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Combustion Safety Checks: How Not to Kill Your Clients
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Combustion Safety Checks:

How Not to Kill Your Clients

People who manage or work within programs that provide any significant service inside a building need to be familiar with the basics of combustion and combustion safety.

by Rob deKieffer

ROB DEKIEFFER

Flame roll-out is an indication of serious combustion problems. Some warning signs of flame roll-out include black or rusted areas in front of the burners (visible here), burnt wires and carbon deposits.

Heating contractors, inspectors, and energy auditors all have different approaches to inspecting combustion appliances. Combustion problems come in various sizes and shapes, and individual tests may not by themselves prove if the house is actually safe. Those of us who work in buildings must be able to understand the signs, and know what and when to test, in order to ensure that a small oversight does not result in a long-term health problem for our client.

Knowing some simple facts about combustion will make analysis easier. Most common fuels have carbon (C) and hydrogen (H) locked up and ready to heat. Add a consistent ignition source and some oxygen and we have combustion. Breaking apart the carbon-hydrogen bond produces heat and releases carbon and hydrogen to find a new bond. On a good day, this will produce water (H_20), carbon dioxide (CO_2) and a bunch of hot air. This means that the carbon had to find some oxygen. To do this, the combustion products must stay hot, and oxygen has to be available. If there is insufficient oxygen, the carbon has no choice but to remain carbon or become carbon monoxide (CO).

Sometimes the rules just do not make sense. For instance, houses with gas ranges dump all of their combustion products directly into the kitchen, so why all of the concern about these other appliances? In Colorado, an average of more than six people a year are killed and 50 people accidently poisoned by carbon monoxide produced from furnaces, gas appliances, and kerosene heaters. These numbers represent only the cases that are properly diagnosed and reported to the state.

The problems with combustion appliances are *not* simply with the devices themselves, but how they work within the building (see "Backdrafting Causes and Cures," *HE* May/June '91 p.30). The safety of the units depends on their installation, operation, and maintenance. Other concerns such as competing air sources, house tightness, and effects of remodeling all can be important to the overall operation of the system.

In developing a program that will check for the safety of combustion appliances, three questions need to be answered:

- Who are you trying to keep safe?
- What are you trying to keep them safe from?
- What is the appropriate level of testing?

Once these seemingly simple questions are answered and the goals of the safety program are defined, standards and procedures can be established to ensure the program will provide the desired level of protection.

Saving Your Staff

The first and most immediate concern should be the safety of the staff going into buildings and conducting tests. A good safety check involves gathering information from the client, visually inspecting the building, and running specific physical tests. Of these, the visual identification of potential safety problems is the most important.

The immediate problems can be defined as those that pose imminent danger. Two groups of concerns are air quality and fire hazard.

Carbon Monoxide in Ambient Air

Carbon monoxide detection systems have advanced significantly in recent years. Digital equipment can be used to provide an indication of elevated ambient levels of CO. Sensors should be turned on and calibrated in a noncontaminated environment, typically outside the building. When preparing to test all of the combustion devices, an ambient reading should be taken and be close to zero. If the initial readings are measurable—0-9 parts per million (ppm) depending on the meter—the source needs to be identified. In no case should exposure exceed 35 ppm.

Gas Leaks

Gas leaks pose a potential immediate threat of fire or explosion. Leaks can be detected by smell, gas leak detection, or fluid and electronic gas leak detectors. A combination of techniques can be used to identify, and ensure the repair of, any leaks prior to additional testing.

Roll-out

Flames unexpectedly coming out the front of the appliance (“roll-out”) indicates serious combustion problems. Visual indications of roll-out will be seen on the appliance body, in the form of black or rusted areas in front of the burners, burnt wires, and carbon deposits. In these cases, a client may mention that they occasionally hear a “boom” when the furnace turns on.

Table 1. Combustion Safety Problems, 1,000 Units

Carbon Monoxide	5.0%
Gas Leaks	8.3%
Spillage	2.4%
Cycle Gas on High Limit	13.5%
Disconnected Ducts	9.1%
Open Return Air Ducts	22.4%

Over the past ten years of testing houses for combustion safety problems, the tests, testing equipment, and procedures have changed. At Sun Power we examined the results from 1,000 tests in 1990.

