**Building Science Education Solution Center – Combustion Safety**

Proficiency Level 3: Apply

**Learning Objective 3.1**

* Demonstrate the difference between testing for combustion safety under the worst-case scenario, and the normal operation scenario.

**Lecture Notes 3.1:**

Reference:

Energy.gov. *Combustion Safety Simplified Test Protocol Field Study*. Accessed 2024   
 <https://www1.eere.energy.gov/buildings/publications/pdfs/building\_america/combustion- safety-protocol-field.pdf>

The main difference between combustion safety testing under worst-case conditions and normal operation conditions is that the worst-case scenario stress test is more intense. For the worst-case test, all exhaust fans are operating on high speed, and all operable doors are adjusted such that the greatest negative pressure is developed near the gas appliance being tested. This is not reflective of the most common real-world conditions, and research has shown that testing under worst-case conditions can cause false positives, where a failure with carbon monoxide (CO) spillage occurs during the worst-case test, but no CO spillage is detected when testing the failing appliances during normal operating conditions.

According to the field study linked above, which examined 11 houses across Minnesota and Wisconsin that had water heaters located in the basement, the conclusions were that:

* Typically, normal combustion systems don’t spill excessively and don’t produce much CO.
* Vent defects such as incomplete vent sealing, under-sizing, or usage of inappropriate vent openings are an important cause, perhaps the largest cause, of excessive spillage. This makes vent inspection critically important in evaluating safe operation.
* Worst-case test conditions were about equal for the simplified and comprehensive testing methods.
* There is a large variation in the level of depressurization required to cause spillage (−1.7 to −7.4 Pa).

Testing standards have moved away from worst-case condition scenarios, creating guidelines for testing combustion safety under conditions more reflective of common household appliance operation, and can be found in the following references:

“Measure Guideline: Combustion Safety for Natural Draft Appliances Using Indoor Air” <https://www.nrel.gov/docs/fy14osti/61326.pdf>

“Measure Guideline: Combustion Safety for Natural Draft Appliances Through Appliance Zone Isolation”  
<https://www1.eere.energy.gov/buildings/publications/pdfs/building_america/measure_guide_combustion_safety_appliancezone.pdf>

**Problem Set 3.1:**

1) Why have residential combustion safety tests changed from testing under worst-case conditions to those at a level closer to common household appliance operation?

**Learning Objective 3.2:**

* Calculate the volume of indoor air required for safe combustion and ventilation of natural draft appliances using indoor air.

**Lecture Notes 3.2:**

Reference:

Energy.gov. *Combustion Safety Webinar*. Accessed 2024.  
 <https://www.energy.gov/sites/prod/files/2015/12/f27/BA%20Combustion%20Safety%20Webi nar%20r3.pdf>

For appliances other than natural draft Category I vented appliances, the required air volume for combustion, ventilation, and dilution air shall be supplied in accordance with the appliance manufacturer’s instructions.

According to the National Fuel Gas Code for natural draft Category I vented appliances, the method to determine the required volume of indoor air is dependent on the air change per hour (ACH) of the location in which the appliance is installed. It is a measure of the air volume added to or removed from a defined space divided by the volume of that space. Realistically, it equates to the number of times the total volume of air in a defined room or space is changed over the course of one hour.

If the ACH is greater than or equal to 0.4, the Standard Method applies, where the required volume of indoor air is equal to 50 cubic feet per 1000 Btu/hr of each combustion appliance in that airspace.

Example:

If the example residence had 8-foot-tall ceilings, the floor area required safe combustion appliance operation would be a minimum of 750 square feet.

If the ACH is less than 0.4 and the air infiltration rate of the airspace is known, then the Known Infiltration Rate Method applies, where the required volume of air varies depending on if the appliance(s) in question is fan-assisted or not.

For any appliance that is not fan-assisted, the required air volume is 21 cubic feet divided by the ACH, multiplied by the appliance’s rating in 1000 Btu/hr.

For any appliance that is fan-assisted, the required air volume is 15 cubic feet divided by the ACH, multiplied by the appliance’s rating in 1000 Btu/hr.

