10 Common Misconceptions About Combustion Safety

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In the home performance industry, most standards require extensive testing to identify vented appliances that could backdraft and spill exhaust gases, particularly when homes are air-sealed. But how good are these tests at finding problems? And how real are the risks? In this article, we answer these questions by addressing ten common misconceptions about combustion safety.

1. Carbon monoxide from backdrafting gas appliances kills hundreds of people each year

CO fatalities from backdrafting appliances are extremely rare. According to a 2012 report by the Consumer Product Safety Commission (CPSC), an average of 169 deaths occurred each year from unintentional carbon monoxide (CO) poisoning between 2007 and 2009. On average, 52 were associated with household gas appliances and most of these were attributed to furnaces or portable heaters (see Figure 1).

The incident reports noted that deaths were generally a result of compromised vent systems, flue passageways, and chimneys, improper installation and poor maintenance. A few appliances had vents blocked by soot resulting from inefficient combustion caused by factors such as leaky or clogged burners, an over-firing condition, or inadequate combustion air. Some furnace incidents included compromised heat exchanges and access panels that were removed or improperly sealed.

The CPSC report mentioned backdrafting as a factor in only one case. But, the vast majority of CO fatalities involved a severely malfunctioning appliance and venting system. While CO fatalities from combustion appliances appear to be rare, sub-lethal CO exposure may be a larger problem. However, we currently lack the exposure and health vulnerability information needed to quantify the hazard of sub-lethal CO associated with backdrafting appliances (or any other source for that mater). Regardless, ensuring gas appliances and venting systems are properly installed, are operating normally, and are well maintained will protect against both fatal and sub-lethal exposures to CO.

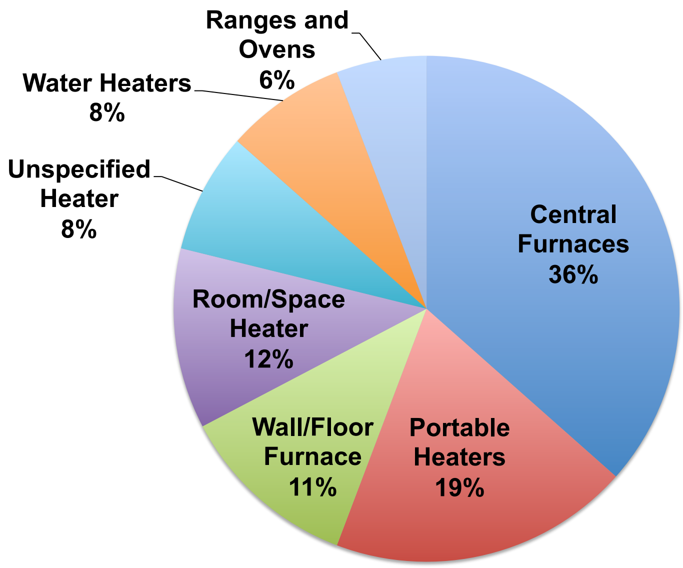

Figure 1: Distribution of 52 average annual CO poisoning deaths from common household gas appliances published by the U.S. Consumer Product Safety Commission (Hnatov, M., 2012).

2. Carbon monoxide is the only pollutant of concern associated with combustion spillage

Although carbon monoxide (CO) is a primary concern, other combustion products, such as oxides of nitrogen and water, can also produce health hazards. The two most prevalent oxides of nitrogen are nitric oxide (NO) and nitrogen dioxide (NO_2). Both NO and NO_2 are toxic gases, but NO_2 is highly reactive and corrosive. Short-term exposures to NO_2 can results in respiratory stress; chest pain; and eye, nose, and throat irritation. The largest by-product of combustion is water, which can lead to moisture related problems including mold. Because combustion appliances can generate hazardous pollutants, it is important to ensure that all combustion appliances are properly vented outside the living space.

