by several other techniques including the following.

- Observing for flame variation when the blower turns on.
- Injecting chemicals or smoke into the combustion chamber and then using detection devices to sense chemicals or smoke in air exiting supply registers.

- Shining a bright light into the combustion chamber and looking for light leaks from the building side of the heat exchanger.
- Using remote-viewing devices.

Spillage and backdrafting — *Spillage* is a temporary flow of combustion by-products out of the dilution device when a furnace or boiler starts. Weak draft during the first moments after ignition causes spillage. Spillage, if present, usually stops after the chimney warms up. Backdrafting is continuous spillage — a reversal of the chimney's normal direction of flow.

Backdrafting is most common in atmospheric, open-combustion appliances. Severe backdrafting can suffocate the flame, producing CO. The draft diverter or barometric-draft control is designed to let backdrafting flue gases escape from the chimney before they dump down onto the burner.

Backdrafting can be caused by the following.

- Suction near the furnace or boiler caused by leaky return ducts, exhaust fans, a clothes dryer, a or fireplace.
- Blocked chimney.
- Chimney too large or small.
- High winds.

Backdrafting may be eliminated by:

- Sealing leaky ducts.
- Repairing the chimney.
- Eliminating depressurization near the chimney.
- Providing outdoor combustion air.
- Replacing the open-combustion, atmospheric heater with a sealed-combustion or power-draft heater.

See "Duct Air Leakage" on page 89 and "Duct Leakage Comparisons" on page 67.

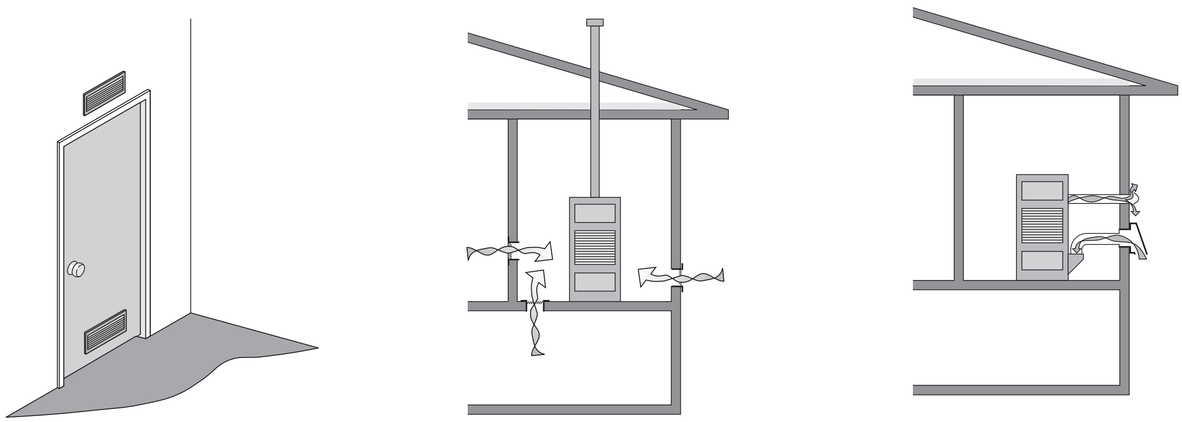
The safest and most efficient new heaters have fans to vent combustion by-products, and they require little indoor combustion air. These fans reduce the threat of backdrafting.

Chimney draft in atmospheric-draft appliances should be negative 1 to 5 pascals (0.004 to 0.020 inches of water) depending on the outdoor temperature. Colder outdoor temperatures produce higher draft. Measured pressure differences between outdoors and the combustion zone — called depressurization — should not exceed 4 to 5 pascals with exhaust fans and furnace fan running during a worst-case depressurization test. The combustion heater should spill — emit combustion gases from its dilution device — for no longer than one minute under worst-case test conditions.

Combustion Appliance Depressurization Limits

Appliance Type	Max. Depress.
Atmospheric water heater only (Category I, natural draft), open-combustion appliances	–2 pa
Atmospheric water heater (Category I, natural draft) and atmospheric furnace (Category I, natural draft), common-vented, open-combustion appliances	–3 pa
Gas furnace or boiler, Category I or Category I fan-assisted, open-combustion appliances	–5 pa
Oil or gas unit with power burner, low- or high-static pressure burner, open combustion appliances	–5 pa
Wood-burning appliances	–7 pa
Open-combustion furnaces or boilers with fan-powered horizontal venting	–15 pa

Combustion Air Alternatives for Confined Spaces



Passive combustion air can be supplied from adjacent indoor spaces to a confined space.