Example: In a residence with an ACH of 0.3, and a 120,000 Btu/hr rated appliance, if the appliance is not fan-assisted, the required volume would be:

In a residence with 8 foot ceilings, the required floor area would be:

If that appliance was fan-assisted, then the required volume and floor area would be:

**Problem Set 3.2:**

1) For a residence with three natural draft Category I vented appliances with natural drafts of 120,000 Btu/hr, 150,000 Btu/hr, and 100,000 Btu/hr, all sharing an airspace with an ACH of 0.5 in a house with a ceiling height of 8 feet, how much surface area is required for these appliances to be considered combustion safe?

2) A residence has three natural draft Category I vented appliances sharing an airspace with an ACH of 0.25. Two of the appliances are not fan-assisted with natural drafts of 80,000 Btu/hr, 120,000 Btu/hr, and the third appliance is fan-assisted and has a natural draft of 100,000 Btu/hr. If the total surface area of the indoor space is 2000 square feet, how high do the ceilings need to be to ensure safe combustion operation of all three appliances?

3) A residence has two natural draft Category II vented appliances and one natural draft Category III vented appliance, all of which are fan-assisted, sharing an airspace with an ACH of 0.5. What would be the required air volume for safe combustion operation?

a) 50 cubic feet per 1000 Btu/hr of each appliance.

b) 21 cubic feet per ACH per 1000 Btu/hr of each appliance.

c) 15 cubic feet per ACH per 1000 Btu/hr of each appliance.

d) The required air volume for each of the appliances will be provided to the residence owner by their individual manufacturers.

**Learning Objective 3.3:**

* Perform a combustion safety analysis on natural draft appliances that use indoor air and make upgrades to these combustion systems.

**Lecture Notes 3.3:**

Reference:

Pages 12 through 26 of “Measure Guideline: Combustion Safety for Natural Draft Appliances Using Indoor Air.” <https://www.nrel.gov/docs/fy14osti/61326.pdf>

The following section on combustion safety has been summarized from the measure guideline referenced above. For the full text, please visit the link.

Combustion Safety Testing for Appliances that use Indoor Air for Combustion:

Combustion safety tests are used to assess any appliances within a building that use combustion for safe operation. The following steps are used for combustion appliances that use a building’s indoor air for combustion and venting of flue gases.

Appliance Assessment:

Check that the appliance is applicable for using indoor combustion air for safe operation:

1. Appliances must be Category 1 natural draft appliances equipped with a draft hood (appliances are labeled as Category 1 on the manufacturer’s nameplate). Fan-assisted Category 1 appliances can apply in cases where they share a common vent with appliances equipped with a draft hood.
2. Appliances must use indoor air for combustion and freely communicate with the indoor environment. Any appliances located in unsealed attics, garages, or outdoor ventilated closets are considered to use outdoor air for combustion.

Check that the residence’s venting system is code compliant. This includes the following steps for vent connectors, the common vent, and masonry chimneys:

1. For vent connectors, check that the vent connector sizing, including diameter, materials, and number of elbows in the vent connector as well as the slope of the vent connector from the appliance to the venting system after installation are all sized according to the National Fuel Gas Code (NFGC), which is also included in National Fire Protection Association (NFPA) 54 (<https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=54>). Appropriate sizing can be found using the appliance input rating (which is located on the appliance’s nameplate) and the code’s vent connector tables. Draft hood appliances refer to the table’s NAT Max value, fan-assisted appliances refer to the table’s FAN Min and Max values.
2. For the common vent, inspect the common vent’s height from the appliance intersection to the roof, and the common vent’s diameter. Compare the height and diameter to the code table values to confirm that the common vent can handle the input values from all attached appliances (as above for the vent connectors, the common vent table lists different values depending on whether all connected appliances have draft hoods, all appliances are fan-assisted, or if there is a mix of draft hood and fan-assisted appliances using the common vent).
3. If masonry chimneys are used, calculate the internal area, and compare the size to the appropriate table in the NFGC. If the chimney is too large, then it should be relined with a metal liner or type B vent. Metal lining may already be required for an external chimney depending on appliance input rates, installation type, and the local 99% winter design temperature. The capacity of common vented appliances that use the masonry chimney must be between the minimum and maximum capacity listed in the appropriate NFGC tables.
4. Additional factors such as manifolds, offsets, vent connectors with three or more elbows, and corrugated liners, have additional sections in the NFGC designed to address these issues.