3. Combustion safety diagnostics have a zero-tolerance policy for exhaust gas spillage

Almost all combustion safety diagnostic procedures allow appliances to spill some exhaust gas into the home. The diagnostics provide strict regulations for preventing depressurization-induced spillage from gas water heaters and furnaces. Yet, many procedures ignore the fact that cooking burners, ovens, vent-free heaters, and vent-free fireplaces directly emit 100% of their exhaust gases into the home. Additionally, some procedures allow homes to pass for combustion safety without addressing emissions from vent-free appliances. For example, vent-free heaters and fireplaces spill all of their exhaust gases by design and are considered acceptable in many parts of the country – though not in California, Michigan, Wisconsin, and a few U.S. cities.

According to a study conducted by researchers at the University of Illinois (Francisco et al., Indoor Air 2010; 20: 370–379), vent-free fireplaces can, "produce indoor air concentrations considered to be unhealthy to at least sensitive or at-risk individuals." In the study, measured nitrogen dioxide (NO_2) levels exceeded the U.S. EPA's 1-h health protection standard for outdoor air in 80% of the homes, regardless of usage; the EPA's 8-h standard for CO was exceeded in 20% of homes when usage patterns did not comply with industry recommendations. Amazingly, these problems were found in just 3-4 days of measurements!

Figure 2 shows an example of the CO measurements from one home in the Illinois study. CO was measured at the mantel of the fireplace and in the living room. Figure 2 shows that CO distributes almost instantaneously throughout the house (using 1-min sampling intervals), as concentrations in the living room and the fireplace room are equal when the fireplace is operating. Although the concentrations in the fireplace room and the living room are far below life threatening, the results indicate that everyone inside the home would be at risk if the appliance emitted hazardous concentrations. Therefore, the risk of exposure should be assessed using the entire living space of the home, not just the combustion appliance zone.

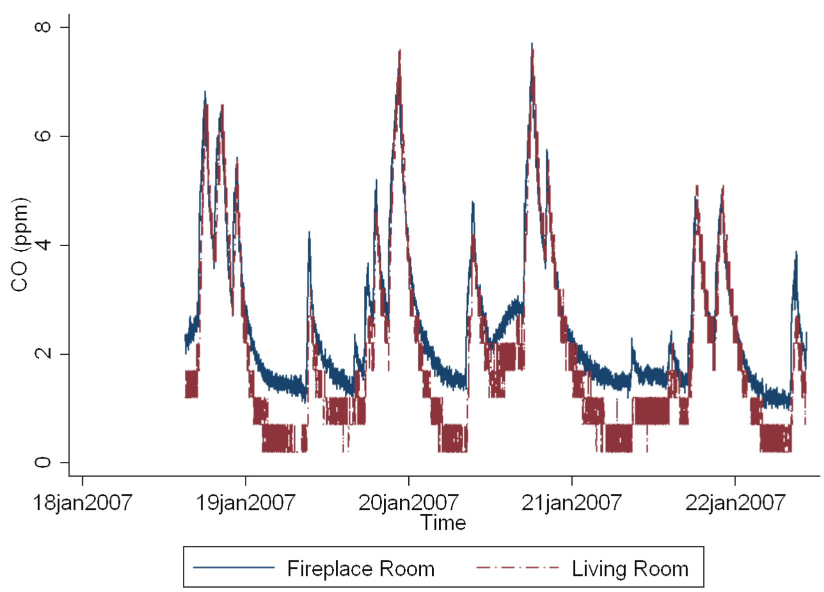

Figure 2: Sample CO concentrations from a fireplace measured at the mantel and the living room (Francisco et al., Indoor Air 2010; 20: 370–379).

4. Combustion appliances ALWAYS backdraft if the house is depressurized beyond the industry standard test thresholds

How effectively appliances vent exhaust gases does not solely depend on depressurization. Normal venting, or draft, largely depends on the firing rate of the appliance, the weather, and the vent system design. Appliances with higher firing rates produce hotter exhaust gases that result in larger upward (buoyant) forces. The large buoyant forces from the hot exhaust gases increase draft and more effectively heat the vent system.

