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FIELD EVALUATION METHODS OF COMBUSTION EQUIPMENT IN RESIDENCES

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EXECUTIVE SUMMARY

Combustion appliances are used in residences every day. Evaluation of these appliances is important to ensure safety of the building's occupants and effective operation of the appliance. Current weatherization practices have increased the need for appliance evaluation. Changes in airflow caused by these practices can affect the operation of the combustion appliances. There are current procedures that are recognized or commonly utilized to evaluate combustion appliances installed in a residence. This literature review evaluated three nationwide methods and three state procedures to determine their effectiveness, how they compared, and if they are sufficient. Two nationwide methods that are most commonly reference include Building Performance Institute, Inc. (BPI) - 1100-T-2012 with BPI's supporting standards and Air Conditioning Contractors of America (ACCA) Standard 12 – 2014, but also included our discussion is the National Fuel Gas Code (NFGC) 2012 Annex G: Recommended Procedure for Safety Inspection of an Existing Appliance Installation. The three state procedures included a Georgia combustion safety testing procedure by SouthFace, a weatherization field guide for the Midwest, and a weatherization field guide for the West Coast by Energy OutWest.

In order to compare and evaluate the procedures, they were broken down into ten sections pertaining to the field evaluation of combustion appliances. The ten sections included combustion fuel leakage check, appliance inspection, ventilation system check, combustion appliance zone (CAZ) analysis, depressurization setup, ignitions, carbon monoxide (CO) testing, spillage test, draft test, and efficiency testing. After breaking down both the nationwide and state procedures, there were deficiencies and questionable procedures found.

For the nationwide methods, the NFGC: Annex G is a simpler method that can be performed with relative ease, but it does not include some key test like CO testing. ACCA Standard 12 provides a more detail approach which provides a more thorough testing protocol. However, it also does not include all the necessary tests and information to properly evaluate a combustion appliance. Lastly, the BPI-1100-T method includes a majority of the tests with detail instructions. There are some sections that are vague, but overall it provides a better approach to testing combustion appliances than the other two nationwide methods.

The state procedures also have variations in the way they evaluate combustion appliances. All of them include a majority of the topics in question, but some of the procedures are missing information or will not produce accurate results. Georgia's procedure is more technician friendly by providing an easier format and includes seven out of the ten topics. Both the Midwest and West Coast procedures provide more information regarding how the appliances are possibly being effected and why the tests are being run. However, the West Coast procedure buries the testing methods within the text which makes it hard to follow. None of the methods completely evaluate all types of combustion appliances or provide testing procedures for these appliances installed in a residence. However, the majority contain the basic information needed and with the right revisions would contain proper evaluation methods.

The scope of this evaluation was not to make a determination of the adequacy of the codes but rather to compare them and discusses the pros and cons of each in comparison to the others. In general, there

are issues that are missing from all of them and an industry wide recommendation should be sought by the code groups to make sure all aspects of the audits serve the best interest of the general public. The authors have included some recommendations as line items in either the column 1 or 2 of the summary Appendix (these are highlighted Boldface and in italics). The list of shortcomings from all the groups is very extensive thus it was felt the best way to present the lack of coverage was to create the list shown in the Appendix which compares each code side by side and where whole segments were missing, to add the highlighted line item. This Appendix also serves as the Summery and Conclusion for this exercise.

For a better code to be generated by each group it is the authors' belief that every box should be populated with a "yes" in it.

Additionally, since appliance design is a rapidly evolving process in today's marketplace, each code group should be constantly reviewing their code and test process in light of the new and ever changing technology being utilized by manufacturers. As an example Flammable Vapor Ignition Resistant water heaters have been in production for 10+ years and yet none of the codes discuss import cleaning aspects of the screens which is fundamental to the safe operation of that product.

INTRODUCTION

Combustion appliances are used in residences each and every day. A gas water heater is used to heat up water for a morning shower, a gas furnace keeps the home warm in the winter time, or a gas range helps us to prepare a delicious meal. However, when we are utilizing these appliances we usually don't give much thought to how well they are operating. A few concerns regarding the operation could be is the appliance leaking fuel? Is it vented properly to exhaust fumes? Do all the safety components still function? Did weatherizing the home effect the appliance? Without properly evaluating combustion appliances, an issue may not be identified until it becomes a serious problem.

There are current procedures that are recognized or commonly utilized to evaluate combustion appliances installed in a residence. This literature review will evaluate three nationwide and three state standard/procedures used for evaluating combustion appliances. The scopes of these procedures are limited to detached family dwellings. The three nationwide methods include:

1. NFPA 54/ANSI Z223.1: National Fuel Gas Code (NFGC) 2012 Annex G: *Recommended Procedure for Safety Inspection of an Existing Appliance Installation* [2]
2. Building Performance Institute, Inc. (BPI) - 1100-T-2012 [3] with BPI's supporting standards
3. Air Conditioning Contractors of America (ACCA) Standard 12 – 2014 [1]

Annex G of the NFGC is only under consideration since the scope of this literature review pertains to pre-existing appliances installed in the home and not new installations.

BPI-1100-T's supporting materials include BPI's Building Analyst Professional [4] and The Heating Professional [5] standards.

The three state procedures include:

1. Georgia combustion safety testing procedure by SouthFace [14]
2. 2007 Midwest Weatherization Best Practices Field Guide[12]which includes:
    a. Illinois
    b. Indiana
    c. Iowa
    d. Michigan
    e. Minnesota
    f. Missouri
    g. Ohio
    h. Wisconsin

3. 2005 Weatherization Field Guide: Best Practice for the Weatherization Assistance Program by Energy OutWest [10] which includes:
    a. Alaska
    b. Arizona
    c. Idaho
    d. Nevada
    e. Oregon
    f. Washington

Throughout this literature review three questions are to be answered:

- Are the current procedures for evaluating the safety and performance of installed combustion equipment in residences adequate?
- How do they compare?
- And if none are sufficient, what proposed procedure will suffice?

WHY THE SPECIFIC PROCEDURES WHERE CHOSEN

A search on the internet of companies that performed energy audit testing indicates that there are select procedures being used by those companies. The BPI and ACCA procedures showed up the most often in the advertising of the evaluation companies as the procedures that they use during their audits and that is why those two were chosen. The NFGC was chosen since it is a code that has been utilized by the gas appliance industry since the early 1980's. As for the three state procedures, they were chosen to give a sampling of the methods used in the different regions throughout the United States. There may be other less significant procedures available but it is suspected that the some of the same shortfalls will be in place for each that is published.

TYPES OF APPLIANCES THAT SHOULD BE ADDRESSED

In reviewing the literature and the comparison of methods noted below, it should be kept in mind that the following categories of appliances needs to be addressed to adequately address the field audit procedures that guarantees safety and reliable performance for the owner of the products:

Gas products using both atmospherically drafted products and fan assisted:

1. Furnaces (both fan assisted and legacy atmospherically vented products central home, manufactured housing, direct vent, and atmospherically vented wall furnaces)
2. Boilers (atmospherically vented and power vented/fan assisted)
3. Water Heaters (atmospherically and power vented)
4. Room Heaters including gas fireplaces (all of which include both vented and direct vented products)

Other gas products both vented and unvented along with fan assisted combustion in specific products:

1. Range (unvented)
2. Cooktops (unvented)
3. Ovens (unvented)
4. Clothes Dryers (both vented and unvented)
5. Unvented Room Heaters (including log sets) as a jurisdiction permits
6. Pool Heaters (vented)

Oil fired equipment is fan assisted and includes:

1. Central Heating Furnaces (including manufactured housing)
2. Boilers
3. Water heaters

As will be noted above when compared to the above lists the authors of the various codes very often did not cover the full range of products that may show up in a household or light duty commercial installation.

METHODS COMPARISON

The methods evaluated in this literature review all contain various procedures and parameters. In order to compare and evaluate each method, they will be broken into ten sections pertaining to the field evaluation of combustion appliances both gaseous and liquid (oil, etc.). The ten sections include combustion fuel leakage check, appliance inspection, ventilation system check, combustion appliance zone (CAZ) analysis, depressurization setup, ignitions, carbon monoxide (CO) testing, spillage test, draft test, and efficiency testing. These specific sections were chosen since they pertain to the major aspects of evaluating a combustion appliance, but may not include every aspect of evaluating an appliance in the field.

During the evaluation, the strengths and weakness of each of the methods pertaining to that specific section will be identified and later compared to the other standards and procedures. To provide a better comparison, the nationwide and state methods will be compared in their own separate categories.

1. COMBUSTION FUEL LEAKAGE CHECK

Before any testing should be done on an appliance the fuel delivery system should be checked for leaks. It can be a simple test that helps to ensure the safety of the technician, the occupants of the home, and protects the environment by helping to prevent a fire, explosion, and for oil fired equipment, ground contamination.

A gas leak can be detected in a variety of ways in the field including smell, using a soap solution, or by using a gas detector. Smell can be used since gas companies put an odorant into the gas which can be identified well below the flammable limit of the gas. This odorant can be the first line of defense in determining when a gas leak is present. However, using smell alone will not help to pin point the gas leak precisely and the odorant can also be masked by other fumes or vapors in the air making it undetectable. A technician can also use a simple soap solution to determine if and where a leak is occurring. Using soap solution alone has a drawback. Leaks can be easily overlooked since the technician can either not see the bubble formation or they didn't apply the soapy water to the right area. A more sophisticated leak test includes using a gas detector. These detectors will produce the most accurate determination of a gas leak, but require training, calibration, and maintenance which make them not as practical [16]. Combustion equipment equipped to use heating oil for their fuel provides a more forward approach in leak checking. Since the fuel is a liquid, a technician can visual inspect the equipment and its fuel delivery system for leaks. If the unit is equipped with a below ground oil tank reservoir, a more involved approach to leak testing is required. A few examples of below ground oil tank leak test include soil testing below the tank, low-psi oil tank pressurization test, or water testing [11]. If a leak is detected, all testing should be stopped, the occupants of the home should be evacuated, and the proper remediation should be taken.

1.1 Leak Testing: Nationwide Methods

All the three of the nationwide methods include a section for fuel leak testing. The gas leak testing method in BPI-1100-T and the ACCA Standard 12 include detail instructions to check the gas supply system not only by a gas detector, but also indicates to locate the source with a soap solution. Both methods also provide the adequate actions and remediation if a leak is found as well. NFGC: Annex G on the other hand is vague and only states to "conduct a test for gas leakage". The vagueness in the NFGC could result in improper testing and cause some leaks not to be found. Also, this statement doesn't provide any instruction on what to do if a leak was found.

Oil leak testing varies between the three nationwide methods. BPI-1100-T includes a section to check the oil lines for leaks, ensure the lines are free of water and other contaminants, and to check the fuel oil storage system for integrity. Not only does this standard check the oil lines, but it also provides additional checks which can help to prevent any future leaks from occurring. However, there are no indications on how to check an oil tank if it were located below ground. ACCA standard 12 provides instruction to do a visual check of the oil lines, mark the location of the leak if one were found, and to notify the owner. It does not indicate to check the oil tank for leakage at all. Without checking the main storage site for leaks this could be a big oversight of current or future problems of the system. The NFGC does not have any indication to check any of the oil delivery system for leaks, but this is due to the purpose of it being intended for gas appliances only.