Determine if there is sufficient indoor air for safe combustion operation following either the Standard Method or the Known Air Infiltration Rate Method (See section 3.2 of this module.)

Test-In:

Safety Concern: At any point during the combustion safety inspection, testing stops immediately if either of the following happens.

1. If combustion appliances are not operating safely at any time.
2. Regularly measure the CO and combustible gas concentrations within the house in addition to the appliances during testing. If CO is detected above the National Renewable Energy Laboratory (NREL) Standard Work Specification Limit, (35 ppm), or there is a gas leak above the 10% lower explosive limit as outlined in Occupational Safety and Health Administration (OSHA, 2011) standard 1915 Subpart B app A (<https://www.osha.gov/laws-regs/regulations/standardnumber/1915/1915SubpartBAppA>), immediately notify the homeowner, and stop the test until maintenance can be done to address the CO spillage.

Note: Any appliances that are going to be replaced through planned upgrades do not need to be tested at this stage.

Perform the following checks on the appliance with the heating element turned **off**:

1. Turn the gas on and test the appliance for gas leakage. Visually inspect the venting system for any blockage, restriction, leakage, corrosion, or other deficiencies that could cause an unsafe condition.
2. Turn the gas and electricity off, and then check all burners and crossovers in the appliance for blockage or corrosion. This includes checking for damage and excessive corrosion in heat exchangers in furnaces and looking for water or combustion product leaks in boilers.

Perform the following checks on the appliance with the heating element turned **on**:

1. Prepare the room by closing all exterior doors, windows, and fireplace dampers, opening all interior doors (except to rooms with central air handlers, or rooms without a ducted return grille), and leaving open all combustion air openings to the outdoors.
2. Turn on clothes dryers and exhaust fans to maximum speed. Do not use a summer exhaust fan.
3. Then, turn on the combustion appliance for continuous operation, and measure the CO level in the flue, and determine that it is not above the ANSI-certified CO limit for that appliance type (NFGC).
4. Measure for spillage after 5 minutes of main burner operation.
5. Next, turn on all of the other fuel gas burning appliances in the room, and test the initial appliance again for CO in the flue gas and for spillage after 5 minutes.
6. Repeat these steps for all appliances being tested.
7. Return all appliances to their previous conditions of operation after testing is done.

Advanced checks for trained HVAC technicians only, for appliances with the heating element turned **on**:

1. Check that the pilots and the main burner gas are operating properly.
2. For furnaces, check the limit control and fan control.
3. For boilers, verify that water pumps are in operating condition, as well as low water cutoffs, automatic feed controls, pressure and temperature controls, and relief valves.

Upgrades:

Planned upgrades of combustion appliances are done after test-in if the residence and inside space have been determined to be combustion safe.

Test-out:

Combustion safety testing of appliances is repeated after upgrade procedures are installed to ensure the house is still combustion safe after the upgrades have been made. If any air sealing measures have been implemented, and this has reduced the air infiltration rate to below 0.4 air changes per hour (ACH), then the Known Air Infiltration Rate Method needs to be used to recalculate the indoor air volume for safe combustion. If there are any equipment or spillage failures during test-out, these will need to be addressed through remediation before the combustion safety inspection can be finished.

Remediation:

Remediation measures are more advanced measures used to ensure a building’s construction safety. Remediation can cover many different types of home modifications, including providing mechanical combustion air supply, providing combustion air ducts, or developing an engineered solution. The specific measures are different depending on whether the combustion safety failure is due to an inability to meet code compliance, or because of combustion equipment or spillage failures. For all types of remediation, the cost should be estimated before proceeding with any measures. More details on remediation measures can be found in Section 4.1 of this module.