Weather conditions can also impact draft. Cold weather conditions often improve draft from appliances because increasing the temperature difference between the hot exhaust gases and the outdoors increases buoyancy-driven ventilation. Conversely, if a cold downdraft is established before the appliance begins operating, then the appliance will have more difficulty reversing the flow and establishing draft after the burner fires. During warm weather conditions, the likelihood of downdraft increases because the indoor temperature is often lower than the outdoor temperature, reversing flow in the vent.

In addition to outdoor temperature, wind can also affect draft from vented appliances. Research conducted by Koontz et al. [GRI Report: GRI-01-250, 2001] showed that houses were more likely to fail combustion safety tests during low wind speeds than high wind speeds. Depending on the vent cap and the location of the vent termination on the roof, windy conditions generally aid in venting exhaust gases.

Although the firing rate, outdoor temperature, and wind contribute to buoyant forces needed for establishing draft, a good venting system is required for maximizing buoyancy driven ventilation. A vent system design that maximizes buoyancy driven ventilation can ensure draft even in cases when the house is depressurized beyond the industry standard test thresholds. For example, appliances with vent systems that consist of a tall, straight stack may be capable of establishing draft even when depressurization far exceeds industry standard test thresholds. In contrast, the same appliances with vent systems that contain multiple elbows or long horizontal runs may backdraft when the house is depressurized less than the protocol thresholds.

Because vent systems are not trivial, local and national codes provide guidelines for reducing the risk of backdrafting and spillage. A weatherization study conducted in Minnesota (Bohac, D. and Cheple, M., 2002) showed that vent system complying with the National Fuel Gas Code were more likely to establish draft, even when the house is depressurized to industry standard test thresholds.

5. Increasing depressurization increases the risk of very high pollutant concentrations in the home

Increasing depressurization actually reduces the risk of high pollutant concentrations. It is true that increasing house depressurization increases the risk of spillage. This is because increasing depressurization increases the likelihood of downward flow in the vent and increases the flow rate of the downward flow. However, higher flow rates of outdoor air entering the house means higher flow rates of indoor air leaving the home, thus removing more indoor pollutants. To better understand the relationship between fan flow and depressurization, Figure 3 provides a graphical representation for a 1000 ft^2 home with varying tightness (ACH50). This figure was generated using the standard power law relation, $Q = C(\Delta p)^n$, where n is assumed to be 0.65 and C, the flow coefficient, is determined using the ACH50. We can see that for a reasonably tight home (ACH50=4), a fan flow of 125 cfm is needed to depressurize the house to -5 Pa.

To explore the impact of increasing dilution with more depressurization, we calculated the concentrations that would result from an appliance spilling exhaust into a house modeled as a well-mixed single-zone (or box). As shown in Figure 2, CO distributes almost instantaneously throughout the house; therefore, the risk of exposure should be assessed using the entire home not just the combustion appliance zone. Figure 4 shows the results for a 1000 ft^2, 4 ACH50 home with a 40,000 BTU/hr appliance – a common size for a storage water heater, small central furnace or large wall furnace – continuously spilling 200 ppm or 400 ppm of air-free CO. The CO emission rates are based on the allowable BPI and RESNET limits (200 ppm) and on the ANSI limits for furnaces and water heaters (400 ppm). The results show that increasing depressurization actually reduces pollutant concentrations inside the home due to the contribution of additional dilution air.