In comparing the three nationwide methods, the BPI-1100-T standard with its supporting materials has the best leak checking procedures for both oil and gas. It has one oversight by not providing instructions on how to check storage tank leaks underground. The ACCA standard's gas leak test is accurate, but the oil leak test is also missing a key component by not checking the oil storage tank at all. The NFGC: Annex G is the most incomplete since it pertains only to gas appliances and is vague in its instructions.

1.2 Leak Testing: State Procedures

The three state procedures differ greatly in their instructions on how to leak test combustion equipment. Georgia's test procedure does not perform any form of leak testing which makes it the weakest out of the three. Midwest's procedure indicates that a gas leak test should be performed with a gas detector and repaired if a leak is found. The procedure does fall short by not leak testing oil based systems. The method in the West Coast procedure is the most complete out of the three methods. It includes detail instructions for testing for gas leaks by using both a gas detector and soap solution and it has an oil leak test method that checks both the fuel lines and storage tanks. The West Coast does not indicate ~~on~~ how to check for below ground storage tanks.

Out of the three state procedures, the West Coast method provides the most complete leak testing procedures. It includes both gas and oil combustion systems, but does not provide how to check for below ground oil tanks. The Midwest procedure covers how to check for gas leaks, but fails to look for oil leaks of any kind. Lastly, Georgia has no leak testing at all and it is recommended that it be re-written to include a leak testing procedure and provide the necessary remediation actions.

2. VISUAL INSPECTION OF APPLIANCE

Another step in evaluating combustion appliances for safety and performance is to visually inspect the appliance and its components. Visual inspection can be a good indicator of how the appliance has been operating and if any future problems may arise. However, in the field a detailed inspection of the appliance and its individual components may be difficult and time consuming. Thus, a trained technician will have to rely mainly on visuals clues and their knowledge gained from working with combustion appliances. For example, when inspecting a gas furnace and there are soot marks identified outside the normal combustion zone, this may indicate the flame is rolling out. Flame rollout is frequently caused by restriction in the flue gas passage. This fact may indicate that the heat exchanger flue is blocked and should be inspected and serviced if needed.

The individual components in the appliance should also be inspected for damage and abnormal wear as well. There are some common components between combustion appliances including burners, ignition system, and controls. These general components are typically included in a general statement to inspect the appliance. However, there are also appliances with unique components they may need identified in a method's instructions in order to ensure they are checked. Some examples include a damper in a gas fireplace, a relief valve on a boiler, or a condensate pipe on a condensing appliance such as a furnace.

A new item that needs to be added to all the inspection procedures is for the tester to look at the door seals of flammable vapor resistant water heaters and make sure the seals are intact and maintaining their integrity. The instructions should refer the tester to the installation and user's manual supplied with the water heater.

2.1 Appliance Inspection: Nationwide Method

The NFGC: Annex G is intended for central furnace and boiler installations only which limit the number of appliances it covers. The general components that are specifically checked during the procedure are the burners and crossover for blockage and corrosion. In order for the NFGC: Annex G to cover more appliances, it is recommended that the procedure included another general statement to check the ignition system. For furnace installations, the procedure calls out to inspect the heat exchanger, limit control, and fan control. A heat exchanger on an already installed furnace will be hard to inspect out in the field due to the unit being hard piped in and ductwork installed. Thus, the technician might have to rely on other clues for heat exchanger's condition. NFGC: Annex G fails to include checking the circulating air and combustion blowers. It does recommended that if a furnace is a condensing unit that the technician should inspect the condensate line for leaks and blockages. For a boiler installation the tank, water pump, controls, and relief valve are called out for inspection which includes all the major components.

BPI-1100-T's procedure includes both general and appliance specific inspection. Under the main body of text, it includes a general statement to inspect the combustion system. A trained technician should be able to use this guidance to inspect the most common components for a combustion appliance including burners, the ignition system, and controls. The appliance specific sections include water heaters, boilers, furnaces, and gas ranges. Water heater inspection only includes checking the relief valve and the safety discharge pipe. These are important components to ensure that they are in proper working condition, but it is advised that the procedure should also include checking the tank for leaks or damp spots. The boiler inspection also checks some major components including the relief valve, the tank for water leaks, and some boiler specific controls. However, this method leaves out to visually check the boiler's pump. Furnace inspection only includes inspecting the heat exchanger. Furnace inspections should include looking at the blower(s) and condensate piping (if equipped). Lastly, this method calls out to inspect the gas ranges burners. Since the method has already made a general statement to inspect the appliances, this statement may not be needed. No other appliances are mentioned which reduces the effectiveness of this procedure.

The inspection of the combustion appliances in the ACCA 12 standard is very limited. It does not provide any general instructions to inspect the combustion appliance. It only calls to identify the data plate information like the appliance's rate, name plate efficiency, etc. This is not a good practice since before any testing should be conducted the unit should be visually inspected in general to ensure proper operation. It does include some appliance specific inspections for water heaters and furnaces. It calls out to inspect the water heaters relief valve and tank for leaks. The furnace inspection includes looking at the blower assembly and condensate line if equipped. These specific component checks for water heaters and boilers would suffice if a general component inspection were included in this method.

None of the three nationwide methods include a complete appliance inspection protocol. The NFGC: Annex G provides both general and appliance specific component inspection. However, it is limited to only furnaces and boilers due to its purpose. The BPI-1100-T method includes the best component inspection protocols out of the other three methods. It includes both general and specific inspection instructions for four different appliances. The ACCA 12 standard is the most limited in inspecting appliance since it does not provide any general guidance and only includes two appliances. All three methods could be improved by including more appliance specific components to ensure that they are not overlooked during inspection. Also, the NFGC: Annex G and the ACCA 12 can both be improved by including more guidance in inspecting an appliance in general.

2.2 Appliance Inspection: State Procedures

Georgia's procedure is very general and only includes statements to "inspect the appliance". A trained professional should know to inspect the general components of an appliance with this statement. However, more unique components for individual appliances may be overlooked during the inspection.

Midwest's procedure for inspecting an appliance, besides ranges, is done as needed. If an appliance fails an operational test, the procedure then calls to inspect the appliance and provides remediation actions. Performing inspections in this manner can be dangerous since the appliance is never deemed safe for initial operation. The appliance inspections the Midwest procedure includes are for ranges, furnaces, boilers, and water heaters. Range inspections include looking at the burners and pressure regulator. For furnaces and boilers, the inspection mainly focuses on the burners and alludes to inspecting the furnaces circulating air blower. While for a water heater, the Midwest procedure focuses on the burners, relief valve, and discharge piping. Every appliance mentioned is missing some other key components inspection which makes this testing procedure less thorough.

The West Coast procedure includes a more detailed inspection compared to the other two state procedures. The general inspection includes looking at the burners, ignition system, controls, and overall appliance condition. It also provides remediation instructions if issues were identified with the burners. Appliance specific inspections include furnaces, boilers, water heaters, and gas ranges. Furnaces only include a heat exchanger inspection. Water heater inspections look at the relief valve and discharge pipe only. Lastly, the gas ranges' burners are inspected for condition. These inspection protocols miss a majority of the components of the various appliances and provide difficult field inspections of the heat exchangers.

Out of the three state procedures, the West Coast procedure provides the best appliance inspection. It includes a general inspection, also provides remediation actions, and five appliance specific inspections. However, the appliance specific inspections are not complete and it is recommended that it include the other major components and other appliances. Midwest's inspection is done as needed which can be dangerous since the appliance was never initially inspected. The procedure could be improved by adding a section to check the components and the appliance's overall condition before any testing is done. The Georgia procedure provides general inspection instructions, but has no specific component sections. It is also recommended that the Georgia procedure include a thorough appliance specific section to ensure nothing is missed during inspection.

3. VENTILATION SYSTEM CHECK

Proper ventilation is crucial in ensuring the safety of the occupants inside the residence. A ventilation system that is improperly installed could result in the appliance not operating properly or even cause it to backdraft. A ventilation system should be check for condition, piping arrangement, size, and pitch. Condition of the ventilation system is the first indicator if the system is operating properly. For example, if a ventilation system were corroding, it could be an indication that the pitch is wrong since water is collecting inside the vent piping. The type of ventilation will determine how the piping arrangement, size, and pitch affect the ventilation system. For an atmospheric vented appliance, the correct piping of the ventilation system ensures that the flow of the flue products is not hindered. Also, the sizing of an atmospheric vented system is important to make sure that there is enough capacity for the flue products to prevent back drafting and not too large such that the natural draft is reduced. For a direct and power vented appliance, piping and size is important to provide the adequate volume and resistance needed inside the vent stack. Lastly, correct pitch prevents water from building up in the vent system and helps to stop spillage for atmospheric systems. The correct piping, size, and pitch can be check against the manufacture's specifications or to local codes [2].

3.1 Ventilation Check: Nationwide Methods

All three of the nationwide methods include similar instructions to check the ventilation systems for condition and proper sloping. However, NFGC: Annex G is the only method that states to check the ventilation system for adequate sizing and proper piping arrangement. This may not be an issue for an atmospherically vented appliance since a secondary spillage test can be performed. From this spillage test, it can be a good indicator if the ventilation system is sized and installed properly. However, for a direct vent system, a spillage test is not performed which will provide a secondary check of the ventilation system. Thus, it is important to check the sizing and piping arrangement per the manufactures installation book to ensure the ventilation system is installed correctly.

3.2 Ventilation Check: State Procedures

The three state procedures provide different levels of detail when checking for ventilation system. First, Georgia's procedure states to check the ventilation system for condition and proper sloping, but fails to determine if the ventilation system is sized or piped properly. Both the Midwest and West Coast procedures include a detailed ventilation inspection of the piping arrangement, sizing, and pitch. They also refer to checking them against their corresponding codes. The Midwest mentions to check the current condition of the system while the West Coast procedure does not.

In comparing the three procedures, the Georgia procedure has the most incomplete ventilation check and can be improved by adding additional segments to include checking the sizing and piping against manufacture's specification and local codes. West Coast's procedure provides the next best ventilation check since it examines three out of the four categories and compares them to current codes, but it does not mention to check the condition of the system and a statement should be added to do so. The Midwest has the best ventilation check out of the three by including a detailed inspection of the ventilation and determines if it is in accordance to the proper codes.

Noted that there is no discussion in any of the above reference procedures that discuss the various venting process for category I, II, III, and IV classified products as to how the vent pipes are to be installed and what type of materials are acceptable. Also, none of the codes mentions to inspect the non-metallic vent system for signs of discoloration or sagging due to heat damage.