**Problem Set 3.3:**

1) When assessing a combustion appliance for spillage, how long should the main burner be in operation before making the assessment?

a) 3 minutes

b) 5 minutes

c) 10 minutes

d) 15 minutes

2) Which of the following does not apply to the screening protocol used to assess combustion appliances that use indoor air?

a) Any upgrades to be made must be less costly compared to alternative methods, e.g., replacement with power-vented or direct vent appliances.

b) Upgrades must be compatible within the elements, structure, and conditions of the building.

c) The methods must be applicable for the types of combustion appliances that are being used in the house.

d) If combustion appliances are older than 20 years, they must be replaced with newer models.

**Learning Objective 3.4:**

* Perform a combustion safety analysis on natural draft appliances that use outdoor air and make upgrades to these combustion systems though appliance zone isolation.

**Lecture Notes 3.4:**

Reference:

Energy.gov. *Measure Guideline: Combustion Safety for Natural Draft Appliances Through Appliance Zone Isolation*. Accessed 2024.   
 < [https://www1.eere.energy.gov/buildings/publications/pdfs/building\_america/measure\_guide\_ combustion\_safety\_appliancezone.pdf](https://www1.eere.energy.gov/buildings/publications/pdfs/building_america/measure_guide_combustion_safety_appliancezone.pdf) >

The following section on combustion safety has been summarized from the measure guideline referenced above. For the full text, please visit the link.

The following steps are used for combustion appliances that use outdoor air for combustion, and use zone isolation to isolate the combustion appliances away from the common living space for safe combustion operation. These steps apply to natural draft and fan-assisted Category 1 combustion appliances. Additional conditions where retrofit work for the residence can proceed without the need for extensive combustion safety diagnostics include:

* There are no vented combustion appliances in the house.
* All combustion appliances in the house are resistant to depressurization.
* The house is extremely leaky with little to no potential for depressurization.
* The house is not leaky but has very high depressurization potential. The only option for improving combustion safety is to replace depressurization-susceptible appliances with ones resistant to depressurization.
* All vented combustion appliances are in a space that is already isolated from the living space.

Screening Protocol:

A screening protocol is first done to determine whether zone isolation is applicable and the optimal choice for ensuring a residence’s combustion safety. The screening protocol consists of an appliance assessment, defining the work scope of the zone isolation process, and conducting a total cost estimate to carry out the zone isolation.

Appliance Assessment:

Determine whether the combustion appliances are in an area that can be isolated from the living space. To be isolated, an airtight pressure boundary must be formed between the appliance’s space and the main living space of the house. Some examples of locations for appliances that are suitable for zone isolation include mechanical closets open to the outdoors, a separate room open to the outdoors, the garage, or an attic.

Test the appliances to determine that they are working correctly. Begin by performing the following tests with the equipment turned **off**:

* Test for ambient CO and combustible fuel gases in the air.
* Check that the venting system is up to code (NFGC).
* Check the amount of air in the space that the appliance can use for combustion and compare that to the outdoor combustion air requirements (NFGC). Take into account the net free area of any louvers or grilles.
* Conduct an inspection of the appliance equipment for its safety systems, inside-wiring, burners, and the heat exchanger.
* If a combustible gas is smelled, or if a gas detector detects fuel gas that exceeds 20% of the lower explosive limit (or 1% in the air by volume), evacuate immediately and contact emergency services.
* There are some special considerations to be made for specific combustion appliances:
  + Forced Air Furnaces: Make sure the air filter is installed and not excessively blocked with dust. Inspect the combustion chamber for cracks, ruptures, holes, and corrosion. Conduct a heat exchanger leakage test.
  + Boilers: Inspect for water leaks around the boiler and connected piping.
  + Water Heaters: Pressure temperature relief valve must be operable. Water in the heater should be at operating temperature. Check that inspection covers, glass, and gaskets are intact and in place on a flammable vapor ignition resistant type water heater. If local building code requires in earthquake-prone locations, inspect that the water heater is secured to the wall studs in two locations (high and low) using appropriate metal strapping and bolts.
  + Gas Clothes Dryer: If it is in a closet, make sure there is a source of make-up air provided and that any openings, louvers, and ducts for the make-up air are free of blockage. Inspect for lint, clean out the lint trap, and make sure the trap does not have holes or tears. Inspect the moisture exhaust duct and connections for loose fittings and connections, blockage, and signs of corrosion. Verify that the termination is not blocked and that it terminates in an outdoor location. Verify that only approved metal vent ducting material is installed.

