Combustion Appliance Safety Testing

Heating Systems for Energy Auditors and Inspectors

Key Terminology

Air free
Ambient air
As measured
Backdrafting
Baffle
Barometric damper
Breech
British Thermal Unit (BTU)
Carbon Dioxide (CO_2)
Carbon Monoxide (CO)
Combustion analyzer
Combustion Appliance Zone (CAZ)
Combustion efficiency
Condensing furnace
Digital probe thermometer
Dilution air opening
DOE Hot Climate Initiative
Draft
Draft diverter
Draft gauge
Draft hood
Draft reversal
Flame impingement
Health and Safety (H&S)
Inches of Water Column (IWC)
Inspection mirror
Liquefied Petroleum Gas (LPG)
Make-up air
National Fire Protection Association (NFPA)
Natural gas
NFPA 54, National Fuel Gas Code
Oxygen (O_2)
Parts per million (ppm)
Pascals (Pa)
Primary air
Propane
Secondary air
Smoke tester
Spillage
Steady-state efficiency
U.S. Department of Energy (DOE)
Worst-case combustion appliance zone testing

Section Transition

Learning Objectives (Slide #2)

By attending this session, participants will understand:

- The basic principles of combustion, distribution, and venting and be able to recognize safety-related problems.
- The health and safety issues related to combustion equipment.
- The basics of visual and diagnostic combustion appliance safety and efficiency inspection.
- The test procedures for various appliance types.
- The relationship between combustion safety problems and poorly designed or non-code-compliant vent systems.
- Worst-case combustion appliance zone testing.

What We Test (Slide #3)

- Worst-case ***combustion appliance zone (CAZ)*** depressurization.
  - ***Carbon monoxide (CO)***.
  - ***Spillage***.
  - ***Draft***.
- Fuel leaks.
  - Fuel oil.
  - ***Liquefied petroleum gas (LPG) (propane)***.
  - ***Natural gas***.

Testing Equipment – Criteria (Slide #4)

- ***Combustion analyzers*** should be able to measure:
  - Flue gas ***oxygen (O_2)*** content.
  - Flue gas temperature.
  - Ambient temperature.
  - Flue gas CO.
  - ***Combustion efficiency.***
  - Flue gas ***carbon dioxide (CO_2)*** content.
  - Flue gas air-free or as-measured CO content.
- A combustion analyzer measures flue gas samples to determine the safety and efficiency of the combustion process.
- Oxygen content or CO_2 content and flue gas temperature are measured to determine ***steady-state efficiency*** (also known as combustion efficiency). Steady-state efficiency is the percentage of heat captured by fluids such as air, water, or steam.
- "***Air free***" refers to the level of CO not diluted with O_2. There is always some excess O_2 or air in combustion byproducts. Air-free values can be extrapolated mathematically if the level of O_2 is known. It can also be read directly on many newer models of combustion analyzers.

- "***As measured***" refers to a sample of CO that includes O_2. The as-measured value of a sample will always be lower than its air-free value.

Show and tell: combustion analyzer

Selected Testing Equipment (Slide #5)

- ***Draft gauge*** – for testing chimney draft.
- ***Smoke tester*** – for measuring the amount of smoke produced by an oil burner.
- ***Inspection mirror*** – for looking into constricted spaces.
- ***Digital probe thermometer*** – for testing temperature rise and fan operating temperatures.

Show and tell: selected testing equipment

Definitions (Slide #6)

CO

- An odorless, colorless gas that, in sufficient concentrations, can cause sickness and even death.

Spillage

- Combustion gases emitted from an appliance or venting system into the CAZ during initial burner startup.
    - A CAZ is any area of the building that contains a vented combustion appliance, whether it is in the main living area or in an isolated area that can be closed off from the main living area.

Draft

- A pressure difference that causes combustion gases to move through a vent connector, flue, chimney, or combustion chamber.
- Types of draft are natural draft, induced draft, and forced draft.

Testing CO, Draft, and Spillage (Slide #7)

CO

- Test at the appliance ***breech***, between the appliance and the first opening in the vent connector directly above the heat exchanger.
- In condensing gas appliances, test at the vent termination.

Spillage

- Test with smoke at vent openings, such as ***dilution air openings*** or the ***barometric damper***.
    - Dilution air is room air that mixes with flue gases. Its purpose is to assist and maintain a consistent draft and counter the effects of wind.