Spillage

We don’t want our staff breathing combustion products for extended periods of time. Combustion products can enter into the living area of the house through disconnected venting systems or systems which are not venting properly. Vents should be visually checked for integrity. All draft diverters should be tested with smoke to ensure that all of the combustion products are leaving through the vent. Testing the draft of the appliance will assist in determining the adequacy of the venting system, but spillage is an immediate hazard.

There are additional factors that affect the testing for these immediate hazards. Our intent is to evaluate the house for combustion safety under conditions that are most conducive to creating a problem. To do this we need to have the house set up in that condition. This means turning on air handling equipment that may move air to the outside (dryers, bath fans, kitchen fans) and closing the doors and windows.

A protocol must be established and followed. Basic combustion tests should be performed on a consistent time schedule. Observation of the appliance’s cycle provides indications of operational components. The observation time should be at least five minutes after ignition. This allows the device time to establish a draft and reflects how it will operate on a consistent basis. The protocol also needs to address different configurations of appliances. If a furnace and water heater are connected to a common vent, both appliances should be tested independently and together.

Client Safety

The second level of concern is for the short- and long-term safety of your client. Visual inspection of the house and appliances is extremely important in this analysis.

Table 2. Sun Power’s Draft Standards

Outdoor temperature	Draft
>80°F	>.005 in. W.C.*
<80 but >32	>.01 in.W.C.
<32	>.02 in.W.C.

Carbon Monoxide

Are there any signs of carbon monoxide being created? Is there any carbon in the burner area, flue or vent? How are the flames burning? Are there any visible signs of a problem, such as flames burning erratically, no flames visible on part of the burner, weak flames, or white tips on the flames? Regardless of the visual inspection, a test must be performed to verify that there is no CO in the combustion gases. The sample

Combustion Safety Tools

Carbon Monoxide Detector: ($150–$800) Mechanical testers use a glass tube that is sensitive to various levels of CO. Each tube costs $2 and can be used 2-3 times in one day. Getting accurate flue samples is difficult with the tube system. Mechanical systems provide a digital readout of the CO levels and are relatively reliable. They need to be calibrated once a year and have a replaceable CO sensor.

Draft Gauge: ($20–$80) A variety of gauges can be used to measure static pressure in the vent. The range should be between 0 and .1 in. water column (W.C.) and be able to withstand short durations of exposure to hot flue gas.

Manometer: ($15-$65) Manometers can be either water or fluid filled. For measuring natural gas pressure, they need to have a range between 0 and 7 in. W.C. For measuring propane, the range is between 0 and 14 in. W.C. We have found the 14 in. water filled are the easiest to use (you fill it with water at the site).

Orifice Drills: ($100-$150) The drills are used to determine the size of the orifice. When matched with the pressure information, this can determine the Btu input.

Efficiency Testing Equipment: ($450-$3,500) To measure steady state efficiency (SSE) you need to know the stack temperature, combustion air temperature, CO level, and either oxygen or carbon dioxide levels. Both analog and digital equipment is available that will test for all of the components. The low cost equipment requires a separate tool and test for each measurement.

Gas Leak Detector: ($200-$250) Specialized soap solutions are available (they do not freeze if left in the truck) to verify leaks. Most equipment is electronic and is sensitive to a wide range of combustible gases.

Federal Safety Commission Pushes CO Detectors

Odorless and colorless carbon monoxide gas (CO) is the number one cause of death by poisoning in the United States and accounts for more than one in five of all unintentional deaths by poisoning. Media accounts generally cite government data showing 5,000 CO deaths annually. This number comes from the U.S. Centers for Disease Control, which estimates there were 56,133 deaths from CO poisoning in the United States between 1979 and 1988. Of the total, 41,622 deaths—nearly 80%—resulted from suicide, fires, or homicide. Some 2,964 CO deaths resulted from "unidentifiable" causes while 11,547 deaths were classified as "unintentional."

According to the U.S. Consumer Product Safety Commission (CPSC), in 1989, the most recent year for which statistics are available, there were about 220 deaths from CO poisoning associated with gas-fired appliances, about 30 CO deaths associated with solid-fueled appliances (like charcoal grills), and about 45 CO deaths associated with liquid-fueled heaters.

These numbers probably underestimate the number of people exposed to non-fatal CO levels, because symptoms of poisoning—including headaches, nausea, fatigue, dizziness—are sometimes mistaken for the flu and go untreated.