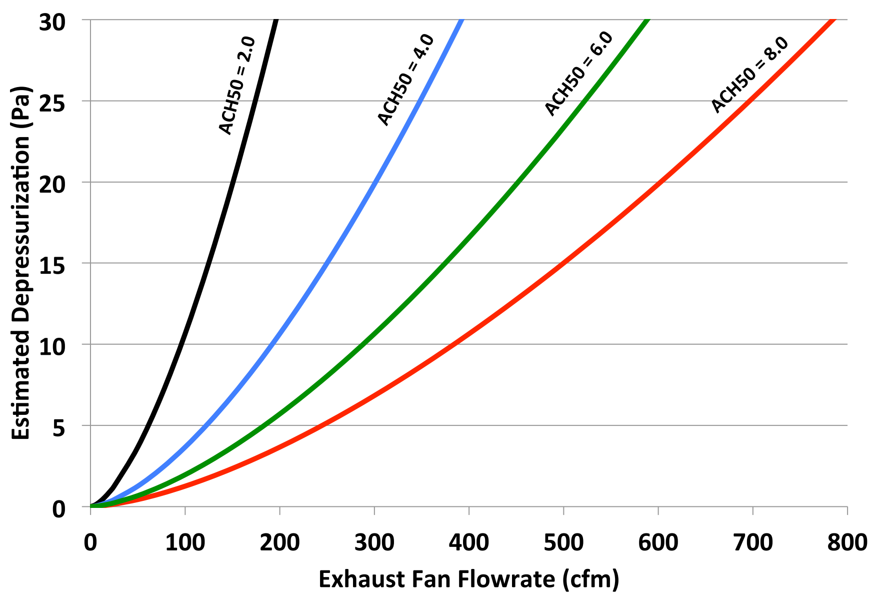

Figure 3: Relationship between fan flow, depressurization, and air tightness for a 1000 ft^2 home using the standard power law relation.

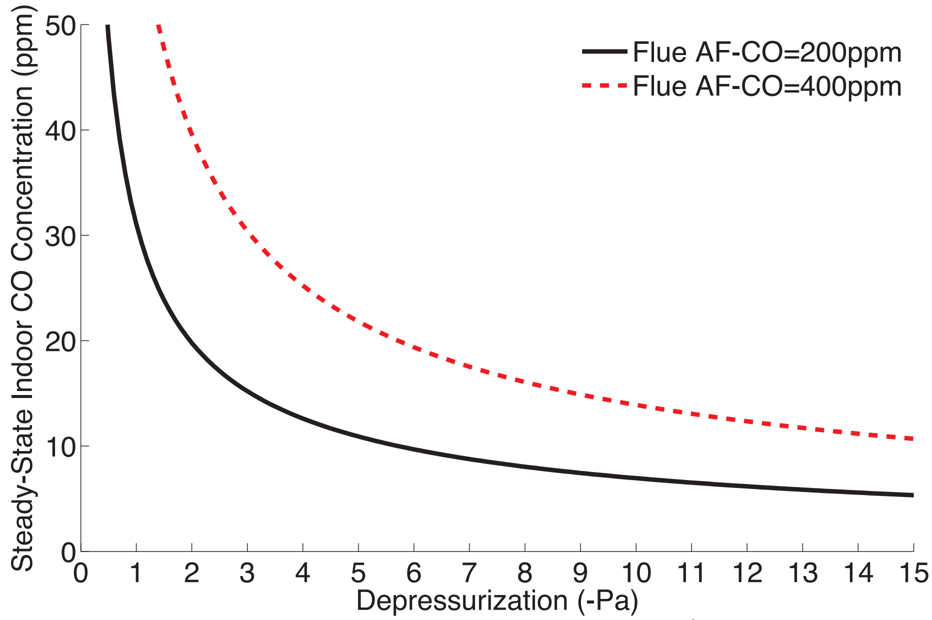

Figure 4: Steady-state indoor CO concentrations in a 1000 ft^2, 4 ACH50 home with a 40,000 BTU/hr appliance spilling continuously with varying levels of air-free CO in the exhaust. Increasing depressurization decreases indoor concentrations.

6. Short spillage events can produce very high pollutant concentrations in the home

Short spillage events are very unlikely to generate high, life-threatening indoor pollutant concentrations. This is because indoor pollutant concentrations depend on the total mass (amount) of pollutant in the home at a given time. The mass of pollutants released by an appliance depends on the burner firing-rate (size), the duration of operation, and the concentration of the pollutant in the flue gases. Over long periods of time, indoor concentrations depend on the air exchange rate of the house.

In order to better understand the relationship between appliance spillage and indoor concentration, let's go through a simple example. A 40,000 BTU/hr appliance produces about 400 ft^3 of exhaust per hour (about 100 ft^3 of exhaust for every 10,000 BTU). In five minutes,the appliance can produce about 33 ft^3 of exhaust that could enter a home. In a 1000 ft^2 home with 8 ft. ceilings the appliance exhaust makes up about 0.4% of the air in the home. Even if the exhaust has 1000 ppm of air-free CO, the concentration in the home would only be about 4 ppm of CO. If the appliance spilled for ten minutes, then the indoor concentration would only be about 8 ppm of CO. These results indicate that short spillage events are very unlikely to generate high, life threatening pollutant concentrations in the home.