Draft

- Test in the vent connector between the last opening in the vent connector and the chimney.
- Oil burners – Test in the vent connector at the breech just above the appliance.

More Definitions – CO (Slide #8)

Air-free CO

- A measurement of CO in an air sample or flue gas that takes into account the amount of excess air (O_2) in the sample. This measurement incorporates an adjustment to the as-measured CO value, thus simulating air-free (O_2-free) conditions in the sample. Usually measured in ***parts per million (ppm)***.

As-measured CO

- A measurement of CO in a sample of air or flue gas that does not take into account the amount of excess air (O_2) diluting the CO concentration. This is usually measured in ppm.

Carbon Monoxide from Incomplete Combustion (Slide #9)

CO occurs when:

- The ratio of fuel to O_2 is either too high to permit the complete formation of CO_2, or
- The temperature is too low to permit complete combustion to occur.

CO is caused by:

- Too much fuel for the amount of O_2.
- Not enough O_2 for the amount of fuel.
- Not enough heat (***flame impingement***).

Combustion Air (Slide #10)

- The ***National Fire Protection Association's National Fuel Gas Code (NFPA 54)*** states that combustion air must be provided for any combustion zone with fewer than 50 ft^3 for each 1,000 ***British Thermal Units (BTUs)*** of collective fuel input.
- ***Make-up air*** can be provided from the outdoors or other zones of the building.
- Natural draft, atmospheric combustion heating systems require combustion air from the room where the appliance is located. If the room is too small to provide adequate combustion air, the chimney may not draft properly.
    - Draft is a measurement used to determine how well a chimney is exhausting combustion gases.
- An easy test is to open a window. If the draft increases, combustion air is most likely needed.

Do a classroom exercise to calculate the volume (in cubic feet) of make-up air required for a 120,000 BTU furnace. See the lesson plan.

CO Poisoning (Slide #11)

Symptoms of CO poisoning include headache, fatigue, dizziness, drowsiness, and nausea. During prolonged or high exposures, symptoms may worsen and include vomiting, confusion, and collapse, in addition to loss of consciousness and muscle weakness.

Carbon Monoxide Action Levels (Slide #12)

This chart of suggested CO action levels is based on industry and weatherization standards cited in the ***U.S. Department of Energy's (DOE) Hot Climate Initiative*** document, "Combustion Appliance Safety and Efficiency Testing."

- When CO exceeds action levels, perform the following tests, adjustments, or fixes:
  - Verify that the vent system is allowing sufficient draft.
  - Verify that the gas pressure is within the acceptable range by checking the gas pressure or clocking the gas meter (natural gas only).
  - Adjust the ***primary air*** and/or ***secondary air*** on gas burners, or clean burners.

If these steps do not reduce CO to acceptable levels, refer the client to a heating technician who can replace the appliance as a ***health and safety (H&S)*** measure before performing any weatherization work that will tighten the building envelope.

Testing Equipment (Slide #13)

- If you're not testing, you're guessing!
- Most modern combustion analyzers have printing capabilities, providing you with hard-copy documentation.

Show and tell: analyzer's printing capabilities.

CO, Draft, and Steady-State Efficiency (Slide #14)

- Test for CO at each burner exhaust port of a natural draft furnace.
- Start the heating unit. Allow it to reach "steady state," a condition that exists when the stack temperature stops rising more than 2ºF in 1 minute as measured by the probe of a combustion analyzer.
- Insert the probe into the heat exchanger ports of a natural draft furnace, taking a complete set of readings in each port.
- In all cases, test CO in undiluted flue gases before they enter the dilution air inlet (***draft hood***). Test in each burner port.
- Test for draft above the draft hood or ***draft diverter***. A draft hood or draft diverter is an intentional opening in the vent system serving a natural draft appliance (i.e., furnace or water heater). This is where dilution air is drawn from the surrounding room to mix with the flue gases in the chimney.

- For an 80+ efficiency fan-assisted furnace, test for CO and draft in the vent above the inducer fan.
- Measure the steady-state efficiency in the flue gases. It is calculated by the combustion analyzer based on the levels of CO_2 or O_2 and the flue gas temperature.