Reflecting a growing awareness of the dangers of poisoning, the CPSC—which recommends that CO detectors meeting Underwriters Laboratory (UL) standard 2034 be installed in all existing residential buildings—has been moving toward requiring the detectors in newly built homes. The CPSC is also working with state and local code jurisdictions to incorporate CO detector requirements into state and local legislation, and is working with the National Fire Protection Association to develop a national installation standard.

Detectors meeting UL standard 2034 currently cost between $35 and $80. *(for a list of manufacturers meeting the standard, contact UL, 333 Pfingsten Road, Northbrook, Illinois, 60062-2096, Tel: [708]272-8800).* Because the toxic effect of CO depends on both concentrations and length of exposure, long-term exposure to a low concentration can produce effects similar to short-term exposure to a high concentration. Detectors meeting the UL standard, therefore, measure both high concentrations over short periods, and low concentrations over long periods. It is estimated that between one and two million such detectors are now in the marketplace, but demand for them is expected to grow rapidly (especially if codes require them).

Chicago's Experience

Following several deaths by CO poisoning, and one particular case where an improperly installed furnace killed a family of ten, Chicago last year became the first city to adopt an ordinance requiring UL-approved CO detectors in all new single-family homes and in existing single-family residences equipped with new combustion furnaces.

The ordinance, however, has been somewhat controversial. When a detector alarm sounds, residents open doors and windows to ventilate their homes, and then call the fire department, gas utility, poison control center, or another response agency. When inspectors appear at the home, they may not be able to detect CO because the windows were opened. This leads to questions about whether the alarm sounded at an appropriate level, whether it was accurate, and so on.

With a burgeoning demand for CO detectors, proper protocols and measurement methods for responding to alarms are needed so that questions about the extent to which alarms represent actual situations of elevated CO levels can be answered. Who, for example, should respond to an alarm and under what conditions—the fire department, a heating technician, or the local utility?

In a space of two months, Chicago's fire department last year responded to nearly 6,000 calls, but according to one department spokesman, all but 33 of them were "unfounded." The fire department reportedly received 244 "unfounded" calls on Thanksgiving day alone.

Some city officials have called for a repeal of the ordinance, but other officials credit the ordinance with having saved 40 lives thus far.

Underwriters Laboratories, meanwhile, is considering changes to its CO detector standard. One proposal would change the "stability test" from 15 ppm for eight hours to 15 ppm for 30 days so that detectors would ignore lower CO concentrations. The standard was written in the context of the existing technology for detectors (in 1992) and new technology may soon dictate a need for an updated standard.

—Cyril Penn

should be taken from each flue (exhaust port), before additional dilution air is added to the gases. In a furnace with four burners, at least four tests should be taken. In a water heater there should be a test taken on both sides of the internal baffle. On a stove, a test should be taken in the oven vent and above each burner. Sealed combustion units can and should be tested as well.

Our field experience has shown that problems with most units that create CO in excess of 25 ppm in the flue can be corrected. Most field standards are higher than this (less than 100–200 ppm). One of the key components of this step is to determine why CO is being created, since CO is a symptom of something being wrong with the building or unit.

Draft and Venting

The draft of the appliance measures the power of the venting system to exhaust. The measurement of the draft is coupled with a visual inspection of the venting system to determine the probability that all of the combustion gases are getting out of the structure. If the draft is measured in cold weather, it can provide an indication of the ability of the appliance to exhaust in warmer weather (if the draft is weak in cold weather, it will be weaker in hot weather). The standard we use was developed from both technical analysis and field testing (see Table 2).

Combustion Air Source

The source of the combustion air for the appliance must be adequate and not come from a prohibited location. (Having a combustion appliance draw air from, and be connected to, a bedroom is not a good idea.) The first test for adequacy of the combustion air has already been completed: no CO, no spillage, and sufficient draft. This test is to identify problems you might have if you change the building tightness. Having an open or not sufficiently connected return air system is a primary concern. Open returns provide a significant depressurization source in the immediate vicinity of the unit.

