



Applications Guide

COMBUSTION ANALYSIS

An Essential Reference for The Advanced Technician

by James L. Bergmann
HVACR Technical Specialist



i. Preface

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WARNING

Information contained is only for use by formally trained competent technicians practicing within the HVAC/R community. The manufacturers' installation, operation, and service information should always be consulted, and should be considered the first and best reference for installing, commissioning and servicing equipment. The author and publisher assume no liability for typographical errors or omissions of information in this guide.

For additional information please contact:

Testo, Inc.
35 Ironia Rd.
Flanders, NJ 07836
+1 800-227-0729
+1 973-252-1720
Fax +1 973-252-1729
www.testo.com
info@testo.com

Author:
James L. Bergmann
HVAC/R Technical Specialist
Testo, Inc.

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ii. Credits and Acknowledgements

Some graphics courtesy of COAD (Corporation for Ohio Appalachian Development)

The equipment inspections covered in this publication meet industry standards as outlined by:

1. The National Fuel Gas Code (ANSI Standard Z223.1 and NFPA 54);
2. State building codes;
3. RSES Publication 630-92 9/86;
4. The Gas Appliance Manufacturers Association (GAMA);
5. The International Fuel Gas Code; and
6. Many manufacturers' equipment installation, operation, and maintenance guides.

Using this Manual

- ♦ **Notes:** suggestions and insights to more effective work
- ♦ **Cautions:** information that may effect testing accuracy, consistency, or might lead to equipment or product damage
- ♦ **Warnings:** information relating to potential physical harm

For additional information on servicing gas appliances, please see **Section 21** the **Servicing Gas Appliances Checksheet**.

1 Introduction

This applications guide is intended to supplement and enhance the knowledge of a trained and qualified HVAC service technician. This applications guide is not intended as a substitute for formal technical training by authorized training organization, the manufacturer's installation, operation and or service instructions.

The appliance manufacturers' installation, operation, and service information should always be consulted, and should be considered the first and best reference for installing, commissioning and servicing equipment. The author and publisher assume no liability for typographical errors or omissions of information contained herein.

Testo is a world leader in handheld test and measurement instrumentation. Testo scientists and engineers pioneered the digital combustion analyzer in 1979 with the introduction of the world's first electronic combustion analyzer, the testo 31. Today, testo sells more combustion analyzers than anyone else in the world. 85 R&D engineers continue to produce cutting edge, innovative and award winning products that lead the world's combustion and emission markets. For example, the testo 350 is one of the first portable combustion analyzers that have been listed by the US-EPA Environmental Technologies Verification program for use in industrial stack measurements.

2 Why Testing is Required for Equipment Setup and Verification

Making and interpreting measurements is a crucial part of any job involving service, installation, design verification, engineering, or factory support of HVAC/R equipment. When it comes to verifying proper operation of the installed equipment it is critical that measurements made in the field are just as accurate as those made the laboratory. At Testo we believe that we all have an obligation to assure that the equipment is operating at peak performance levels for the benefit of consumers or end users of HVAC/R equipment, equipment manufacturers, utilities, the nation's energy future and the environment.

Combustion analysis is only part of the equipment installation and commissioning procedure. A complete installation includes but is not limited to proper equipment selection and sizing, proper airflow and fuel pressure, verification of proper draft, combustion and ventilation air, verification of proper operation of all limit and safeties as recommended by the manufacturer and as outlined in the International Fuel and Gas Code, and a final combustion analysis along with written and printed verification of the commissioning procedure.

3 The Need to Test with Digital Instruments

Today, most oil fired equipment is still being serviced and adjusted with traditional manual combustion efficiency test equipment (or wet kits) for field service and seldom is testing is done on gas, coal, or wood burning appliances. These kits generally consist of a stack thermometer, draft gauge, wet chemical CO₂ gas tester, slide rule and smoke pump. Although this equipment has served the industry well over the years, faster, more accurate, real time flue gas analysis is necessary.

Many service technicians are reluctant to used digital instruments; there is a certain comfort in using what we are used to, and in some cases we figure if we don't know, we cannot be held responsible. Nothing could be further from the truth. Failure to test does not absolve you of liability. Information is power whether it is used for you or against you.