4. COMBUSTION APPLIANCE ZONE (CAZ) ANALYSIS

A CAZ is the connected spaces within a building that contain a combustion appliance. The zone may include, but not limited to, a mechanical closet, mechanical room, or the main body of the home [1]. For a combustion appliance to operate safely and efficiently it requires adequate combustion and ventilation air inside the CAZ. However, the CAZ can be affected by weatherization practices or after a home remodel. Thus, the CAZ should be analyzed and measured. To determine if the CAZ still provides enough air for the appliance, the measurements should be compared to local codes or Section 9.3 of the NFGC. It should be noted that direct vent appliances do not need combustion air from the CAZ since it is a sealed system that draws in air from outside. Also, any stored objects or boxes that may be obstructing the CAZ can limit ventilation air.

Also of note by the author is that sometimes the changing of the CAZ by the homeowner or a home remodeling company has resulted in accidents. Given these past issues, one would hope that the energy audit firms and energy audit procedures would post a notification or make note that any changing of the utility room, closet or other location where the combustion equipment is located should only be done after a thorough review of the combustion air requirements of the appliances installed in the CAZ.

4.1 CAZ Analysis: Nationwide Methods

Out of the three nationwide methods, the ACCA 12 is the only method that examines and measures the CAZ before testing. This is an issue for the other two methods since they do not provide an adequate check to see if the appliance is getting enough combustion and ventilation air. Other operational tests, like ignitions and CO check, may provide an indication if the appliance is getting enough air feed. Testing can be deceiving since it is usually done with the CAZ altered. For example, testing might be done with the door open to a furnace that is installed into a mechanical closet. Thus, it is recommended that these methods include a section to analysis the CAZ to ensure the unaltered CAZ is adequate for the appliance.

4.2 CAZ Analysis: State Procedures

All three state procedures include a section to check the CAZ for adequate air flow. Georgia's procedure calls to identify the CAZ and determine if additional combustion air is needed by a general rule of thumb of 50 ft^3 of open space per 1,000 BTU. This general rule of thumb comes from Section 9.3 of the NFGC for the minimum volume of air required [2]. Midwest checks to see if the CAZ is getting enough combustion air by determining if the CAZ is in accordance to local codes or to the NFGC if local codes are not present. The West Coast procedure calls to analyze if the CAZ is getting enough air through worst case depressurization testing. If it is found out that more combustion air is needed, it provides instructions for how to supply adequate combustion air to the CAZ. It is difficult to determine how one would determine if the CAZ was changed during worst case depressurization, but there may be some form of damper or other air inlet supply devices which may close during a depressurization, so a cursory inspection may be helpful.

Midwest's analysis of the CAZ is straight to the point by checking local codes for compliance to the correct code. The other two procedures have both pro's and con's such that neither makes one better or worse than the other. Georgia's procedure for CAZ analysis is simplistic and to the point. It can determine the minimum amount of combustion air required for the combustion appliance by using the rule of thumb set out by the NFGC. However, not all appliances may fall under this rule of thumb and that is where the West Coast procedure is better than Georgia's procedure. It provides detailed instructions on how to supply adequate combustion air for different situations. However, The West Coast performs CAZ analysis during testing and does not measure the volume. Performing the analysis this way may produce false results since the CAZ may be altered during the testing. Thus, the analysis of the CAZ should be done by measuring first and then performing operational test to verify.

5. DEPRESSURIZATION SETUP

To make sure that an appliance will operate safely and effectively, the appliance should be able to pass operational tests performed while under the worst possible scenario. In order to place the CAZ under the worse possible case it should be depressurized. Depressurization of a CAZ is the process in which the air flow leaving the CAZ is maximized. The general way this is done is by closing all exterior doors and windows, turning on indoor exhaust fans (bathroom exhaust, clothes dryer, etc.), and opening and closing the interior doors to produce the highest pressure difference between the CAZ and the outdoors. While under these conditions, the operational tests that should be performed include ignitions, CO testing, and spillage.

It is important to point out that a study conducted by the Lawrence Berkeley National Laboratory (LBNL) questions the effectiveness of worst case depressurization testing. In the literature review titled: *Assessment of Literature Related to Combustion Appliance Venting Systems*, the LBNL states three main points. First, the complexity in setting up a CAZ for the worst case scenario can be an issue. It was found that many technicians without the proper training and knowledge setup the worst case incorrectly. Thus, testing may produce false failures or passes during depressurization. Second, depressurization is not the only factor that will effect an atmospheric venting appliance. For example, weather can play a key role in how a draft is established in the flue vent. A flue vent of an atmospherically vented product may draft fine during the warmer periods of the year. However, during cold-weather months, the appliance may spill longer since the air inside the flue is colder and may require a longer time for it to heat up to establish a draft. Yet during colder periods of the year some venting systems will maintain a better draft in the off appliance cycle due to the temperature differential between the inside of the CAZ and the outside of the house. Lastly, even though depressurization may cause backdrafting, it may or may not be a problem; because of the probability of three factors co-existing may be rare. The three factors include the probability that the depressurization leads to backdrafting, the probability the combustion appliance is operating under depressurization, and the probability if backdrafting leads to an air quality problem when backdrafting and depressurization occur simultaneously. The last statement about air quality not being an issue when the unit is backdrafting during depressurization is an interesting concept. As the depressurization levels in the house start to increase, the depressurization will extract the pollutant air out through the exhaust fans and pull in fresh (clean) air from the outside. Thus, diluting the indoor pollutant concentration and staying below thresholds [13]. However, it is still believed by some that worst depressurization testing is worth doing, if properly setup, since it will reveal problems for appliances that are worst case offenders.

It is the opinion of our company that the relationship of the exhaust fans turned on during depressurization testing should be directed to the type of fuel burning equipment that would normally be in operation. As an example: It is not normal that a whole house fan be operating with the house heating systems in operation such as a furnace or space heater. Additionally, it would be very unusual to operate the whole house fan and solid fuel fireplace at the same time. Yet we would expect that the water heater may be in operation when a whole house fan and clothes dryer are in use and the same may be true for the decorative gas fireplace and the whole house exhaust fan. We see that the whole house fan may be the single largest device to cause depressurization and result in "failing" results but in reality the situation may be very unrealistic and if actually done would result in a cleansing of the indoor air as postulated by LBNL. It is normal to expect kitchen and bath fans to be in operation at any time of the year and thus may affect the heating equipment operation.

There is a question whether the depressurization is to be done with all appliances or only select appliances. It should be pointed out by these procedures that unvented products such as ranges or unvented room heaters do not need depressurization testing.

5.1 Depressurization: Nationwide Methods

NFGC: Annex G provides a general way to depressurize the combustion zone before testing. The procedure includes closing all doors and windows within the residence, turning on interior exhaust fans (excluding the whole house exhaust fan), and closing fireplace dampers if present. This procedure simplifies the depressurization process by only having one way to setup the home with all the interior doors closed. However, with all the doors closed it may not present the worst case scenario of depressurization inside the home. Also, the procedure does not mention to measure the CAZ depressurization.

The depressurization of BPI-1100-T's procedure is more involved than the NFGC: Annex G and includes measuring the pressure within the CAZ with respect to the outdoors. First, the exterior doors and windows are sealed and all combustion appliances are turned to their pilot or off setting. The baseline pressure in the CAZ is measured and recorded. Next, the worst case scenario is setup by turning on all indoor exhaust fans, closing any interior doors that make the CAZ pressure more negative, and turning on the air handler if the CAZ is further depressurized. During this worst case depressurization, the CAZ pressure is measured, corrected for the baseline pressure, and compared to allowable limits set out by BPI. If the appliance fails under worst case, the procedure calls to return the home to its natural conditions and retested. Double checking to see if the appliance fails under normal conditions ensures that there is an issue present.

ACCA standard 12 includes similar steps to depressurize as BPI-1100's procedure, but it does not measure and compare the CAZ depressurization to allowable limits. First, all the exterior doors, windows, and attic hatches are closed. Also, all "temporary" openings to the outside are sealed such as broken windows. Then, all combustions appliances are turned off or set to pilot setting. Next, the drain traps within the home are filled with water. Then, all indoor exhaust fans are turned on besides the whole house exhaust fan. Now, the air handler fan is turned on to see if the differential between the CAZ and outdoors becomes more negative. If not, the air handler is to remain off. Then, the interior doors of the home are opened and closed to find the highest pressure differential with the CAZ compared to the outdoors. Lastly, the fireplace damper is closed or a simulator placed into operation with the damper open.

The three nationwide methods vary in complexity for depressurizing the CAZ. The NFGC: Annex G provides the most basic depressurization setup. The simplicity of the procedure helps to save time and confusion when setting up the depressurization, but it may not provide the absolute worst case scenario. Without measuring the CAZ zone, it cannot be determined for certain that the CAZ is at its worst case depressurization. An additional statement could be added to measure the depressurization within the CAZ to determine the depressurization effectiveness. BPI-1100-T provides a more thorough, but complex depressurization procedure. If the setup is done correctly, it can produce the worst case scenario and the measurements taken can be compared to allowable limits. Comparing to allowable limits can give a good indication if the depressurization will be an issue. Lastly, the ACCA standard 12 has a similar complex setup as the BPI-1100-T's procedure. It provides more details such as sealing broken windows, filling up drain traps, and includes instructions to simulate a fireplace unlike the other two methods. A more thorough procedure is more likely to produce the absolute worst case, but can lead to a higher chance that a technician may perform the setup improperly.

5.2 Depressurization: State Procedures

Georgia's depressurization setup is the same as the nationwide procedure in the BPI-1100 method. It records a base pressure of the CAZ with respect to the outdoors after the home is sealed, the fireplace damper(s) is closed, and all combustion appliances are on their pilot setting. During the baseline readings, it provides additional information on how to record the pressure for open or enclosed CAZ's. Providing this information for the technician helps to ensure that the pressure reading is accurate. After the baseline pressure has been recorded, the worst case depressurization is established. All the interior exhaust fans are turned on, closing any interior doors that make the CAZ pressure more negative, and turning on the air handler if it further depressurizes the CAZ. The CAZ is measured again and corrected from the baseline reading. The corrected reading is compared to allowable limits setout be the procedure.

Methods used in the Midwest procedure to depressurize follow similar guidelines as Georgia's, but does not compare the CAZ measurements to allowable limits. First, the home is sealed by closing the exterior doors, windows, and fireplace damper(s). The procedure includes some additional checks to see if the furnace filter and dryer's lint trap are dirty. If so, they are to be cleaned or replaced. These additional cleaning steps help to ensure that air movement within the home is maximized when the blowers are turned on. Next, appliances are set to their pilot settings and the baseline pressure reading inside the CAZ is recorded. From here the worst-case depressurization is established. All interior exhaust devices are turned on besides the whole house exhaust fan. Interior doors are handled in a different way than the other procedures. They are to be all closed unless the room contains an exhaust fan with no supply register. If an exhaust fan is present, the door is closed and smoke is used to determine airflow within the room. If the smoke is pulled into the room, the door is to be opened and vice versa. Lastly, the air handler is operated to determine if it depressurizes the CAZ further. If not, it is to remain off. There is an additional section within the procedure regarding fireplace simulation during depressurization. It calls to simulate a fireplace if the residence has multiple combustion appliance zones.