Standards range from simply ensur-

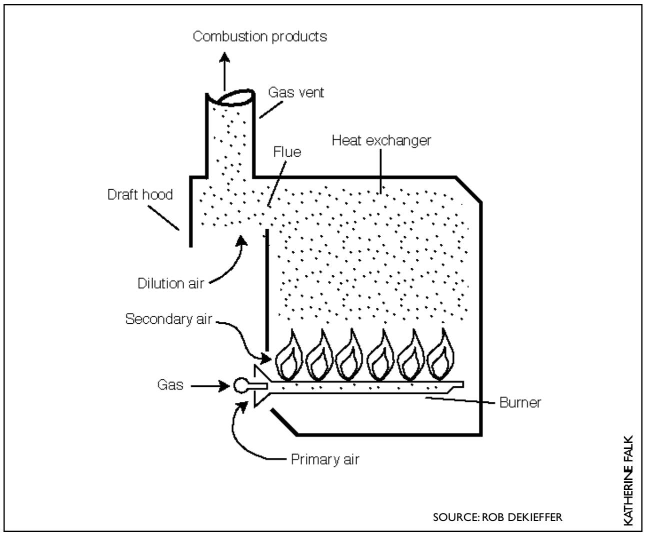

Figure 1. Schematic of a combustion furnace.

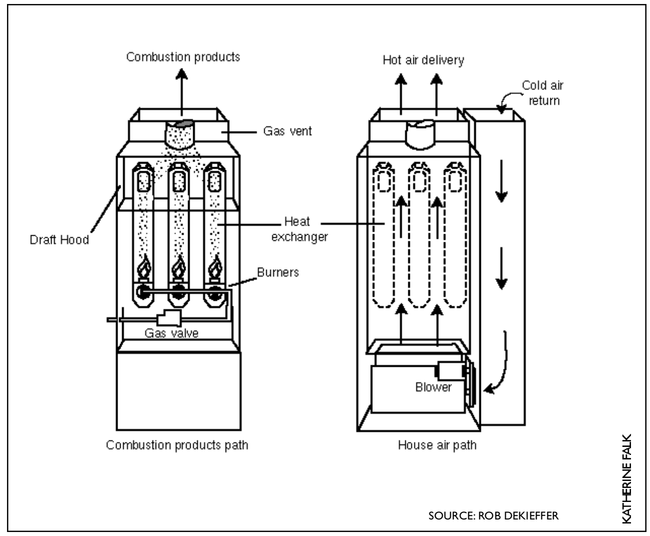

Figure 2. Air paths in a combustion furnace.

ing that the appliances work under the worst case conditions, to installing combustion air that meets current building code.

Appliance Safety

Most appliances are equipped with safety devices to prohibit them from overheating and from allowing fuel into the device if there is no ignition source.

> **Key Terms**
>
> **Flue:** Part of the combustion venting system below the draft hood.
>
> **Vent:** Part of the combustion venting system above the draft hood that carries diluted combustion products to the outside.
>
> **Primary air:** Air mixed with fuel before combustion.
>
> **Secondary air:** Air introduced into the combustion chamber after combustion has begun.
>
> **Combustion air:** Air that is used to provide oxygen for combustion.
>
> **Roll-out:** Flames and combustion products that exhaust from the appliance at the burner area.
>
> **Spillage:** Combustion products that spill out of a draft diverter and do not exhaust through the vent.
>
> **Draft:** A measure of the potential of a system to exhaust.
>
> **Draft diverter:** A safety device installed on atmospheric appliances to (1) allow draft to divert into the building if the vent becomes blocked, and (2) add dilution air for draft efficiency (sometimes called a draft hood).

You should check the limits if you are doing anything that might affect the heat transfer. This can include cleaning blowers, repairing ducts, insulating boiler pipes, and so on. The gas supply to a forced air furnace should be turned off before the plenum temperature reaches 275°F. If this occurs during the normal operation of the unit, it can be indicative of an overheating problem and should be corrected. Checking the pilot safety and 100% closure of the main burner valve can also be done as a precautionary procedure.

Cracked Heat Exchanger

Examining appliances for a breach in the heat exchanger is potentially significant, but of lesser importance than the previous tests. Checking for cracks is done by examining the flames for interference when the blower is operating and by direct inspection of the heat exchanger.

Other Potential Problems

There are a number of other code and safety issues that programs can address. These are primarily addressed due to a specific program bias or documented regional safety problems. These include inspecting and repairing gas lines due to galvanized pipe, copper pipe or soldered flex lines, testing fuses, replacing venting due to improper materials or insufficient clearance, gas pressure, and other items that do not meet current building code.

Safety Program

Those who work in programs that provide any significant service inside a building should be knowledgeable of the unanticipated consequences of their actions. Changing a furnace filter, changing a client's use of the thermostat, fixing a bath fan, or hanging a door, can all potentially effect the operation of combustion devices.