With digital equipment, many errors with the measurement process are reduced or eliminated. Analog measurement errors can be the result of interpolation errors, calibration errors, poor repeatability of the measurement, and most importantly not having a procedure in place to consistently repeat the measurement process.

Tuning a system should happen in *real time*, not "after the fact" with a very highly "averaged" sample. (Each squeeze of a wet kit bulb represents a different snapshot of the flue gas. A traditional test blends all those snapshots together into one reading.)

Only digital analyzers allow you to take *real time* tests. You **cannot** do a *real time* test with a wet kit; it is physically impossible to take the sample fast enough and do the slide rule calculation.

Today testing is not an option, but a necessity on every gas, oil, wood, or coal appliance that you might service. The truth is digital instruments are faster, more accurate, more reliable, and have a higher repeatability than most analog tools. Digital instruments stay in calibration, allow trending, allow more complex functions and save time. Digital instruments allow data to be recorded and reported without human error, and provide reliable and accurate results for you and your customers. Data can be recorded much faster than any technician could ever do the calculations and data can also be recorded whether or not the technician is there to see it (eg. using features like the online mode on a Testo 330). In most cases, the data is an un-editable record, so what you see was what was measured at the jobsite. Permanent records allow the user to track system changes and determine if the system is operating within the design parameters or if changes have taken place.

4 Benefits of proper system setup through testing

Whether working on gas, oil, coal, or wood fired appliances it is imperative to perform a combustion analysis during routine service, or any time changes are made that will affect the combustion process. This can be as simple as adjusting an air shutter, changing gas pressure or as involved as changing an oil nozzle. A combustion analysis is performed for four primary reasons:

1. To verify the safety of the appliance prior to and after service
2. To calculate the combustion efficiency of the appliance
3. To determine the amount of pollution the appliance is producing
4. To review operation in conformance with the manufacturer's guidelines
5. To assess equipment longevity/warranty issues (eg. Improper fuel pressure or airflow settings may cause excessive CO production, or burned out heat exchangers, etc.)

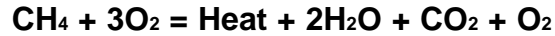
Combustion testing provides numerous benefits to the service technician, end user of the appliance, and the appliance manufacturer.

Combustion Testing:

- ♦ Saves money
- ♦ Saves time
- ♦ Avoids callbacks
- ♦ Limits liability
- ♦ Maintains equipment warranty
- ♦ Provides confidence
- ♦ Provides increased comfort
- ♦ Provides increased safety
- ♦ Increases energy efficiency
- ♦ Lowers environmental emissions (Pollutants)

5 The Combustion Process

Combustion is a chemical reaction of rapid oxidation started by the correct mixture of fuel, oxygen and an ignition source. The chemical reaction for natural gas is:



Where:

CH_4 = 1 cubic foot of Methane Gas (Natural gas)

3O_2 = 3 cubic feet of Oxygen

Heat = 1027 BTU's of energy produced from the chemical reaction

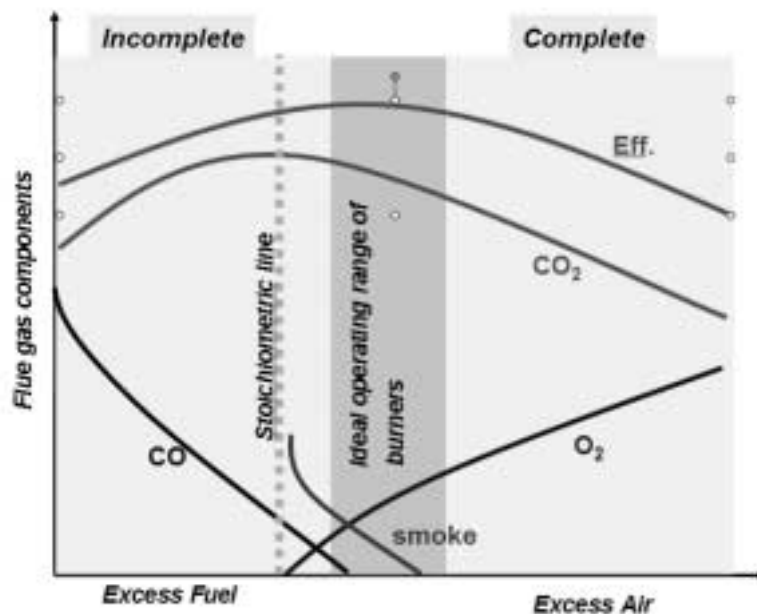
$2\text{H}_2\text{O}$ = 2 cubic feet of Water Vapor

CO_2 = 1 cubic foot of Carbon Dioxide

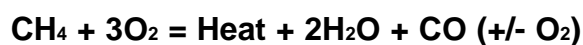
O_2 = 1 cubic foot of Excess Oxygen

Combustion Diagram

The ideal operating range is a setting with excess air.