Next, conduct the following tests with the equipment turned **on** and running:

* Test for ambient CO and combustible fuel gases in the air.
* Check the ignition and controls for proper appliance operation.
* Check for spillage or back-drafting.
* Check the input for over-firing.
* Check for any oil smoke and set draft at the barometric damper.
* Check the flue gas for CO concentration. Furnaces must have no flame distortion when the fan is running.
* Check that any temperature rise is within the manufacturer’s recommendation.
* Check all safety and protective devices.
* There are some special considerations to be made for specific combustion appliances:
  + Forced Air Furnaces: Limit control and fan control must be working properly. Blower compartment door must be properly installed, properly resecured if opened, and the safety switch must operate properly. Check for flame disturbances before and after the blower comes on. Any disturbances could indicate a heat exchanger leak. Measure CO after 5 minutes of main burner operation, check CO level against the NFGC value for the appliance.
  + Boilers: Inspect for water leaks around the boiler and connected piping. Verify that the water pumps are in operating condition. Measure CO after 5 minutes of main burner operation (NFGC).
  + Water Heaters: Check that the thermostat is set within the manufacturer’s recommendation, and measure CO after 5 minutes of main burner operation (NFGC)
  + Gas Clothes Dryers: Verify that all mechanical components are operating properly. Operate the clothes dryer and verify that the exhaust system is intact and that the exhaust is exiting the termination. Measure CO after 5 minutes of main burner operation (NFGC)

Define the Isolated Appliance Work Zone Scope:

After the appliances have been assessed, the scope of the isolation work must be determined. The work scope will define an appliance isolation zone with the following qualities:

* There will be a continuous, durable, air-sealed boundary that can separate the appliances from the house. If the boundary is not complete, completing the boundary must be included in the work scope.
* Adequate isolation is achieved when the pressure difference between the appliance zone and the outside is less than 5 Pa for a blower door induced house depressurization of 50 Pa, or less than 10% of the house depressurization if 50 Pa cannot be reached. If the pressure difference is not small enough, include isolation work in the work scope.
* All of the ductwork and the cabinet within the isolation zone is completely sealed. Adequate sealing is achieved when the exterior duct leakage is less than 6% of the nominal system flow rate, and a smoke test shows that there is no return leakage. Duct sealing must be included in the work scope if adequate sealing is not achieved.
* Check that the venting system is compliant with local codes and NFGC. If the system does not meet the codes, work must be done to make them up to code.
* All combustion air must be supplied from the outside. No return air is drawn from a garage, boiler room, furnace room, unconditioned attic, or any areas with flammable vapors.

Job Cost Estimation:

Estimate the cost of the options available for safe combustion operation, comparing zone isolation to other methods.

At this point, if the combustion appliances have been found to not be operating safely, the appliance zone cannot be isolated, or the cost to isolate the zone exceeds other suitable alternatives, these issues must be resolved before the zone isolation work can continue.

Create the Isolation Zone:

After defining the work scope and estimating the cost, perform the work necessary to create an isolated zone or repair an existing failing zone.