Liability

The long-term liability will sit with those agencies that ignore the facts. The facts show that the air inside buildings is connected to a myriad of systems. These systems use the air in

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Dirty filters,such as this graphic example, can cause a reduction of inlet pressure at the blower. Such reduction can become hazardous if a leak exists inside the furnace, since it can cause leakage of combustion gases.

Steps to CO Production

The most common carbon monoxide (CO) problems involve a lack of oxygen—either because there is simply not enough, or because the flames cool off before the carbon can join with it. CO is produced whenever a fuel is burned without enough oxygen on hand. Carbon atoms in the fuel that normally join up with two oxygen atoms to form carbon dioxide, which is harmless to human health, end up with only one oxygen atom and instead form CO.

Basic Steps to Getting CO Into Your Life

It is not enough to understand how to create CO, we need to examine all of the coordinating factors which can create it and allow it into the living space.

Five basic factors not only lead to the production of CO, but will aid in getting it into your homes. Any one major failure can get CO into your home, but typically three of these factors must go awry to produce a major problem.

The Flow of Fuel

As you add fuel to a fire, the fire produces more Btus of heat. It also requires more oxygen to combine with the carbon and hydrogen to form carbon dioxide and water vapor (H_2O). As you continue to add fuel, the amount of available oxygen needs to keep up or CO will be produced, which is incompletely burned carbon. In engineered systems (all modern combustion appliances) the amount of air that can move through the unit is limited by the design. Any additional restriction (dirt, lint, carbon) will result in the air flow being reduced. The air flow is controlled by the laws of nature (hot air rises). The flow of fuel is controlled by the pressure applied to the fuel and the size of the hole it is forced through. Any problem with the pressure of fuel input can lead to problems with the fuel/air mixture.

Competition for Air

We refer to many kinds of air when describing a standard combustion appliance (combustion air, primary air, secondary air, dilution air, return air, supply air, and so on). Air, or more precisely the oxygen in the air, is fundamental to the combustion process. The amount of air that can come into standard appliances is typically controlled by two basic systems. First is the mix of gas and air before combustion (primary air). This is controlled by the design of the burner, the pressure of the gas, and any control of the air stream. The secondary air, or additional air that is needed to supply oxygen to the flames, is simply controlled by the amount of air that is drawn through the heat exchanger.

In order for these two simple systems at the appliance to supply adequate oxygen for complete combustion, there needs to be sufficient air to the area around the appliance. Any competition for the air needed for the combustion process can lead to problems. The power of the competition does not need to be strong to overcome the natural forces of the combustion appliance.

Venting: The Wild Card

Getting all of the combustion products out of the living space, a matter of indoor air quality, is fundamental to the safety of our clients. Codes and venting systems are designed to ensure this happens. In the cases that combustion appliances are unvented (they vent into the living space), there are specific directions for additional ventilation needs (like opening a window).

Venting can be a wild card due to its relationship to both the weather and the physical configuration, time of year, time of day, connection with other appliances, connection with the house, and so on. All of these relationships can have a dramatic effect on the draft of an appliance. The fundamental principle is that hot air rises. We can thus figure out how much area in the vent is needed to get all the combustion products out of the building. These rules may not always result in successful venting in actual buildings. Only testing can provide an indication of the operation.

Operation

The operations of the appliance can be broken down into two components: those defined primarily by the internal controls of the unit and those dictated by the occupant. We have found many units where the appliance is not able to operate correctly and that just happened to keep the unit from being a major liability to health and safety. Changing any portion of the operation may affect safety. This includes adjusting the distribution, air tightness of the unit, ductwork, load/insulation, not to mention touching the unit itself. The client's operation of the unit can also affect safety.

Luck (Or Lack of)

Luck is the final card. It is the random combination of the first four factors and other things that affect the building. Simple things like unclogging a dryer vent, fixing a bath fan, repairing ducts, or insulating walls, can change the operating patterns of the combustion devices.

How it Happens

In addition to the five basic components, we have seen significant patterns in the creation of CO.

Very few HVAC installers have the equipment necessary to ensure a safe installation of a combustion appliance is completed. Many units create CO because of improper setup and testing. Problems with gas pressure, orifice size, and improper venting are the most common.

Remodeling

Remodeling a building often involves adding walls and changing the combustion air location and source availability. At Sun Power we have seen new house designs which virtually ensure that the combustion air source will be eliminated. In addition to limiting the combustion air, remodeling typically increases the pollution in the area of the combustion devices (for instance installing a dryer in a small room with the furnace).