The formula for **incomplete combustion** in a gas fired furnace is



Note: CO can be produced with or without excess air. That is primary reason why there is a diluted and undiluted flue gas test available in a combustion analyzer. CO is Carbon Monoxide and CO₂ is Carbon Dioxide. CO is deadly, CO₂ is normally not considered to be harmful (poisonous, deadly).

The air is composed of 20.9% oxygen, 78% nitrogen and 1% other gasses. For every cubic foot of oxygen needed, approximately 10 cubic feet (CF) of air are needed to provide complete combustion for natural gas. For most residential appliances, an additional 5 CF of air is added to assure there is ample oxygen to burn all of the fuel. In other words, 15 CF of air are required to support the combustion process, and provide enough excess air to insure complete combustion. An additional 15 CF of air are required if the furnace has a draft hood, bringing the total to 30 cubic feet air per cubic foot of gas burned. The combustion process creates exhaust gasses that contain heat that will be extracted to heat a heat exchanger, and transfer the generated energy to air, water, or any other desired heat transfer medium.

Exhaust gasses along with any excess air are vented outdoors through vent pipes, chimneys or plastic exhaust pipes after the majority of their useable heat has been transferred. The venting materials must be sized properly to insure the flue gasses can be vented without creating a positive (back pressure) within the heat exchanger. If the gasses back up in the heat exchanger, the flames will come out of the front of the combustion chamber, creating dangerous conditions called rollout and/or spillage.

6 Understanding Combustion Efficiency

Combustion efficiency is a measurement of how well the fuel being burned is being utilized in the combustion process. This is different from the efficiency number produced on the analyzer, which is reflective of the total amount of heat available from the fuel minus the losses from the gasses going up the stack. Stack loss is a measure of the heat carried away by dry flue gases and the moisture loss. It is a good indicator of appliance efficiency. The stack temperature is the temperature of the combustion gases (dry and water vapor) leaving the appliance, and reflects the energy that did not transfer from the fuel to the heat exchanger. The lower the stack temperature, the more effective the heat exchanger design or heat transfer and the higher the fuel-to-air/water/steam efficiency is. The combustion efficiency calculation considers both the stack temperature and the net heat and moisture losses. This would include losses from dry gas plus losses from the moisture and losses from the production of CO.

Each type of fuel has specific measurable heat content. The maximum amount of heat that can be derived from a fuel is based on using pure oxygen as the oxidizer in the chemical reaction and maximizing the fuel gas mixture. In field practice, the oxygen is derived from the air which is 20.9% oxygen, 78% nitrogen and 1% other gasses.

Because the oxygen is not separated from the air prior to combustion, there is a negative effect on the chemical reaction. Air is primarily nitrogen. While nitrogen is inert, and plays no role in the combustion process, it cools the chemical reaction (burning temperature) and lowers the maximum heat content deliverable by the fuel. Therefore, it is impossible to achieve *combustion efficiencies* above 95% for most fuels, including natural gas, when air is used as the oxidizer in the combustion process.

The combustion efficiency or maximum heat content of the fuel is then based upon the quality of the mixture of fuel and air, and the amount of air supplied to the burner in excess of what is required to produce complete combustion. The efficiency calculated by the combustion analyzer is a modified equation that considers combustion efficiency and stack losses. It is a part thermal, part combustion efficiency calculation. The equation is a reasonable estimation of the steady state operating efficiency of the appliance. This is true of all analyzers currently manufactured, and is not proprietary to Testo.¹

The entire system (furnace/boiler, ducting, and piping) must be evaluated to determine the true efficiency of the system. Combustion efficiency is a valuable part of the system evaluation, but it is only one part of the evaluation process and cannot be used as the sole reason or justification for keeping or replacing existing equipment.