CO and Draft Test Locations #1 (Slide #15)

- For a 90+ efficiency condensing furnace, test for CO at the vent termination. A draft test is not required for a condensing furnace because it operates with positive pressure in the flue.
- For a floor furnace, test for draft downstream of the draft diverter and for CO at the burner exhaust port.

CO and Draft Test Locations #2 (Slide #16)

- For a fuel-oil furnace, test for CO and draft before the barometric damper. The barometric damper on an oil-fired system consists of a short section of vent and a counterweighted gate. The gate is balanced and adjustable to allow dilution air from the house to mix with exhaust gases going up the chimney. Its purpose is to assist and maintain a consistent draft and counter the effects of wind.
- Measure the combustion efficiency and perform a smoke test. As measured with a smoke tester, the amount of smoke in the flue gas sample of an oil furnace is an indication of how efficiently the burner is operating. An improper fuel-to-air ratio will result in high smoke.

Minimum Acceptable Draft (Slide #17)

- Draft can be measured in ***inches of water column (IWC)*** or ***pascals (Pa)***.
- This chart of minimum acceptable draft for combustion appliances suggests values based on industry and weatherization standards cited in "Combustion Appliance Safety and Efficiency Testing."

Test for Spillage (Slide #18)

- This smoke-generating device tests for spillage.
- There should be no spillage after 1 minute of furnace operation.

Fuel Leak Testing #1 (Slide #19)

Use a combustible gas leak detector to locate fuel leaks.

- To set the instrument, adjust the dial until you hear a slow but steady clicking sound. Run the probe along the pipes and fittings. If a gas leak is detected, the clicking intervals will shorten and rise to a shrill, continuous sound.

Fuel Leak Testing #2 (Slide #20)

- Test all joints, valves, and fittings.
  - Natural gas is lighter than air, so test for leaks in natural gas systems above joints, fittings, and pipes.
  - Propane is heavier than air, so test for leaks in propane systems below the connections.
- Use soap bubbles to confirm a leak or check that you've sealed it properly, because some types of pipe dope (joint sealant) may set off the detector.
- Check the entire area with the leak detector before using soap bubbles, since they sometimes also set off the fuel leak detector.

Fuel Leak Testing #3 (Slide #21)

Photo on the right: Oil tank for a fuel-oil furnace.

- In addition to using soap bubbles, do a visual inspection and the personal sniff test to check for oil leaks.

Cook Stove Testing (Slide #22)

Pictured: The innards of a gas cook stove.

Why test gas cook stoves?

- Elevated levels of CO are common.
- People often use them as a heat source.
- CO kills.
  - Gas- and propane-fired cook stoves release combustion byproducts into the air. They must be tested and repaired if CO exceeds suggested action levels:
    - Gas furnace, boiler, or water heater – 100 ppm, as measured.
    - Unvented gas space heater – 200 ppm, air free.
    - Oil-fired furnace, boiler, or water heater – 100 ppm, as measured.
    - Gas cook stove: range-top burner – 25 ppm, as measured.
    - Gas cook stove: oven – 100 ppm, as measured.

Gas Cook Stove Testing – Stove Top (Slide #23)

- Photo on the left: A range-top burner.
  - Test each range-top burner for CO. Hold the probe 6" above the flame and measure the CO content in the ***ambient air***.
- Photo on the right: A CO Hot Pot, or portable flue section used for range testing.
  - A portable flue section contains combustion byproducts for a more accurate CO measurement.
- Calibrate or "zero" the instrument in outside air before testing.

- To protect yourself and the client, continually monitor CO in the ambient air. If ambient levels of CO exceed 20 ppm as measured, stop the test immediately.
- Remedial action is required when CO levels from the burners exceed 25 ppm as measured.

Gas Cook Stove Testing – Oven (Slide #24)

- Prepare the oven for the test by removing any stored items, aluminum foil, etc.
- Turn the oven on to 350°F – 500°F depending on your state's protocol.
- Insert the probe of the analyzer into the oven vent and read the CO content after the oven has warmed.
    - Calibrate or "zero" the instrument in outside air before testing.
    - To protect yourself and the client, continually monitor CO in the ambient air. If ambient CO levels exceed 25 ppm as measured, stop the test immediately.
    - Remedial action is required when CO levels exceed 100 ppm as measured.