West Coast's method is different than the other two state procedures. The depressurization within the CAZ is measured while the combustion appliances are turned on. Performing the depressurization in this way could be dangerous since the appliances could start backdrafting within the home. However, the procedure later mentions to monitor ambient CO levels within the home during depressurization and cease testing if levels exceed 20 parts per million. After the appliances are turned on, it follows similar depressurization practices as the other methods with corresponding measurements. Exterior windows and doors are closed and interior exhaust fans are turned on. The air handler is only turned on and kept on no matter its effects on the CAZ. Interior doors are only in one position, closed, which might not produce the highest negative pressure within the CAZ. Lastly, if a fireplace is present, it is to be simulated by a blower door. It should be noted that this procedure only calls for drafting to be tested while under depressurization and not ignitions or CO testing.

All three of the state procedures include decent depressurization setups, but vary slightly from one another. The Georgia procedure is the most precise method since it progressively measures how the changes to the home are affecting the CAZ. Also, it compares the final depressurization measurements to allowable limits which provides an indicator if the CAZ is likely to backdraft. However, it does fail to simulate a fireplace while the other two methods do. The Midwest procedure is very similar to Georgia's procedure, but it handles closing interior doors by a visual check of airflow using smoke and does not compare final measurements to allowable limits. Not measuring how the position of the interior doors affect the CAZ could result in incorrectly setting up the worst-case depressurization. Lastly, the West Coast procedure is the least effective out of the three. It provides a more simplistic setup by having the air handler on and the interior doors closed, but again this might not produce the worst-cast scenario. It is recommended that the procedure include varying the interior doors positioning and turning the air handler on or off to produce the worst-case condition. Also, the procedure would be improved if it included the ignition and CO testing to be done while under depressurization.

6. IGNITIONS

Following the depressurization setup, the first operational testing done on an appliance should be ignitions. Conducting ignition testing ensures that the appliance is lighting efficiently and the gas is burning in a safe manner. Ignitions include looking for flame rollout, carryover, & delayed ignition along with proper flame behavior including no floating, lifting, or flashing back of the flame to the orifice.

6.1 Ignitions: Nationwide Methods

The sections pertaining to ignitions for the NFGC: Annex G and BPI-1100-T methods are similar. Both procedures call to inspect the burners by checking for proper ignition and flame behavior. If the unit is not igniting properly, their remedial actions include cleaning the burners or adjusting the primary air shutter if applicable. The NFGC: Annex G goes beyond the BPI procedure by including additional information to check for proper pilot operation and provides instructions on how to run the ignition testing. Providing these additional items ensures a more thorough ignition test. The ACCA standard 12 on the other hand does not indicate to check for ignitions. This is a downfall to this standard since it could be missing key issues and can be improved by including an additional section for ignitions testing.

6.2 Ignitions: State Procedures

The state procedures vary from including no ignitions to covering a wide range of appliances. The Georgia procedure does not indicate to conduct any ignition testing on the combustion appliance. This can be an issue since the procedure could miss initial problems while proceeding with testing. It is recommended that the procedure add a section to check for proper ignitions and flame behavior to ensure adequate testing of the appliance. The Midwest procedure only includes a section to check ignitions and flame characteristics on ranges. Additional sections pertaining to other appliances would improve the Midwest procedure. West Coast procedure includes a general statement to check for satisfactory pilot operation and ignitions on all combustion appliances and burners should display hard blue flames. Although these are vague statements, a trained technician should be able to perform and diagnose ignitions under these instructions.

7. CARBON MONOXIDE (CO) TESTING

On average, about 170 people in the United States die every year from carbon monoxide (CO) produced by non-automotive consumer products, primarily gas appliances. Carbon monoxide is a colorless and odorless gas that is virtually impossible to detect with the human senses [6]. This makes carbon monoxide testing one of the most crucial evaluations when evaluating a gas combustion appliance.

CO testing can be a straight forward test out in the field. After the combustion appliance has started from a cold start, a sample of the flue products is taken at a set time with a handheld combustion analyzer and analyzed. From the value obtained, it can be determined if the combustion appliance is operating safely by comparing it to allowable limits. Also, it is advised to monitor the ambient CO levels while operating the appliance. Any testing should be stopped when the ambient CO limit has been reached. Currently, there is no agreed upon ambient CO limit for indoors. Thus, a procedure could use ambient CO limits set out by the National Institute of Occupational Safety and Health (NIOSH) or the American Conference of Governmental Industrial Hygienists (ACGIH) for work related CO limits.

The time at which the sample of flue gas should be taken can vary from appliance to appliance. For instance, when a range is tested by procedures set out in the American National Standard Institute (ANSI) Z21.1, *Household Cooking Gas Appliances*, the combustion sample is taken at five minutes [8]. While the procedures in ANSI Z21.47, *Gas Fired Central Furnaces,* flue samples are taken at three minutes and at fifteen minutes for the appliance operating at normal conditions [9]. For simplification purposes out in the field, a flue sample at five or ten minutes should suffice for all residential appliances.

The allowable limits of CO for appliances are different as well. Looking again at the standards ANSI Z21.1 and ANSI Z21.47, the allowable air-free CO can be up to 800 parts per million (ppm) for household cooking appliance such as ranges and 400 ppm for central furnaces, respectively [8][9]. However, the limits set by these standards are intended not only for normal conditions, but also for extreme testing criteria as well. Thus, the allowable limits for combustion appliances in the field should operate well below the thresholds noted above. Also, the standards call for the CO to be calculated on an air-free base to ensure that the CO recorded can't be masked by dilution air in order to pass the test set out by the standard. When a flue sample is taken in the field, the technician should do their best to capture the most undiluted sample as possible.

All gas equipment noted above can be tested by taking a sample of the flue gases as they enter the vent system with the exception of household cooking equipment and unvented log sets which have no vent system. For gas cooktops or the top section of a gas range, the test procedures do not require any pan to place over the burner. Simply taking a sample over each burner accomplishes very little in determining if the burner is performing satisfactorily. The procedure should be that a pan of approx. 6" to 8" in diameter and filled with 2" to 3" of water should be placed on each burner. The sample location of the top burners after the pan is in place is one that will need to be discussed by the appliance manufactures/auditors to ensure an accurate and uniform sampling. This more closely approximates the test procedure in ANSI Z21.1. For unvented gas log sets the sample should be taken approx. 10 inches above the highest open flame and along the full length of the log set to achieve an average reading of the emissions. This would approximate outlined in ANSI Z21.11.2 Unvented Room Heaters.

In good practice, a CO detector should be installed in every home with a gas combustion appliance or wood burning appliance. If there is not a CO detector installed, a proper procedure should recommend installing at least one to help ensure the safety of the occupants. Noted that most of the procedures recommend that CO detectors be installed in the dwelling that contain gas cooking equipment. The NFGC and Georgia were the only two procedures that did not include recommendations to install CO detectors.

On the other hand, oil fired equipment does not produce CO but soot/carbon is an issue and its production can lead to build of residue in the heat exchangers or vent system that can result in an internal fire. Thus, for any general comments noted in this discussion, soot checking of oil fired equipment should replace any discussion of CO testing in a gas appliance.

7.1 CO Testing: Nationwide Methods

A major downfall to the NFGC: Annex G is that it does not indicate to test appliances for proper combustion. It is highly recommended the procedure includes a CO testing section since it is a key component when evaluating any gas combustion appliance. It can help to determine if there are any issues with the appliances which could possibly save the lives of the occupants.

The BPI-1100-T method does include CO testing which is done under worst case depressurization and again under normal conditions if the unit fails while the CAZ is depressurized. A flue sample is taken when the appliance has reached steady-state or ten minutes after a cold start, whichever comes first. It can be difficult to determine when an appliance has reached steady-state out in the field. Thus, it is recommended for the procedure to only indicate a finite time to reduce confusion and ensure that the testing is done uniformly across all appliances. Using the sampling time of ten minutes stated by the procedure is reasonable and could accurately depict how the appliance is operating.

After the flue sample is taken and analyzed, the results are compared to action levels set out by the procedure shown in Table 1 [5].

Table 1. BPI-1100-T's Combustion Safety Test Action Levels

CO Test Results	And/Or	Spillage and Draft Test Results	Retrofit Action
0 - 25 ppm	And	Passes	Proceed with work
26 -100 ppm	And	Passes	Recommend that the CO problem be fixed
26 -100 ppm	And	Fails at worst case only	Recommend a service call for the appliance and/or repairs to the home to correct the problem
100 – 400 ppm	Or	Fails under natural conditions	<u>Stop Work</u>: Work may not proceed until the system is serviced and the problem is corrected
>400 ppm	And	Passes	<u>Stop Work</u>: Work may not proceed until the system is serviced and the problem is corrected
>400 ppm	And	Fails under any condition	<u>Emergency</u>: Shut off fuel to the appliance and have the homeowner call for service immediately

The actions levels presented are within reason and provide both proactive and reactive actions. It is good practice for the procedure to include proactive actions to help resolve issues before they become a bigger problem.

There are two separate action levels used for gas cook tops, ranges (this is top burners plus and integral oven) and ovens. The two action levels include a 100 to 300 ppm CO and anything over 300 ppm CO. The first action level indicates to install a carbon monoxide detector and recommend service. This action range is reasonable since ranges are known to usually produce higher levels of CO and it is highly recommend installing a CO detector with a gas burning oven. The last action level calls for the unit to be serviced. If the high levels of CO remain after service, an exhaust vent is to be installed that vents to the outdoors. With the higher levels of CO, it is a good idea to have a ventilation system for the oven. A cooktop ventilation hood would suffice. However, this is a not a permanent fix for ranges producing CO levels well above these levels. The procedure should include an additional action level to possible replace the oven or range if the high CO levels remain after service.

In addition, the procedure calls to monitor the ambient CO during all testing. It follows the recommended exposure limit set out by NIOSH of 35 ppm. This is a good idea to ensure that the technician and occupants of the home are kept safe.

CO testing done in the ACCA standard 12 breaks the appliance into their designated categories. It has four separate categories which include atmospherically vented appliances, direct vented appliances, unvented appliances, and gas ovens. All four sections indicate to take a combustion sample after at least five minutes and breaks up how to retrieve the sample for each unique category. For example, a sample of a gas oven is to be secured from within the oven vent. This added detail in the CO testing helps to ensure the CO testing is done properly. Also, the flue sampling time is reasonable.

The results from the CO testing are then compared to threshold limits listed in the NFGC, Table G.6. It breaks appliances into their own respected categories which only have one threshold limit for each. If an appliance were to surpass this threshold, the procedure calls to have the appliance serviced, notify the occupant, and deem the appliance unsafe until fixed. Gas ranges have separate limits that are the same as BPI's procedure. It includes two action levels of 100-300 ppm CO and anything greater than 300 ppm. The remedial actions are same with the first action level calling to service the appliance and install a CO detector. While the second, calls for service and an exhaust hood if high levels of CO are still present after service. Like the BPI procedure, it does not mention how to treat cases were gas ranges produce CO levels way beyond 300 ppm. Thus, the procedure could be improved by adding an additional action level to possible replace the oven if the high CO level remains after service.

Following safe work practice, this procedure does call to watch the ambient CO level while testing. It has two different levels. If the ambient hits nine ppm for more than fifteen minutes, the auditor has the discretion to stop all testing. Second, if the ambient CO level is over twenty-five ppm, the auditor should stop all testing without question.