Deterioration and Proper Installation

Long-term deterioration of an appliance is not a common factor leading to CO production. However, deterioration is a common problem with units that were marginally installed: vents with long horizontal runs may have just met standards when they were installed but are prone to rust out over time. Venting into an unlined chimney can lead to problems (erosion of the chimney can eventually lead to leaks). Dirt from a crawlspace can fall down and block the combustion air holes in a water heater. Even crawlspace furnaces stay fairly trouble-free unless major contaminants are introduced into the area. Dryers and water are the chief causes, but rust and lint are good at blocking everything.

CO can be drastically reduced in the home if the units are installed correctly in a dedicated area which is not connected to the living space. This requires a room for the combustion appliances that is vented with outside combustion air (or sealed combustion units) and has sealed ductwork.

—Rob deKieffer

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A technician uses a CO meter to check the safety of this furnace.

different ways. If you want to avoid liability problems with building failure or combustion problems, you need to test the building and the appliances. Testing must identify problems that exist before any work is done. Tests must also be done on completion of work to ensure that the systems that were in place were not adversely affected.

Other combustion issues have a potential impact on liability such as unvented combustion appliances and kerosene heaters. At Sun Power we will not work on the building unless we can eliminate those types of combustion appliances.

Sun Power's Furnace Specifications

For a job to be considered complete, the following specifications must be met. This is not meant to be an exhaustive list.

Forced Air Standing Pilot Furnace

Gas leaks:	No leaks smelled in the building or detected with gas leak solution
Venting problems:	Entire venting system connected and intact (not deteriorated to the point that it is falling apart) and continuous to the outside of the building
Carbon monoxide indicators:	No carbon built up anywhere in the system No flame problems (ghost flames, inconsistent pattern, flames hitting heat exchanger) No white flames
Flame interference:	No flame interference when the blower comes on
Carbon Monoxide:	<100 ppm in the flue. All reasonable attempts should be made to eliminate CO
Spillage:	No spillage from around the draft hood or burner area using smoke test with a light
Draft/outside temperature:	Measured draft in the vent must be higher than: -005 in.W.C. @ >80°F -.01 in.W.C. @ 30° to 80°F -.02 in.W.C. @ <30°F
High limit switch:	Installed and operating at 275°F The furnace is not shut down by the switch during five minute test
Ductwork:	All supply and return ducts sealed All registers removed and ducts and boots sealed with mastic
Open return air:	No open returns in furnace room, or in a location that could interfere with the combustion air for any combustion device

Water Heater

Gas leaks:	No leaks detected with gas leak solution
Venting problems:	Entire venting system intact
Carbon monoxide indicators:	No carbon, no flames, no white flames
Carbon monoxide:	<100 ppm in the flue
Spillage:	No spillage using smoke tests with light
Draft/outside temperature:	Measured draft in the vent must be higher than: -.005 in.W.C. @ >80°F -.01 in.W.C. @ 30° to 80°F -.02 in.W.C. @ <30°F

Setting Your Standards

For every program there needs to be a written set of standards. These standards provide the basis for any work done and give management a basis to evaluate the coverage and liability exposure. An example of such a standard is: *No furnace or water heater may have over 100 ppm carbon monoxide in the flue.* This establishes the quality threshold which needs to be maintained.

Written policies and procedures must be in place to establish how these standards are to be met—or, more importantly, what is not wanted. As in the previous example, the policies will establish how much money to spend to correct the problem, what to do if the problem cannot be fixed, whom to contact, and so forth. The procedures will provide the guidance on what to do first.

A quality assurance program will help staff follow the policies and procedures in pursuit of the quality standard. Effective communication and training rely on having a quality assurance program which can change and have direct input into improving the staff's abilities. In the case of CO production, we want to make sure that we have found the true cause of the problem and that we have corrected the CO problem as inexpensively as possible. We do not necessarily need to inspect the unit to determine if the problem was properly diagnosed. Systems should be in place to determine if staff understand the process and a training component should be available to improve abilities.

Focused evaluation makes sure that the program intended to be delivered is really in place. Many programs adopt standards that do not relate to their building stock, climate, or staff's ability. A good evaluation will show the strengths and weaknesses in the system.

Evaluation also needs to be used to examine technical issues such as: do we need to simulate a fireplace draft when testing the other appliances? Should we test the ability of the house and appliances to backdraft the fireplace? How do the results of the testing vary if the furnace is hot?

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