Furnace Testing Protocol (Slide #25)

Photo: Oil furnace showing a single-wall flue graduated to a double-wall flue to maintain clearance to combustibles.

Furnaces must be tested to assess:

- Safety (fuel leaks, clearances, etc.).
- Flue gas temperatures.
- O_2.
- Carbon monoxide levels.
- Draft.
- Condition of the heat exchanger.

Note the test hole where samples of flue gases will be taken and draft measured.

Furnace Testing Methods – Visual (Slide #26)

Check for:

- Dirt and debris.
- Improper burner alignment.
- Soot, evidence of flame roll-out.
- A cracked heat exchanger.
- Vent pipe and roof termination.
- Gas or oil leaks.
- Frayed wiring.
- Dirty air filter.

Heat Exchanger Leakage Testing (Slide #27)

- Test methods:
  - Look for flame-damaged areas on the heat exchanger.
  - Look for rust on the burner ports.
  - Measure flue CO concentration before and after the blower starts.
  - There should be no more than a 1% O_2 change when the blower starts.
  - Observe change in draft, CO, or flame when the blower turns on.
- Combustion byproducts and conditioned house air should never mix.
- Use both visual checks and a combustion analyzer to assess the condition of the heat exchanger.
- If there are flame-damaged areas, a cracked heat exchanger is the likely cause.
  - If a heat exchanger is defective, it must be replaced. In many furnaces, the heat exchanger cannot be replaced, so the entire furnace must be replaced. Repairing a heat exchanger is not acceptable.

Worst-case Combustion Safety Testing (Slide #28)

- ***Worst-case combustion appliance zone testing*** determines if combustion appliances will vent under worst-case conditions and protects occupants from the hazards of ***backdrafting***, also known as ***draft reversal***.
  - Find the worst-case depressurization in the CAZ.
  - Under worst-case conditions, conduct the following tests:
    - Spillage test.
    - Draft test.
    - CO test.
  - Perform these tests during the audit and at the end of each work day.
  - If you identify a problem, deactivate appliances until the hazard is fixed.
  - Conduct these tests for vented systems only!
- Ambient CO levels should be monitored in the CAZ during worst-case testing, especially if depressurization of the combustion zone exceeds -5 Pa during house depressurization testing. If ambient CO levels in the combustion zone exceed 20 ppm, stop the draft test for safety reasons. The combustion zone should be ventilated before testing and repair of CO problems resumes.
- If you find a problem, deactivate combustion appliances until the hazard is fixed.

Setting Up Worst-case Conditions (Slide #29)

- Record the outdoor temperature.
- Clean the dryer lint filter and furnace filter.
- Deactivate all combustion appliances.

- Close all exterior doors and windows.
- Open doors to interior spaces containing exhaust fans.
- Close all other interior doors.

Conducting a Worst-case Test (Slide #30)

- Measure the pressure difference of the CAZ with respect to the outdoors using a manometer. This is the baseline pressure that should be subtracted from all other CAZ readings.
- Operate all exhaust devices, including the dryer and air handler.
- Record the pressure difference of the CAZ with respect to the outdoors.
- Open and close interior doors (including the door to the CAZ) to induce the greatest CAZ depressurization.
    - Check interior doors using a smoke puffer. If smoke enters the room from the main body of the house, open the interior door. If air from the room blows smoke back into the main body of the house, close the interior door.
- Turn on the furnace blower. If it makes the CAZ pressure worse, leave it on for worst-case testing. If it makes the CAZ pressure better, turn it off.
- Conduct CO, spillage, and draft tests under worst-case conditions.
    - Test the weakest drafting appliance first. If the draft in the combustion appliance vent is less negative (closer to zero) than minimum draft, the vented combustion appliance is susceptible to extended periods of pressure-induced spillage and/or backdrafting when exhaust devices are in operation.
- Draft is a measurable pressure difference caused by combustion byproducts exhausting through a chimney flue as influenced by the temperature difference and the height of the flue. Draft for a natural draft appliance such as a furnace or water heater should be a negative value such as -0.02 IWC or its metric equivalent, -5 Pa.
- Repeat for all other vented appliances.
- Return dwelling, exhaust fans, and combustion appliances to normal settings.