With the NFGC: Annex G not including any CO testing, its procedure is the weakest out of the three for CO testing. It is recommended that the procedure should include an additional section for CO testing. Both the BPI-1100-T and ACCA Standard 12 have pro's and con's in regards to their CO testing methods and actions. Both methods continually monitor the ambient CO level while testing which helps to protect the technician and the occupants within the home. BPI-1100-T's procedure includes a generic testing protocol which can limit the effectiveness of the CO testing. However, it breaks down the results into varying action levels that are reasonable and provide both proactive and reactive responses. Providing both types of responses ensures current problems are fixed and future issues are resolved before they become a bigger problem. ACCA standard 12 includes more detail for testing different categories of appliance and then compares the results to the individual threshold limits set out by the NFGC. If the threshold is surpassed, the unit is deemed unsafe until the issue can be resolved. Using set thresholds limits the procedure to only being reactive to current problems. It is recommended that the procedure includes some proactive measures to try and resolve any future issues before they happen. Also, it is recommended that both methods include an additional action level for gas ovens producing CO levels higher than normal levels after servicing.

There is no testing of unvented room heaters in any of the three nationwide methods. BPI even goes as far to indicating that there should be no unvented room heaters in operation. The ACCA Standard 12 at least checks the unvented room heater to make sure it is listed under ASNI Z21.11.2 and makes aware of its presence. It is recommended that the other two methods check to see if the unvented room heater is listed to ANSI Z21.11.2 and ensure that and oxygen depilation sensor is present. It should also be noted that none of the nationwide methods include smoke testing oil fired appliances. This is an important assessment to ensure they are in working order and it is recommended that the methods include it in their procedures.

7.2 CO Testing: State Procedures

Testing for CO in the Georgia procedure is straight forward and simple. After the combustion appliance has been turned on, a sample of the flue gas is to be taken and analyzed after spillage and draft testing. It does not include a set time for when the sample of flue gas is to be taken. Not defining a set time may cause confusion and inconsistent results between appliances. From the testing, the results, including ranges, are compared to action levels that are the exact same as BPI-1100-T action levels shown in Table 1. The action levels stated provided actions within reason, but grouping gas ranges into these levels might not be sufficient. Since gas ranges produce higher levels of CO but operate for shorter periods of time, it is recommended they have a separate category on how they are handled. The procedure does call to check the ambient CO level, but only before any testing has begun. By not measuring the ambient levels constantly, the technician may be putting themselves into harm's way and not know it.

CO testing for the Midwest procedure is broken out into three separate categories. The categories include furnaces and boilers, water heaters, and ranges. Each of the testing procedures varies for each one. It should be pointed out that although these are the most common household appliances, the procedure does not include how to test other combustion appliances not listed. This is a downfall in providing a more detail approach to combustion testing for these individual categories. In the furnace and boiler section, CO testing is done under the worst-case depressurization and a flue sample is taken when the appliance has reached steady-state. Again, steady-state determination in the field might be hard to determine and it is recommended that the procedure includes a time frame to ensure consistent testing for each appliance. From the measured CO reading, it is compared to the allowable limit of 100 ppm set out by the procedure. If the reading is above 100, the unit is to be cleaned and tuned to try and lower the CO emissions. The procedure suggests replacing of the unit if unable to lower CO levels. Ambient CO levels are monitored and the technician is to stop testing when the CO level reaches 10 ppm.

Testing water heaters includes the same basic procedure, but the time at which the sample is taken is specified at two minutes. Two minutes might not be long enough for the appliance to operate normally and may produce false failures. It is recommended that the procedure allow more time, at least 5 minutes, before a flue sample is taken. The allowable CO limit set out by the standard is 100 ppm for water heaters. If the CO limit is surpassed, the procedure uses the same remedial actions as furnaces and boilers. However, the ambient CO emissions are not measured during water heater testing. It is strongly recommended that they are to protect technician and occupants of the home.

Emission testing for ranges includes a more thorough approach by not only testing the oven, but by also tests the top burners as well. Also, the ambient CO levels are monitored throughout testing and have a stop work limit of 20 ppm. Top burner testing can be difficult in the field since it is hard to capture an adequate representation of the flue gas. In this procedure, the top burner emission is captured six inches above the burner which could possible provide false readings. As stated above, the top burners should have a 6”-8” pot placed on the burner to more accurately represent testing done in ANSI Z21.1. . There are three action levels to be taken as show in Table 2 [12].

Table 2. Midwest’s Action Levels for Range Top Burners

As Measured CO PPM	Measuring Time	Action
< 25 PPM	After 4 minutes of operation	Should be cleaned by client to prevent possible CO problems.
25 to 50 PPM	After 4 minutes of operation	Have appliance serviced.
> 50 PPM	After 4 minutes of operation	Appliance should not be used until either repaired or replaced.

The lower emission levels compared to other appliance are reasonable since the amount of dilatation air that will be capture will be a lot higher. A four minute sampling time is close to the five minutes the ANSI standard calls for combustion readings for ranges and should suffice. The action levels also present both proactive and reactive measures. The range tops are to be cleaned even if there are no issues which help to prevent future problems.

Oven testing listed in the Midwest procedure are different than the other methods. One difference from the other methods is it only pertains to testing the bottom burners within the oven cavity and omits testing to be done on broilers. Although broilers are normally only used for short periods of time, they can produce high levels of CO and should be checked if they are working properly. A second difference is the time at which the sample is taken. For this procedure, the flue sample is taken after 15 minutes of operation. The longer sample time may more accurately depict how the range will operate normally since the oven is usually on longer than 15 minutes. However, the CO emissions should clear up in a much shorter time period. If they do not than there is likely to be an issue with the unit. Lastly, the varying degrees of action levels are higher than the other methods, as seen in Table 3 [12].

Table 3. Midwest’s Action Levels for Range Ovens

Air Free CO PPM	Measuring Time	Action
< 800 PPM	After 15 minutes of operation	Should be cleaned by client to prevent possible CO problems.
800 to 1000 PPM	After 15 minutes of operation	Have appliance serviced.
> 1000 PPM	After 15 minutes of operation	Appliance should not be used. Replace appliance.

The reason the actions levels are higher is the fact that the CO emissions are measured on an air free bases. Even with that fact taken into account, the actions levels are still high. If an oven is operating anywhere near the 800 ppm threshold, it should be recommended that the appliance be cleaned and serviced. An oven operating above 800 ppm should not be used and replaced if the issue cannot be resolved.

The procedures set out by the West Coast method for CO testing are vague and have no instructions to test under worst-case depressurization. There are two separate sections one for heating appliances and one for gas ranges. In the section for heating appliances, there is a generic statement to take an undiluted sample of flue gas. There is no indication of when to take the sample whether it is at steady-state or a finite time. Again, no indication of when to take a sample can produce inconsistent results. From the measured CO emissions, the general allowable limit for all appliances set by the procedure is 100 ppm. If the appliance surpasses this limit, the burners are to be serviced and adjusted. Gas ranges include similar instructions, but are broken into two parts for the top burners and oven. Emission samples of the top burners are taken eight inches above the flame and have an allowable CO limit of 25 ppm. Ovens only have an allowable limit of 100 ppm which is relatively low compared to the other methods. Due to the normal operation of gas ovens, a 100 ppm allowable limit may be unrealistic and it is recommended that the procedure increases the allowable limit. Ambient CO levels are only stated to be measured during gas oven testing. The only possible justification for stating that only the oven be tested for ambient air is that generally the oven is operated for a longer period of time in an unsupervised mode. Depending upon the appliance one cannot say with certainty whether the oven or the top burners will produce the higher CO concentration than other appliances. Therefore, it is recommended that ambient CO levels be measured during all testing.

There are both pro's and con's to all three state procedures. Both the Georgia and West Coast procedure do not indicate a finite time at which emission samples are taken. It is recommended that they include a designate time in order to produce more consistent results between appliances. All three procedures compare the measured results to allowable limits and include remediation actions. However, the Georgia procedure and the gas range section of the Midwest procedure include proactive remediation actions. It is recommended that the other procedures include additional action levels to help prevent future problems. Lastly, all three procedures include monitoring ambient CO levels in some degree. However, the Midwest procedure is the only one to constantly measure the ambient CO levels throughout testing. It is recommended that the other two procedures do the same to ensure the safety of the technician and the occupants.

Similar to the nationwide methods, there is no testing of unvented room heaters in any of the three state procedures. Both the Midwest and West Coast indicate that there should be no unvented room heaters in operation or weatherization shall not occur. It is recommended that the methods do not deny weatherization, but ensures that the appliance safely operates after weatherization. At least the three procedures should check to see if the unvented room heater is listed to ANSI Z21.11.2 and ensure that and oxygen depilation sensor is present. It should also be noted that Midwest and West Coast are the only procedures out of the six to include smoke testing oil fired appliances.

8. SPILLAGE TEST

Along with CO testing, testing for spillage of flue products into the living space is an important safety test for atmospherically vented products, i.e. draft hood equipped, such as most water heaters, room heaters, floor furnaces, etc. If an appliance were to spill flue gases for an extended period of time, the CO released could possible harm or even kill the occupants within the residence. Even a product that is spilling flue gases with low levels of CO at the beginning of the spill process may over a period of time start to experience an increase in CO as the CO_2 builds up near the appliance and reduces the oxygen content of the combustion air supply.

The type of appliance will determine how the spillage test should be conducted. The procedure for testing atmospheric appliances for spillage is done by placing a smoking item such as a smoke stick, extinguished match, etc. around the relief openings, barometric dampers, and vent connections to determine the air flow direction. For relief openings, the smoke should be pulled into the opening and out the flue stack after a set amount of time. For vent connections incorporating barometric dampers, there should be no sign of flue gases escaping during any time the appliance is in operation. Spillage test for appliances with a sealed flue (such as all furnaces manufactured since the mid-1980s) should be tested for leakage around vent connections. The vent system may be either pulling room air in due to bad connections or rusted out flue pipes; or if may be forcing products out the breeches if there is also some form of downstream vent restriction such as at the exhaust terminal. Additionally, the area around the burner entrance into the heat exchanger should also be checked on both atmospherically and power vented products to make sure no combustion products are spilling back into the control compartment of the appliance or living space.

Also, spillage test done out in the field should be tested while under the worst-case depressurization to ensure that the appliance still vents properly under extreme circumstances.

It is expected that for atmospheric and induced appliances with a barometric damper to spill when it is first started it would be due to the air inside the ventilation system being cold. After the air has begun to heat up, it will start to rise through the vent and begin drafting the flue products. The time in which it takes for this to occur can depend on a number of issues such as the differential between the indoor and outdoor temperature, outside wind conditions, etc. For field testing purposes, the set time in which the appliance should start drafting is not agreed upon. During certification testing, a gas fired water heater equipped with a draft hood has 15 minutes for spillage to stop under the provisions in ANSI Z21.10.1 [7]. This time limit of 15 minutes is fairly uniform in most appliance standards for laboratory test purposes but the test is conducted at the worst case scenario with the minimum height/length vent stack permitted in the NFGC. Fifteen minutes is a relatively long time for an appliance to stop spilling in a real world field installation and a more realistic number in which an appliance should stop spilling in the field should be shorter. The NFGC Section 11.6 for draft hood-equipped appliances indicates that spillage should stop after five minutes of operation which is a more realistic number [2]. If an appliance would spill any longer than five minutes then there is most likely an issue with the appliance or ventilation system.