Installing low combustion-air vents is preferable to installing high ones because high ones may create a stack effect that competes with the chimney.

Sealed combustion, high-efficiency furnaces and boilers are far less affected by pressures and are the safest alternative.

***Combustion air* —** Air leakage through the building shell usually provides combustion air. Some codes and code officials require combustion air piped in from outdoors, especially for confined spaces. A confined space is a room containing less than 50 cubic feet of volume for every 1000 BTU per hour of appliance input.

However, if a small mechanical room is connected to adjacent spaces through large air passages like floor-joist spaces, the room may not need additional combustion air despite sheeted walls and a door separating the mechanical room from other indoor spaces. On the other hand, if the home is unusually airtight, even a large mechanical room may be unable to provide adequate combustion air.

A sealed-combustion heating system is always preferable for reliable combustion-air delivery and combustion-gas venting. Passive intake vents from outdoors or neighboring indoor areas are unreliable sources of combustion air, if wind or indoor pressures occur.

The location of a passive combustion air inlet is important. The wind creates a positive-pressure area on the building's windward side and a negative pressure near walls parallel to the wind direction. If the inlet were located in a negative-pressure area, this inlet could suck air out of the building instead of letting air in.

Some codes specify two sources of air to prevent pressure or suction in the mechanical room. With two openings, if one is creating a pressure, the other opening can relieve the pressure. While this approach is better than a single combustion-air source, wind, cold weather, or indoor depressurization can still overwhelm atmospheric chimneys. Combustion-air vents located high in walls or in ceilings may also depressurize the mechanical room by way of the stack effect.

When the combustion-air duct brings outdoor air into a living area, a control mechanism — like a damper — may be necessary to prevent residents from closing the duct permanently because of the drafts it causes. Isolating the central heater in an airtight room and providing this room with outdoor combustion air is preferred over dumping combustion air into living spaces. Connecting the combustion-air duct to the furnace's return ducts solves the comfort problem, but the cold make-up air may cause condensation and corrosion in non-condensing furnaces during cold weather and after thermostat setback. The return air mixed with outdoor air shouldn't enter the furnace at less than 55°F.

Combustion and Dilution Air Requirements

Appliance	Combustion Air (cfm)	Dilution Air (cfm)
Conventional Oil	38	195
Flame-Retention Oil	25	195
High-Efficiency Oil	22	–
Conventional Atmospheric Gas	30	143
Fan-Assisted Gas	26	–
Condensing Gas	17	–
Fireplace (no doors)	100–600	–
Airtight Wood Stove	10–50	–

A.C.S. Hayden, Residential Combustion Appliances: Venting and Indoor Air Quality; and Solid Fuels Encyclopedia

Combustion and dilution air can create large airflows and result in depressurization of the combustion zone. Depressurization can affect draft and result in carbon-monoxide production. Sometimes providing outdoor combustion air can solve combustion problems. Worst-case draft and depressurization testing can identify the problem as either related to combustion air or not related. Depressurization can also be caused by exhaust fans and furnace blowers, so it makes sense to find the depressurization source before prescribing a solution. Providing combustion air from outdoors may fail to solve a depressurization problem or may make the problem worse.

In tight homes or windy regions, sealed-combustion appliances may be the only reliable venting-and-combustion-air systems. For retrofitting hard-to-vent homes, sealed mechanical rooms with horizontal venting, power venters, and fan-powered combustion air may be necessary.

Flue-gas Testing

Combustion-gas testing is used to estimate steady-state efficiency (SSE). SSE is a good measurement of a heater's potential for improvement, or the cost-effectiveness of replacing the heater.

Heating professionals sample combustion gases as they leave the heat exchanger, before being diluted by the dilution device. They measure SSE with chemical or electronic gas analyzers.

The chemical testers use the predictable change in volume of a liquid chemical as it absorbs carbon dioxide (CO_2) or oxygen (O_2). Entering the percentage of either oxygen or CO_2 with the combustion gas temperature into an equation gives an estimate of SSE.

The electronic analyzers measure the percent of oxygen, using an electronic sensing device whose electric output varies with its exposure to O_2. Electronic analyzers have a built-in calculator that figures SSE automatically.

CO_2 is the product of complete combustion. The higher the percentage of CO_2 the greater the SSE. CO_2 varies between 3% and 13%. Oxygen is an indicator of excess air. The higher the level of O_2, the lower the SSE. Oxygen varies from 3% to 13%. Higher exhaust temperatures predict lower SSE, but the temperature must be compared with oxygen or CO_2 levels to determine SSE. The O_2 level also indicates whether the combustion air is adequate — if the O_2 level is above 4%.