Combustion Safety Problems – Fixes (Slide #31)

Solve excessive depressurization or inadequate draft:

- Remove chimney obstructions and repair disconnections and leaks.
- Properly size the vent, connector, or liner.
- Install a metal chimney liner and/or wind-rated chimney cap.
- Seal leaks in the return ducts of the CAZ.
- Balance supply and return air by adding new returns or by adding passive return air openings to the main body of the house.
- Reduce the capacity of large exhaust fans.
- Provide make-up air for dryers and exhaust fans.
- Provide a combustion air inlet to the CAZ.

Combustion Safety Problems (Slide #32)

- Rust on the draft hood of a natural gas furnace is evidence of severe spillage of flue gases.
- Soot stains at the inspection port of an oil-fired boiler indicate the need for a tune-up. Spillage of flue gases into the house occurs when there are physical problems with the vent system or there is sufficient depressurization in the CAZ.
- Depressurization and the resulting spillage is a function of the interaction between the tightness of the house and the capacity of exhaust devices such as dryers, fireplaces, or forced air systems.
    - Exhaust devices tend to exert more suction on a tight house than on a leaky house. Think of all the exhaust fans in a house acting like mini blower doors. The tighter the house, the more negative pressure is created. Open a window and the pressure is relieved.
- Some spillage when a combustion appliance turns on is normal, but it should last no more than a minute as the chimney heats up.
- Continuous spillage is known as backdrafting and can be caused by depressurization, a chimney blockage, or an oversized chimney.

Testing Water Heaters #1 (Slide #33)

- Insert the combustion analyzer probe into a natural draft hot water tank before the draft diverter and take CO readings on both sides of the ***baffle*** that runs through the center of the flue inside the water tank. The baffle slows the flow of hot flue gases to facilitate the transfer of that heat to the water surrounding the flue.
- Test for draft above the draft diverter.
- Monitor ambient CO levels in the living space and the CAZ to ensure the safety of agency staff, weatherization contractors, and occupants.
- Remember to calibrate the combustion analyzer outside and measure outdoor baseline CO levels before the test to ensure the accuracy of CO readings.
- If ambient CO levels exceed 9 ppm in the house, the CAZ should be ventilated before further testing and repair of the CO problem.

Testing Water Heaters #2 (Slide #34)

Photo on the left: Testing CO through the draft diverter. Test for CO directly in the breech of the unit on both sides of the baffle that runs up through the center of the tank.

Photo on the right: On start-up, time the spillage, then test the draft above the draft diverter. Spillage should not exceed 1 minute.

Chimney Liner (Slide #35)

Photo on the left: A chimney liner.

Photo on the right: This water heater was orphaned in the chimney when the furnace was replaced with a direct-vent model. Installing a chimney liner solved the problem.

- An oversized chimney will have a hard time heating up enough to allow adequate draft. An appliance served by an oversized chimney may have spillage and backdrafting problems.
- A good example of this is when a water heater remains connected to a chimney after a high-efficiency, direct-vent heating system is installed to replace the furnace. The chimney is no longer needed for the new furnace and the hot water tank remains, orphaned at the oversized chimney.
- A stainless steel liner should be installed to serve an orphaned hot water tank stuck with an oversized chimney. Refer to NFPA 54 for proper type and size.

Show a sample of the chimney liner and cap.

Summary (Slide #36)

- Safe combustion requires adequate combustion air, near-complete combustion (to avoid CO production), and safe exhaust of combustion byproducts from the living space.
- The most serious health and safety issue faced by weatherization personnel related to combustion equipment is CO poisoning.
- Visually inspect combustion appliances to ensure heat exchangers are intact, venting systems are intact and unblocked, and there is no evidence of spillage, flame roll-out, or oil leaks. Use testing equipment to check for CO, draft, and spillage, including under worst-case CAZ depressurization conditions, and check for gas leaks.
- Refer to the slides and included resources for proper test locations on various furnace types, water heaters, and gas cook stoves.
- Inadequate draft, and the resulting spillage and high CO levels in the living space, can be a symptom of a poorly designed vent system, e.g., chimney too short or blocked, too many elbows, orphaned appliance, etc.
- Testing under worst-case CAZ depressurization conditions ensures that we have anticipated the highest potential for draft reversal that could naturally occur in the home, and confirmed safe operation even under those conditions.