Constantly monitoring the ambient CO levels during this test is also important, because appliances may fail the spillage test which could pollute the CAZ. The amount of spillage could possibly be harmful and the procedures should set out allowable limits for the testing to be stopped if they are surpassed during the specified warm up time chosen.

8.1 Spillage Test: Nationwide Methods

All three of the nationwide methods include spillage test while under depressurization. However, they differ in the amount of detail they provide. NFGC: Annex G includes testing for spillage at the draft hood with smoke or a flame after five minutes of operation. The testing is done while the appliance under inspection is operating alone and then with all other appliances in the CAZ operating simultaneously. Repeating the test while the other appliances are operating ensures that they are not interfering with the appliance's ability to induce a draft within the vent stack. There are no remediation instructions included in the NFGC: Annex G along with any instructions to monitor the ambient CO levels. It is recommended that it should include additional statements which provides remediation and instructs to monitor CO levels for technician safety.

Both BPI-1100-T and ACCA standard 12 procedures includes a more complete spillage test. They provide a set time in which the spillage should stop at the draft hood, how to test with multiple combustion appliances present, remediation actions, and ensure the ambient CO levels are constantly monitored during testing. However, the two methods indicate different times in which the appliance should stop spilling. The ACCA standard 12 indicates five minutes in which the spillage should stop which is the same as what is set forth by the NFGC Section 11.6. The BPI-1100-T procedure on the other hand only allows one minute for the spillage to stop. Allowing only one minute for spillage to stop seems extreme and will probably present false failures especially when during the time of year when the vent stack is colder. Thus, it is recommended that the method increases the allowable time to five minutes to provide a more reasonable acceptance rate. However, all three methods fail to mention to check for spillage in other locations besides the draft hood. It should be recommended that the procedures check other possible leakage sites on the appliance and the ventilation system for leaks.

In comparing the three methods, the ACCA standard 12 provides the most complete procedure. The BPI-1100-T procedure is second strongest out of the three. It includes the three main parts by determining spillage, providing remediation instructions, and monitoring the ambient CO levels. However, the procedure sets forth an unreasonable time for the spillage to stop by one minute. It should be revised to allow for a more reasonable stoppage time of five minutes. The NFGC: Annex G provides the weakest spillage test. It does provide instructions on how to test multiple appliances and provides a reasonable stoppage time, but it lacks ambient CO monitoring and provides no remediation instructions.

8.2 Spillage Test: State Procedures

Out of the three procedures, Georgia and the Midwest are the only ones to include a spillage testing procedure. The West Coast procedure only has a vague statement to check for spillage and skips to measuring the draft within the ventilation system. Draft testing will be discussed further in the next section. The rationale behind doing this might be that by determining the draft it will indicate if the appliance will have spillage or not. However, there are cases in which atmospheric and induce draft appliance can produce the adequate amount of draft, but still have spillage. One example includes when a vent stack is sized to small. The appliance can produce adequate draft inside the vent stack, but since the vent stack is not big enough the flue products will spill into the CAZ. Another example includes when the appliance produces too much draft, known as updraft. When this occurs, the appliance will pull in more dilution air into the flue than flue gas which traps the flue gas inside appliance causing spillage at other locations. Thus, it is recommended that the West Coast procedure ensures the spillage testing is being done.

Both Georgia's and Midwest's spillage test are similar to one another. They both include instructions on how to test spillage with multiple combustion appliances in the CAZ and provide remediation actions. However, they differ in the amount of time the spillage can stop. The Georgia procedure allows only one minute for the spillage to stop while the Midwest procedure allows only two minutes. Again, with the allowable times below five minutes the test could possible indicate false failures. Thus, it is recommended that they indicate at least five minutes for the spillage to stop. The two procedures also differ in how they monitor the ambient CO levels. As in the CO testing, the ambient CO for the Georgia procedure is only determined before any testing is conducted and not during. Without monitoring the CO levels constantly, the spillage testing could be putting the technician into danger without them knowing. The Midwest procedure does better and constantly measures the ambient CO levels helping to protect the technician. Lastly, both procedures fail to mention to check if spillage is occurring in other areas including vent connections and other relief openings. Both procedures would be improved if they include more instructions to check these additional areas.

9. DRAFT TESTING

For atmospheric and induced draft appliances, an additional draft test should be conducted. Measuring the draft within the ventilation stack checks to ensure there is a driving force exhausting the flue gas to the outside. The driving force for these appliances is a negative pressure within the venting system. For draft testing, the net pressure is determined by comparing the pressure within the vent stack with respect to the CAZ. From this pressure reading, it is compared to acceptable draft ranges which depend upon the outside temperature. An additional benefit to draft testing is it will give a better idea of what is happening inside the ventilation system by providing a physical measurement. This can help to troubleshoot spillage and draft issues since it can be seen how remediation to the flue has affected the draft of the appliance.

9.1 Draft Testing: Nationwide Methods

BPI-1100-T is the only nationwide method that includes draft testing in addition to performing spillage testing. The draft is measured under worst-case depressurization and if the appliance fails it is retested under normal conditions. If the measured draft is more positive then the allowable limit, it fails the draft test. From the results of the test, it is compared along with the CO testing to determine the appropriate action as based in Table 1. Measuring the draft provides an additional check which can show quantitatively that the appliance is indeed drafting acceptably. Also, a draft test can provide a way to troubleshoot venting issues since it can be seen how changes to the venting system have affected the appliance's operation. It is recommended that the other two nationwide methods include a draft section to help with fixing draft issues.

9.2 Draft Testing: State Procedures

All three of the state procedures include measuring the draft of an atmospherically and induced drafted appliance. Both Georgia and the Midwest use the draft test as a second check for how the appliance is operating. While the West Coast procedure only uses draft testing by itself. A draft failure would be if the draft pressure inside the flue is more positive than the ranges listed in the procedures. Georgia's procedure includes remediation based upon Table 1, while the Midwest and West Coast procedures both provide more detailed remediation actions including checking previously stated sections like ventilation or combustion air.

10. EFFICIENCY TESTING

Efficiency testing can be helpful to understand how a combustion appliance is performing in the field. Efficiency tests done in the field are limited though, because certain parameters, such as jacket lost, are hard to assess. A simpler “combustion” efficiency can be calculated which is the measurement of how effectively the fuel is turned into usable energy. The calculation for combustion efficiency is the fuel input minus stack losses. In which stack lose refers to the wasted heat, unburned fuel, and excess air that is carried away in the flue gas. Most hand held combustion analyzers are able to calculate the combustion efficiency by measuring the concentration of the gases in the flue along with the flue temperature [15]. A technician can use this information to help determine issues and how to improve the operation of the appliance.

The Midwest procedure approach to determine if an appliance is operating efficiently is to analyze the flue gas for stack temperatures and flue gas composition. In general, a lower stack temperature is desirable because it indicates that the appliance is operating more efficiently since more heat is being transferred to the heating medium and not going up the flue stack. The analysis of the flue gas composition should be compared to the acceptable valves set by the procedure.

The time of appliance operation before an efficiency reading is taken can play a key role in obtaining reliable data. At a minimum most appliances should be in operation for 15 minutes before a reliable value can be obtained. Additionally most combustion analyzers that calculate efficiency require the operator to step through a process of calibrating the instrument for the proper fuel gas (natural gas, LP gas, oil, etc.) and any recommended test procedure should defer to the instrument makers instructions.

10.1 Efficiency Testing: Nationwide Methods

None of the nationwide methods provided any detail instructions for efficiency testing. The only method that vaguely states to test for efficiency and performance is the BPI-1100-T method. It is recommended that all three methods include thorough efficiency testing. Performing efficiency testing will help in evaluating how the appliance is operating in order to improve its performance.

10.2 Efficiency Testing: State Procedures

The Georgia procedure does not include efficiency testing in its protocol, but the Midwest and West Coast procedures do. However, both of the procedures limit themselves to only a few appliances. Midwest testing procedure is by far the most complete by providing background information and how to setup and run the test for furnaces and boilers. The setup procedure includes calibrating the handheld analyzer and determining where the flue sample should be taken for different types of furnaces and boilers. When the unit is ready to be tested, it is turned on and operated until the flue gas temperature has stabilized (steady-state condition). Once steady-state has been reached, the net stack temperature and flue composition are measured. From these measurements, they are compared to the acceptable values set out by the procedure. Table 4 below shows the acceptable values listed by Midwest's procedure [12].

Table 4. Midwest's Acceptable Combustion Test Values for Furnace & Boilers

Heating Unit Type	Oxygen (O_2)	Carbon Dioxide (CO_2)	Net Stack Temperature
Gas			
Atmospheric	4 – 9%	Natural 9.6-6.8% LPG 11.2 – 7.8%	300-600 ^{o}F
Fan-assisted	4 – 9%	Natural 9.6-6.8% LPG 11.2 – 7.8%	300-480 ^{o}F
Condensing	See man. Info.	See man. Info.	See man. Info.
Standard Power Burner	4 – 9%	Natural 9.6-6.8% LPG 11.2 – 7.8%	300-650 ^{o}F
Oil (No. 1 & 2)			
Oil gun burner	4 – 9%	12.5 – 8.8%	325-600 ^{o}F
Flame Retention Burner	4 – 7%	12.5 -10.3%	325-600 ^{o}F

If the tested appliance does not fall within these ranges, it is to be cleaned and tuned accordingly.

A fundamental issue with the above chart is that the flue gas temperature of vented equipment should be no more than 480^{o}F plus room temperature (or about 540^{o}F) due to limitations on flue pipe installations near combustible surfaces. The only exception are generally for direct vent heaters incur[orating concentric vent pipe systems (exhaust pipe within a inlet air pipe) usually employed with small gas room heating and gas fireplace equipment and some manufactured home types of furnaces where the manufacturer supplies the vent system. Therefore some reconciliation of the chart needs to be done if temperatures to 650^{o}F are mentioned for gas equipment.

The West Coast procedure includes similar instructions to analyze the flue gases for temperature and compositions. Then, it compares them to acceptable ranges similar to Midwest's acceptable values. However, the procedure only indicates to test furnaces that run on oil. Interestingly, the procedure provides acceptable combustion ranges for gas furnaces as well, but does not indicate to test for efficiency for gas-fire furnaces.

It is recommended that all three procedures revise their efficiency testing. The Georgia procedure should add a section for efficiency testing by either testing for combustion efficiency or flue gas analysis. Both the Midwest and West Coast procedure should expand their efficiency testing to appliances other than just furnaces and boilers and included vented space (room) heaters.