* Ensure that the venting system complies with the manufacturer’s specifications and local codes (including the chimney venting system, common vent, and vent connectors).
* Air seal any cracks, gaps, or openings in the physical boundary to ensure that it is airtight to the living space.
  + Leaks can be found using a blower door to pressurize the zone, and a smoke pencil to find air leaks within the system.
  + Seal air leakage with caulk, gaskets, weather-stripping, or other closure methods and materials to limit airflow.
  + If there are any louvers between the zone and the conditioned space in the residence, they shall be removed, and the opening covered with sheet metal or gypsum board.
  + Seal all joints, seams, and penetrations between the zone and living space with joint tape, sealant foam that can be used as a fire stop and is approved for uncovered use, or sealant caulk.
  + Weather-strip the door to the inside of the house (if any), provide a door sweep, and make sure the door is self-closing and self-latching.
* Seal all ducts and cabinet leakage located in the zone to ensure that ducts and cabinet meet the leakage requirements.
  + Seal all joints, penetrations, and openings in the cabinets of the air handling unit. Use metal tape or suitable gaskets on service openings and permanent seals on fixed joints and seams. All air handling units should be mechanically attached to other air distribution systems.
  + Provide access as needed to seal all return and fan cabinet leaks in the space. Provide continuous sealed ductwork from the living space directly into the blower housing for the forced air furnace, or other air handler. Maintain at least the cross-sectional area of the return inlet and size the liner or duct to meet the manufacturers’ required airflow without restriction.
  + For any furnace returns that do not have manufacturer’s information, they must provide at least 2 square inches of total cross-sectional area for every 1,000 BTU of output.
  + Mechanically fasten the duct to the furnace cabinet and at the connection to the interior. Tape all cabinet service openings and joints. Seal all joints and seams with Underwriters Laboratories (UL) standard-approved mastic and mesh tape or foil tape. Sealant foam approved for use as a fire stop in combustible construction is acceptable at the connection to the interior construction materials.
  + No return air can be taken from a garage, boiler room, furnace room, crawlspace, or unconditioned attic. Line any enclosed support platform or building cavity used as a return air duct with continuous, durable, air impermeable material and seals that show a flame spread index of 25 or less and smoke development index of 50 or less when tested to American Society for Testing and Materials (ASTM) E 84 (<https://www.astm.org/e0084-21a.html>) or UL 723 (<https://standardscatalog.ul.com/ProductDetail.aspx?productId=UL723>), or use a standard material listed for use in duct systems (i.e., sheet metal, duct board, or flexible duct).
* Provide combustion air openings as required by code (NFPA 54 or applicable local codes).
  + The permanent air openings to the outdoors cannot be smaller than 3 inches in diameter.
  + Two acceptable methods based on NFPA 54 can be employed in setting up the combustion openings:
    - Use two openings, one within 12 inches of the top and the other within 12 inches of the bottom of the isolation zone. If the opening is directly to the outside or connected through vertical ducts, the minimum net free area of each opening should be 1 square inch per 4,000 Btu/hour of the total input of all appliances in the zone. If the openings are connected to the outside through horizontal ducts, the minimum net free area of each opening should be at least 1 square inch per 2,000 Btu/hour of the total input of all appliances in the zone.
    - Use one opening, located within 12 inches of the top of the isolation zone. The minimum net free area of the opening should be 1 square inch per 3,000 Btu/hour of the total input of all the appliances. This value must not be smaller than the sum of the net free area of all the vent connectors in the space.
  + If a mechanical damper is installed in the combustion air opening, interlock this with the furnace or boiler, but provide a passive combustion air opening in the same space for a natural draft water heater, if present, because there is no electrical control circuit on residential water heaters.
  + Consider the presence of louvers, screens, or grilles over the openings when calculating the free area of the openings. Use the manufacturer’s labeled free air where provided. If unlabeled, assume that free air is 75% of the metal louver area and 25% of the wood louver area.
* Remove all exhaust devices located in the area that can depressurize the zone or provide makeup air if there is a clothes dryer in the isolated zone.
  + Each clothes dryer should be provided with 100 square inches of makeup air. If closure is required during the off cycler of the dryer, a mechanical damper interlocked with the dryer should be provided, with the interlock wired to prevent dryer operation if the damper fails.
  + All other exhaust fans should be removed from the isolated combustion appliance zone.
  + If appliances are installed in an attic powered attic fans in an attic space should either be disconnected, or additional air inlets should be provided as per the requirements of the fan manufacturer.

Conduct Field Confirmation:

The field confirmation is done to confirm that the zone is isolated properly and meets all code requirements. This is done through the following steps:

1. Visually inspect the air handler to verify that all the relevant locations have been sealed:
   1. All seams, joints, and openings at the fan cabinet, furnace cabinet, the cabinet section with the air conditioner coil, and connections to return and supply plenums.
   2. The refrigerant line and any other penetrations into the forced air unit.
   3. The air handler door and other service panels (These are sealed with tape or and adjustable approved gasket. These are not sealed permanently).
   4. All plenum and duct seams.
   5. The return plenum joints at the filter grille and to the back side of the interior finish materials.
   6. The gap between any duct and duct chase where it passes out of the combustion space.
2. Perform a smoke test to confirm completion or compliance of duct and cabinet sealing work.
   1. Pressurize the residence to 25 Pa and use theatrical fog or equivalent non-toxic smoke into the fan inlet while observing for any smoke coming out of the ducts and cabinet.
   2. Seal all areas where there is smoke leakage.
   3. Run smoke through the fan inlet again and make sure that there are no more leaks.
   4. If smoke comes out of the burner area, heat exchanger, or vent connector, note it to be addressed in follow-up service.
3. Perform an isolation pressure test. The following conditions must be met, as applicable:
   1. The appliance zone pressure change to the outside must not be more than 5 Pa when performing a blower door test placing the house at 50 Pa house depressurization.
   2. The appliance zone pressure change to the outside with dryer and makeup air must not be greater than 2.5 Pa during dryer operation.
   3. The garage pressure change to the outside must not be greater than 2.5 Pa during garage exhaust fan operation if the appliances are in the garage.

**Problem Set 3.4:**

1) Which conditions for residences do not allow retrofit work to proceed without extensive combustion safety diagnostics or performance-based protocols, similar to those that qualify for appliance zone isolation?

a) All combustion appliances are depressurization resistant.

b) The residence is extremely leaky with little or no potential for depressurization.

c) All vented combustion appliances are located in a space with only one connection to the residential living space.

d) No vented combustion appliances are present in the residence.

2) What level of depressurization indicates a successful zone isolation for combustion safety?

3) Why is a worst-case appliance zone depressurization test not applicable to assessing combustion appliances that do not use indoor air for combustion?

**Learning Objective 3.5:**

* Determine what should be done if significant levels of CO are detected in the ambient air of the building or in the appliance’s flue gas during a combustion safety test.

**Lecture Notes 3.5:**

Reference:

Building Performance Institute’s. *Combustion Appliance Safety Inspection for Vented Appliances*. January 1, 2016.  
 <http://www.bpi.org/sites/default/files/COMBUSTION%20APPLIANCE%20SAFETY%20INSPECTIO N%20FOR%20VENTED%20APPLIANCES.pdf>

When testing an appliance for combustion safety, the concentration of ambient carbon monoxide (CO) in the building’s indoor air must be constantly monitored for safety. If sufficient levels of CO are detected in the ambient air, measures must be immediately taken to ensure the safety of the inspector and any other occupants in the building. These actions can range from opening the doors and windows to provide ventilation to dilute the ambient CO air concentration, to immediately stopping the inspection and calling the appropriate emergency services.

Refer to the table “Required Actions in Response to Ambient CO Measurements” on page 1 of the reference for a list of actions to take at different levels of detected ambient indoor air CO concentrations.

If the appliance’s flue gas has a concentration of CO that exceeds the appliance’s CO threshold limit, then the appliance should be inspected by a qualified professional for repairs or replacement. Refer to “Table 1: CO Thresholds for Fossil Fuel-Fired Combustion Appliances” on page 2 of the reference for a list of CO threshold limits for common combustion appliances.

**Problem Set 3.5:**

1) At what concentrations of indoor air ambient CO should a qualified professional be contacted to address the CO contamination due to a permanently installed appliance? Select all that apply.

a) At CO concentrations of 9 ppm to 35 ppm.

b) At CO concentrations of 36 ppm to 69 ppm.

c) At CO concentrations of 70 ppm or greater.

2) At what concentrations of indoor air ambient CO should the building be evacuated, and emergency services contacted? Select all that apply.

a) At CO concentrations of 9 ppm to 35 ppm.

b) At CO concentrations of 36 ppm to 69 ppm.

c) At CO concentrations of 70 ppm or greater.

3) At what concentrations of indoor air ambient CO should CO sources be turned off immediately? Select all that apply.

a) At CO concentrations of 9 ppm to 35 ppm.

b) At CO concentrations of 36 ppm to 69 ppm.

c) At CO concentrations of 70 ppm or greater.

4) Sort the following appliances from highest to lowest CO threshold limit.

a) Refrigerator

b) Water Heater

c) Floor Furnace

d) Oven/Boiler