7. Compared to other vented appliances, water heaters have the highest risk of harming occupants

Water heaters are less likely to result in an indoor air quality hazard than other appliances because they are typically operated for short periods of time and generally produce little to no CO or NO_2. Water heaters are commonly believed to have the highest risk of causing harm because they are operated during warm weather conditions, which increases the likelihood of downdrafting (due to the reverse stack effect) and backdrafting (due to a lower temperature difference between the flue and the outdoors). However, water heaters are generally operated for short periods of time, reducing the risk of ongoing pollutant production and entry into homes. According to a study that monitored water heater operation in 143 California homes for one-week (Mullen et al., LBNL-6374E, 2013), 95% of the homes monitored had a maximum water heater operating time of 2.3 hours in an 8-hour period. Furnaces, specifically wall and floor furnaces, pose a larger risk than water heaters because they operate more frequently during some seasons and if undersized, they can operate continuously.

In addition to operating for short periods of time, water heaters generally emit low concentrations of CO and NO_2. As mentioned by Rick Karg in the July/August 2013 issue of Home Energy, most gas appliances operate with 4-9% excess oxygen, reducing the risk of CO production from combustion. Bohac and Cheple (2002) measured CO from 1,356 water heaters and 548 furnaces during downdrafting conditions in Minnesota. They found that only 2% of water heaters had CO concentrations greater than 500 ppm, while 7% of the furnaces had CO concentrations greater than 500 ppm. Figure 5, provides a summary of their CO test results from water heaters and furnaces. The authors noted that a standard “clean and tune” resolved many of the CO problems. A study in California (Singer et al., CEC-500-2009-099; 2009) showed that functioning storage water heaters and furnaces rarely emit enough NO_2 to result in an indoor air quality hazard. Based on these results, we cannot confirm that water heaters present a greater risk than other vented appliances.

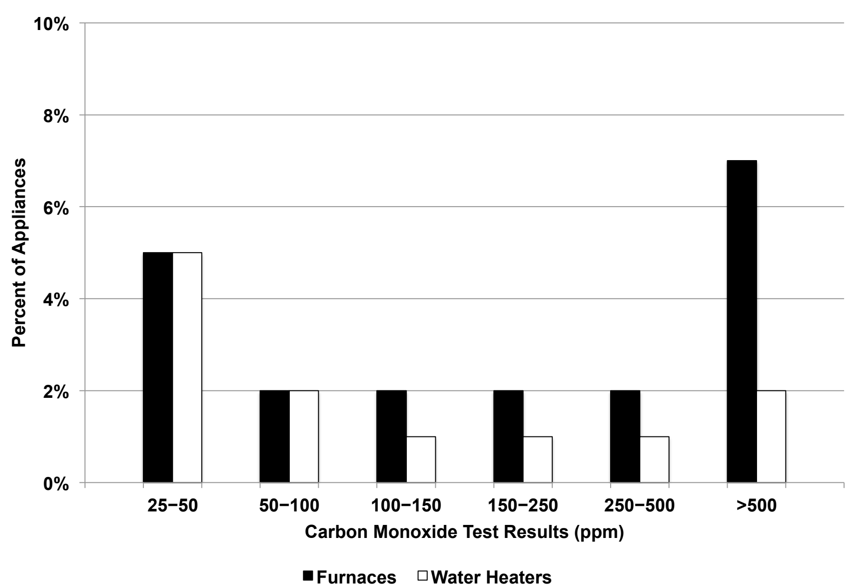

Figure 5: Carbon monoxide test results from 1,356 water heaters and 548 furnaces located in Minnesota (Bohac and Cheple, 2002).