OVERALL EVALUATION

11.1 National Fuel Gas Code 2012 (Annex G) Evaluation

The NFGC: Annex G is a rather simple and straight forward method. The method includes leak testing, limited component and ventilation inspection, testing ignitions, and ensuring the appliance does not spill flue products. The simplicity is a benefit for this method since it can be performed in the field with relative ease and does not need specialized equipment including a CO analyzer or a digital manometer. It is limited to gas appliances due to its purpose and was mainly intended for testing furnaces and boilers, but the method does not include key safety and performance evaluations. The method does not analyze the CAZ, measure the CO levels, or include any efficiency testing. The biggest downfall out of these three is not performing CO testing. It is one of the most important things to ensure that the appliance is operating properly and that dangerous CO levels are not being produced.

11.2 BPI-1100-T Evaluation

The BPI-1100 method provides a more thorough testing protocol for evaluating combustion appliances. However, the main body of BPI-1100-T is vague and requires one to dig into the supplemental documents for more detailed instructions for testing. This method does well in testing for CO levels by measuring both appliance and ambient levels. It provides both proactive and reactive remediation procedures for CO related issues to ensure that the appliance will operate and continue to operate in a safe and effective manner. Also, it includes draft testing that the other methods do not. The component inspection is lacking though since it mainly focuses on the burners themselves while not providing instructions to check other various safety devices. The CAZ is also not properly analyzed and the efficiency testing is vague.

11.3 ACCA Standard 12 Evaluation

The ACCA standard 12 includes most of the important elements for evaluating combustion appliances, but leaves out a number of items that should be field evaluated. The method does well by including a leak testing procedure that provides a double check with a gas detector and soap solution. Also, it includes analysis of the CAZ and provides detail instructions to setup and measure the worst-cast depressurization to ensure it is done properly. The CO testing is thorough as well by providing threshold limits in which the unit should operate within. If the appliances surpass these thresholds, it includes remediation actions to fix the issues. The method does fall short by limiting its appliance and ventilation inspection to the basics and not including any ignition work. Ignitions can be the first indication if the appliance is operating properly or not. Also, it checks for the spillage of flue gases, but does not include any secondary checks to measure the draft within the flue. Lastly, the method does not include any kind of efficiency testing.

11.4 Georgia Evaluation

Georgia's procedure for evaluating combustion appliance is laid out to where it can easily be followed and covers most of the topics discussed in this literature review. The procedure does a decent job in performing the tests with some minor issues. For example, during CO testing, there is no set time in which a flue sample should be taken. By not providing a set time the testing between units will be inconsistent and may produce false failures or passes. The procedure does have more significant deficiencies by not including leak detection, ignitions, or efficiency testing. Also, the appliance inspection is vague which could possible lead to components being overlooked.

11.5 Midwest Evaluation

The Midwest procedure includes all of the ten sections discussed. The testing procedures are fairly easy to follow since the appliances are broken out into separate categories with corresponding sections. However, some sections provide adequate testing procedures while other sections are limited or missing information.

First, the leak testing includes gas appliances, but does not discuss checking oil appliances. Next, appliance inspection is done more as an afterthought than as a separate testing section. If the unit were to fail an operational test, the procedure would then backtrack and look at the appliances components. However, one of the few sections that provide adequate information is the ventilation check. The depressurization setup is decent, but lacks checking the depressurization measured to allowable limits. While ignitions only include ranges which could possibly skip ignition issues with other appliances. The CO testing is done fairly well by providing limits and ensuring ambient CO levels are constantly monitored. The spillage and draft are both determined which provides a double check in ensuring the flue gas is being vented properly. Lastly, the procedure does well in testing for efficiency, but is limited to only furnaces and boilers.

11.6 West Coast Evaluation

West Coast's procedure includes a majority of the sections discussed, but most of them fall short of providing adequate information to properly test combustion appliances. Also, the tests are buried in the text which makes it hard to follow and perform. The procedure starts off well by providing decent leak testing, appliance inspection, and ventilation system check for combustion appliances. It starts to begin to fall short when it gets to CAZ analysis. The CAZ is never measured, but determines if the CAZ has enough combustion air through other testing. This could provide false positives since during testing the CAZ could be altered. Depressurization setup is also different than any of the other procedure by initially starting the appliance and then starts the depressurization process. Also, the only test that is run under depressurization is the draft test. Not performing ignitions and CO testing while under depressurization does not ensure that the appliance will perform safely under the most extreme conditions. Both the ignitions and CO testing are vague and do not provide enough details to test consistently and efficiently. Spillage testing is skipped completely and the procedure goes directly into draft testing. Skipping the spillage test could be missing key issues with the appliance that could be harmful or even deadly for the occupants. Lastly, the procedure does include efficiency test, but is limited to only oil furnaces.

METHOD RANKINGS

12.1 Nationwide Methods

All of the nationwide procedures include both pro's and con's in their testing protocols. The NFGC: Annex G is a simplistic in nature which makes it an easier testing protocol. However, the simplicity limits the method and this is where the other two methods excel. Both the BPI-1100-T and the ACCA standard 12 include more detail and more testing procedures than the NFGC: Annex G. The ACCA standard 12 does fall behind the BPI-1100-T procedure by lacking ignition and draft testing. Out of these three nationwide methods, BPI-1100-T's procedure would be the strongest since it provides the most adequate testing procedures out of the three. Then, the ACCA standard 12 would be the next best since it includes a majority of the tests minus a few key components. The NFGC: Annex G would be the least effective since the procedure is limited and missing major components like testing for CO levels. However, it is limited due to the fact the NFGC method is intended for gas appliances only.

12.2 State Procedures

The three state procedures include most of the topics discussed, but vary in the degree in which they are explained and implemented. Georgia's procedure does well in the procedures it lays out, but fails to include leak testing, ignitions, and efficiency testing. The Midwest includes all the sections in questions although some of the sections are limited and missing information. Lastly, the West Coast procedure includes a majority of the sections, but the information provided is not enough. Each of the procedures has their benefits and their drawbacks which makes ranking them difficult. However, if they are to be ranked, the Midwest procedure would be the best out of the three since it includes all of the sections but with some issues. The second best procedure is the Georgia's procedure since it can be followed easily and includes a majority of the test with minor issues. The West Coast procedure would be the weakest out of the three since most of the sections included do not provided adequate information in evaluating combustion appliances.

CONCLUSION

The three nationwide methods vary and each of them has their own strengths and weaknesses. The NFGC: Annex G is a simpler method that can be ran with relative ease, but does not include some key testing. ACCA Standard 12 has a more detailed approach which provides a more thorough testing protocol. However, it also does not include all the necessary testing and information to properly evaluate a combustion appliance. Lastly, the BPI-1100-T method also includes a majority of the tests with detailed instructions. Some sections that are vague, but overall it provides a better approach to testing combustion appliances than the other two nationwide methods.

The state procedures also vary in the way they evaluate combustion appliances. All of them include a majority of the topics in question, but some of the procedures are missing information or will not produce accurate results. Georgia's procedure is most technician friendly by providing an easier format while including seven out of the ten topics. Both the Midwest and West Coast provide more information which helps to understand how the appliance is possibly being effected and why the tests are being run. However, the West Coast procedure buries the testing methods within the extra detail which makes it hard to follow and a majority of the sections do not provide the proper information. This makes the Midwest procedure the best out of the three state procedures.

After evaluating all the methods and procedures listed, it can be seen that none of them provide a complete protocol that adequately covers evaluating a combustion appliance in the field. Does this mean there should be a new procedure developed and implemented? No. By making changes to the issues outlined in this literature review, most of these procedures can properly evaluate a combustion appliance installed in a residence. However, some procedures will never be able to cover all the topics since they are limited because of their scope. Whichever method is chosen though, it should include at least the ten sections outlined in this literature review.

It is believed that having a number of independent procedures is not the best approach for the public but rather the authors of all the procedures need to update and upgrade their procedures to a minimum common level. It is difficult to understand why there are deviations amongst the most common of field evaluation procedures other than to say that the authors where not thinking in a broad enough venue and that they lacked experience in the full range of combustion appliances available to the North American public.

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Appendix

Section numbers below refer to basic report section numbers		**National Guides**			**State Guides**		
Note: A " –" in the space means that no reference to the subject could be found in the code and a "Yes" means coverage was found.	Specific Issues	**NFGC-2012 Annex G (1)**	**BPI-1100-T (2)**	**ACCA Std 12 (3)**	**Georgia (4)**	**Midwest (5)**	**West Coast (6)**
	Sec 1: LEAK TESTING						
	Conduct a Gas Leak test	**Yes**	**Yes**	**Yes**	**-**	**Yes**	**Yes**
	Leak Test with a Leak Detector	**-**	**Yes**	**Yes**	**-**	**Yes**	**Yes**
	Leak Test with a Soap Solution	**-**	**Yes**	**Yes**	**-**	**-**	**Yes**
	Conduct an oil leak test	**-**	**Yes**	**Yes**	**-**	**-**	**Yes**
	Leak Test Fuel Lines	**-**	**Yes**	**Yes**	**-**	**-**	**Yes**
	Leak Test Above Ground Tank	**-**	**Yes**	**-**	**-**	**-**	**Yes**
	Leak Test Below Ground Tank	**-**	**Yes**	**-**	**-**	**-**	**Yes**
	Detail How Test Above Ground Tank	**-**	**-**	**-**	**-**	**-**	**-**
	Detail How Test Below Ground Tank	**-**	**-**	**-**	**-**	**-**	**-**
	Check for Water in Oil Tank	**-**	**-**	**-**	**-**	**-**	**Yes**
	Sec. 2: VISUAL INSPECTION						
	Inspect before testing	**Yes**	**Yes**	**Yes**	**Yes**	**-**	**Yes**
	Inspect as part of testing	**-**	**-**	**-**	**-**	**-**	**-**
	Inspect as needed only	**-**	**-**	**-**	**-**	**Yes ***	**-**
	Inspect by dataplate review	**-**	**-**	**Yes**	**-**	**-**	**-**
	Inspection of specific products is specified?	**Yes**	**Yes**	**-**	**-**	**Yes**	**Yes**
Specific Products Covered							
Furnaces	Addressed specifically in code	**Yes**	**Yes**	**-**	**-**	**Yes**	**Yes**
	Overall appliance condition	**-**	**-**	**-**	**-**	**-**	**Yes**
	Heat Exchanger	**Yes**	**-**	**-**	**-**	**-**	**Yes**
	Combustion air blower if equipped	**-**	**-**	**-**	**-**	**-**	**-**
	Circulating air blower	**-**	**-**	**-**	**-**	**Yes**	**-**
	Combustion system	**Yes**	**Yes**	**-**	**-**	**-**	**-**

	Burners	**Yes**	**Yes**	**-**	**-**	**-**	**-**
	Crossovers	**Yes**	**-**	**-**	**-**	**-**	**-**
	Condensate lines	**Yes**	**-**	**Yes**	**-**	**-**	**-**
Boilers	Addressed specifically in code	**Yes**	**Yes**	**-**	**-**	**Yes**	**Yes**
	Overall Appliance condition	**-**	**-**	**-**	**-**	**-**	**Yes**
	Relief Valve	**Yes**	**Yes**	**-**	**-**	**-**	**-**
	Control Components	**Yes**	**Yes**	**-**	**-**	**-**	**-**
	Water leaks in tank	**Yes**	**Yes**	**-**	**-**	**-**	**-**
	Circulating pump	**Yes**	**-**	**-**	**-**	**-**	**-**
	Combustion system	**Yes**	**Yes**	**-**	**-**	**-**	**Yes**
	Burners	**Yes**	**Yes**	**-**	**-**	**-**	**Yes**
	Crossovers	**Yes**	**Yes**	**-**	**-**	**-**	**Yes**
	Condensate lines	**-**	**-**	**-**	**-**	**-**	**-**
Water Heater	Addressed specifically in code	**-**	**Yes**	**Yes**	**-**	**-**	**Yes**
	Relief Valve	**-**	**Yes**	**Yes**	**-**	**-**	**Yes**
	Relief Valve discharge line	**-**	**Yes**	**-**	**-**	**-**	**Yes**
	Control Components	**-**	**-**	**-**	**-**	**-**	**-**
	Water leaks in tank	**-**	**-**	**Yes**	**-**	**-**	**-**
	Circulating pump	**-**	**-**	**-**	**-**	**-**	**-**
	Combustion system	**-**	**Yes**	**-**	**-**	**-**	**Yes**
	Condensate lines	**-**	**-**	**-**	**-**	**-**	**-**
	Seals on Flammable Vapor Ignition Resistant (FVIR) units	**-**	**-**	**-**	**-**	**-**	**-**
	Clean flame arrestors on FVIR units	**-**	**-**	**-**	**-**	**-**	**-**
Ranges	Addressed specifically in code	**-**	**Yes**	**-**	**-**	**Yes**	**-**
	Specific detail on how or what to check on top section	**-**	**-**	**-**	**-**	**Yes**	**-**
	Specific detail on how or what to check on oven or broiler	**-**	**-**	**-**	**-**	**Yes**	**-**
Room Heaters	***Addressed specifically in code***	**-**	**-**	**-**	**-**	**-**	**-**
	Heat Exchanger	**-**	**-**	**-**	**-**	**-**	**-**
	Combustion system & control components	**-**	**Yes**	**-**	**-**	**-**	**Yes**
Gas Fireplaces	***Addressed specifically in code***	**-**	**-**	**-**	**-**	**-**	**-**
	Heat Exchanger	**-**	**-**	**-**	**-**	**-**	**-**
	Combustion system & components	**-**	**Yes**	**-**	**-**	**-**	**Yes**

	Check pressure relief damper or glass front relief springs	**-**	**-**	**-**	**-**	**-**	**-**
	Anti burn barrier (new products)	**-**	**-**	**-**	**-**	**-**	**-**
	Logs in proper position and undamaged	**-**	**-**	**-**	**-**	**-**	**-**
Unvented room Heaters (as local codes permit)	Addressed specifically in code	**-**	**-**	**Yes**	**-**	**-**	**-**
	Logs in proper position and undamaged	**-**	**-**	**-**	**-**	**-**	**-**
	Oxygen Depletion Sensor pilot clean and undamaged	**-**	**-**	**-**	**-**	**-**	**-**
All Condensing products (Other than furnaces) Now includes boiler, water heaters, gas fireplaces and room heaters		**-**	**-**	**-**	**-**	**-**	**-**
	Condensate trap and drains	**-**	**-**	**-**	**-**	**-**	**-**
Combustion blowers for no rubbing or bearing noise/failure		**-**	**-**	**-**	**-**	**-**	**-**
All products in general							
	Damaged wires in safety circuits	**-**	**-**	**-**	**-**	**-**	**-**
	Damaged wires in general	**-**	**-**	**-**	**-**	**-**	**-**
	Safety controls bypassed or out of proper position	**-**	**-**	**-**	**-**	**-**	**-**
	Corded products: properly grounded into grounded socket	**-**	**-**	**-**	**-**	**-**	**-**
Sec. 3: Ventilation System							
	System integrity (screws or glued)	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
	System configuration per manufacturer's instructions or local codes	**Yes**	**-**	**-**	**-**	**-**	**-**
	Proper pitch on horizontal runs	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
	Proper support on horizontal runs	**-**	**-**	**-**	**-**	**-**	**-**
	Horizontal intake and discharge exterior terminals clear of nests,	**-**	**-**	**-**	**-**	**-**	**-**

	leaves and grass clippings						
Sec. 4: Combustion Air Zone (CAZ)							
	Defer to local codes first and if none then National code	-	-	-	-	**Yes**	-
	Prior to testing check measure and check CAZ	-*	-	**Yes**	**Yes**	**Yes**	-
	Check during depressurization	-	-	-	-	-	**Yes**
	Relies on testing to determine adequacy of CAZ	-	**Yes**	-	-	-	-
	Discuss possible remedial action		-	-	-	-	**Yes**
Sec. 5: Depressurization							
	Close all unintentional openings such as broken windows, condensate traps, etc.	-	-	**Yes**	-	-	-
	General depressurization process evaluation	**Yes**	-	-	-	-	-
	Bath and kitchen fans	**Yes**	-	-	-	-	-
	Air handler	**Yes**	-	-	-	-	-
	Whole house fan	**Yes**	-	-	-	-	-
	Wood fireplace damper closed	**Yes**	-	-	-	-	-
	In depth depressurization study using multiple trials	-	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
	Bath and kitchen fans	-	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
	Air handler	-	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
	Whole house fan	-	**Yes**	**Yes**	**Yes**	**Yes**	-
	Wood fireplace damper closed	-	-	-	-	**Yes**	**Yes**
	During depressurization run each appliance individually	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	-
	During depressurization run all appliance at the same time	-	-	-	-	-	**Yes**

	Establish allowable limits	**-**	**Yes**	**-**	**Yes**	**Yes**	**Yes**
	Suggest remedial actions	**-**	**-**	**-**	**-**	**Yes**	**Yes**
	Instruct technician to check CAZ by appliance testing and then starting depressurization	**-**	**-**	**-**	**-**	**-**	**Yes***
	Use Smoke to trace airflow in a closed room	**-**	**-**	**-**	**-**	**Yes**	**-**
	Interior doors only checked in one position only	**Yes**	**-**	**-**	**-**	**Yes***	**Yes**
	Interior doors checked both open and closed	**-**	**Yes**	**Yes**	**Yes**	**Yes**	**-**
	Simulate wood fireplace operation by multiple appliances in operation	**-**	**-**	**-**	**-**	**-**	**-**
	Simulate wood fireplace operation by exhaust fan	**-**	**-**	**Yes**	**-**	**Yes**	**Yes**
Sec. 6: Ignition							
	Conduct ignition testing during depressurization	**Yes**	**Yes**	**-**	**-**	**Yes**	**-**
	Instruct how to run ignition trials	**Yes**	**-**	**-**	**-**	**-**	**-**
	Instruct to inspect pilots	**Yes**	**-**	**-**	**-**	**-**	**Yes**
	Conduct ignition trials on all appliances	**Yes**	**Yes**	**-**	**-**	**Yes***	**Yes**
	Look for flame behavior	**Yes**	**Yes**	**-**	**-**	**Yes***	**Yes**
	Suggest remedial action as necessary	**Yes**	**Yes**	**-**	**-**	**-**	**-**
Sec. 7: Carbon Monoxide Testing							
	Require CO testing	**-**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
	Detail whether to run CO testing under depressurization or not	**-**	**Yes**	**Yes**	**-**	**Yes**	**-**
	CO Testing during worst case depressurization	**-**	**Yes**	**Yes**	**Yes**	**Yes**	**-**
	CO testing without depressurization	**-**	**Yes**	**-**	**Yes**	**-**	**-**
	Specify to monitor ambient air for CO while conducting individual appliance checks	**-**	**Yes**	**Yes**	**-**	**Yes**	**Yes***
	Specify to test vented heating appliances	**-**	**Yes**	**Yes**	**-**	**Yes**	**Yes**

	(furnaces and boilers)						
	Test water heater	-	**Yes**	**Yes**	-	**Yes**	**Yes**
	Specify to test range top burners	-	-	-	-	**Yes**	**Yes**
	Specify to test oven burners	-	**Yes**	**Yes**	-	**Yes**	**Yes**
	Specify to test broiler burner	-	-	-	-	-	-
	Specify where the sample is to be taken for each appliance type	-	**Yes**	**Yes**	-	**Yes**	-
	Establish test time/operation for each appliance type covered in code (see item 2 above)	-	**Yes***	**Yes***	-	-	-
	Establish individual CO limits for each heating appliance type covered in code (see item 2 above)	**Yes (table G5)**	**Yes**	**Yes**	**Yes**	**Yes**	-
	Establish separate limits for ovens (if covered in code –see section 2 above)	**Yes**	**Yes**	**Yes**	-	-	-
	Establish separate top burner CO limits	-	-	-	-	**Yes**	-
	Suggest form of remedial action (if required) for each appliance type	-	**Yes**	**Yes**	**Yes**	**Yes**	-
	Code mentions unvented heaters	-	**Yes**	**Yes**	-	**Yes**	**Yes**
	Testing/weatherization stop if an unvented heater found	-	-	-	-	**Yes**	**Yes**
	Code call for testing CO from unvented heaters	-	-	-	-	-	-
	Smoke test of oil based heating	-	-	-	-	**Yes**	**Yes**
Sec. 8: Spillage Test (of Draft Hood equipped products)							
	Run draft test rather than spillage test	-	-	-	-	-	**Yes**
	Spillage conducted under depressurization	**Yes**	**Yes**	**Yes**	-	-	-
	Spillage conducted under worst case depressurization	-	**Yes**	**Yes**	**Yes**	**Yes**	-
	Specify when to test for	**Yes***	**Yes***	**Yes***	**Yes**	**Yes**	-

	spillage after start appliance						
	Operational time for spillage check in minutes	**5**	**1**	**1**	**1**	**2**	**-**
	Monitor ambient CO levels during testing	**-**	**Yes**	**Yes**	-	**Yes**	**-**
	Suggested remedial actions	**-**	**Yes**	**Yes**	**Yes**	**Yes**	**-**
	Run test with other appliances in operation	**-**	**Yes**	**Yes**	**Yes**	**Yes**	**-**
	Specify to check for spillage from other areas of the appliance such as by burner control covers, access plates, etc.	**-**	**-**	**-**	-	-	**-**
Sec. 9: Draft Testing							
	Run/Measure Draft	**-**	**Yes**	**-**	**Yes**	**Yes**	**Yes**
	Remediation suggestions	**-**	**-**	**-**	**Yes**	**Yes**	**Yes**
Sec. 10: Efficiency Testing							
	Call for an Efficiency test on specific appliances	**-**	**Yes**	**-**	-	**Yes**	**Yes***
	Detailed instruction on how perform efficiency test	**-**	**-**	**-**	-	**Yes**	**-**
	Acceptance values given in code	**-**	**-**	**-**	-	**Yes**	**Yes**

Note: The authors have included some recommendations as line items in either the column 1 or 2 of the summary table (these are highlighted Boldface and in italics).