8. Carbon monoxide alarms protect occupants from short-term and long-term carbon monoxide exposure

Most carbon monoxide alarms available on the U.S. mass market are designed to protect healthy adults against short-term CO exposure that could result in death or hospitalization. According to the UL-2034, CO alarms are to remain silent during "long term, low level carbon monoxide exposures." The alarms allow indoor CO concentrations of 30 ppm for up to 30 days, 70 ppm for up to 4 hours, 150 ppm for up to 50 minutes, and 400 ppm for up to 15 minutes. These limits do not protect against CO levels that are deemed unacceptable for the general population. For example, the CO limits set by the EPA National Ambient Air Quality Standards (NAAQS) [EPA, 2012] are 35 ppm for 1 hour and 9 ppm for 8 hours, well below the UL-2034 CO alarm limits. Low-level CO alarms are available, but they may not meet code requirements for CO alarms and may be difficult to obtain unless you are a building professional. Even though most CO alarms provide partial protection, a CO alarm is essential if you have a combustion appliance that is not direct vent located in your home.

9. "Worst-case depressurization" means worst-case for appliance venting

The worst-case for appliance venting does not always include "worst-case depressurization" conditions. In order to understand why, let's first review what "worst-case depressurization" means. "Worst-case depressurization" is the maximum differential pressure between the combustion appliance zone (CAZ) and the outdoors induced only by exhaust fans. This is measured by subtracting the baseline pressure from the maximum CAZ differential pressure. The baseline pressure is the differential pressure between CAZ and outdoors when no exhaust fans are operating. The maximum CAZ differential pressure is determined by turning on all the exhaust fans, and configuring the interior doors to maximize depressurization between the CAZ and outdoors. The purpose of this method is to eliminate effects from weather and determine the maximum house depressurization induced by exhaust fans. This method is problematic because weather is also capable of affecting house depressurization. Removing depressurization and pressurization induced by weather can result in a false indication that an appliance experiences more or less depressurized than normal over the course of a year.

Additionally, the "worst-case depressurization" measurement does not provide an accurate indication of the likelihood of spillage from a combustion appliance. Instead of assessing weather and fan-induced depressurization, it assesses depressurization only from fans installed in the home at the time of the test. If fans are replaced and weather remains the same, then the worst-case situation could arise from a combination of weather with some fan use. Additionally, effects of depressurization on a combustion appliance must include the effects of weather to accurately capture the risk of spillage. An instantaneous measurement on a given day may not provide an accurate representation of the venting performance over the course of a year. Therefore, a probability-based metric is needed properly identify the risk of depressurization-induced spillage.

10. In tight homes, all appliances should be direct vent or installed outside the living space

For naturally vented appliances in tight homes (2 ACH50 to 4 ACH50), several problematic events must coincide to generate a health risk. In very tight homes (2 ACH50 or tighter), problematic events are also necessary but more likely to occur. The combination of low air exchange rate and increased risk of spillage significantly increases the potential for prolonged pollutant exposure. Therefore, in very tight homes, all combustion appliances should be direct vent or installed outside the living space.

Concluding remarks

A key to reducing health risk associated with spillage is a properly functioning appliance and a connected, well-designed vent system. The simulated results show that although depressurization can increase the likelihood of backdrafting and spillage, depressurization also increases airflow into the house, thus increasing the rate of indoor pollutant dilution and removal. Although current combustion safety tests provide a first step towards mitigating hazards, the tests do not assess the risk of a home being depressurized long enough to create an IAQ problem, assuming the appliance is malfunctioning. A diagnostic that effectively mitigates risk must consider physical parameters (i.e., house size, burner, size, and house tightness), the flow required to depressurize the house, and statistical parameters (i.e. weather, appliance operational patterns, and occupant behavior) associated with combustion spillage.

Combustion safety assurance should target effective risk mitigation and management, not risk elimination. Incorporating a probability-based metric that identifies the risk of prolonged depressurization over the course of a year will assist in identifying homes that are truly high risk. Additionally, spillage from the highest risk appliances, such as stoves, ovens, and unvented heaters should be identified and addressed. By ensuring appliances are functioning properly, the vent system design meets local codes, and removing or venting unvented appliances, we can significantly reduce the risk of spillage and exposure to harmful indoor pollutants.