If the excess air is carefully controlled, most furnaces are capable of performing at higher levels than their rated Annualized Fuel Utilization Efficiency or AFUE level, AFUE levels typically range from 80% to 95%.²

The ultimate thermal efficiency of the appliance is determined by dividing the heat output rate of the appliance by the rate of fuel input. During the combustion process, all furnaces that operate with the same combustion efficiency will produce the same amount of heat with the same fuel input. **The *combustion efficiency* has no bearing on how well the appliance utilizes the heat produced after the combustion process has taken place.** Heat exchanger design and its ability to transfer the sensible³ and possibly the latent⁴ heat to the room air determine how well the heat produced by the combustion process is utilized.

During combustion, new chemical substances are created from the fuel and the oxidizer. These substances are called **exhaust gasses**. Most of the exhaust gas comes from chemical combinations of the fuel and oxygen. When a hydrocarbon-based fuel (Natural Gas) burns, the exhaust gasses include water (hydrogen + oxygen)

¹ Manufacturers use differing forms of combustion equations. This modified equation is often referred to as combustion efficiency, even though as a matter of pure science it is not.

² AFUE is also known as the Department of Energy Minimum Seasonal Efficiency

³ Sensible heat is the heat measured with a thermometer

⁴ Latent heat is the heat available when the water vapor in the exhaust gas has been condensed out

and carbon dioxide (carbon + oxygen). But the exhaust gasses can also include chemical combinations from the oxidizer alone. If the natural gas is burned with air, which contains 21% oxygen, 78% nitrogen and 1% trace gasses, the exhaust can also include carbon monoxide (CO), oxides of nitrogen (NO_x, nitrogen + oxygen) and if sulfur is present in the fuel, sulfur dioxide, SO₂ (Sulfur + oxygen).

The temperature of the exhaust will be high because of the heat that is transferred to the exhaust during combustion. Because of its high temperature, exhaust usually occurs as a gas, but there can be liquid or solid exhaust products as well. Water (H₂O) is always present in natural gas and oil combustion in residential furnaces. **Soot**, which is incompletely burned fuel, is a form of solid exhaust that occurs in some combustion processes.

During the combustion process, as the fuel and oxidizer are turned into exhaust products, heat is generated. Interestingly, some **source of heat** is also necessary to start combustion. Gasoline and air are both present in your automobile fuel tank; but combustion does not occur because there is no source of heat. Since heat is both required to start combustion, and is itself a product of combustion, we can see why combustion takes place very rapidly. Also, once combustion gets started, we don't have to continue to provide the heat source, because the heat produced by the combustion process will keep things going. We don't have to keep lighting a campfire, it just keeps burning.

Flue gasses are the gasses produced by burning fuel. These gasses are hot, but have not given up all their heat in the combustion process. Depending on the type of furnace, a certain amount of heat must go out of the flue to prevent the gasses from condensing. With high efficiency furnaces, condensing is desirable because of the additional heat extracted from the flue gasses.

A digital combustion analyzer performs all of the mathematical calculations and measurements necessary to determine efficiency, safety, dew point, and the amount of pollution the appliance is producing. For most technicians, the safety (CO) and efficiency (EFF.) readings will be the most important and most frequently referenced numbers. When safety or efficiency is compromised, other portions of the chemical reaction (CO₂, O₂) will be referenced, along with calculated values like excess air, to determine the cause of the problem in the combustion process. Other variables like NO_x and SO₂ are referenced and controlled to keep them at levels that are safe for the environment and acceptable to the local authority having jurisdiction over these matters. Some areas do not currently regulate levels of NO_x and SO₂ and where they are not controlled they are also not typically measured. Usually, larger exhaust sources (higher BTU systems) are targets of NO_x and SO₂ regulations. (NOTE: Testo also has a full line of emissions products to measure regulated emissions.)

As a service technician, unless a component has failed, there are only three things can be adjusted on a gas/oil appliance that will affect the combustion process.

- ♦ Fuel pressure
- ♦ Primary air (on newer furnaces this is not adjustable)
- ♦ Draft, also known as secondary air

Other factors can affect the combustion process. These include impingement for example from an improperly placed pilot, excess air from a cracked heat exchanger, insufficient combustion air due to tight construction or improper ventilation, an improperly installed venting system, or incorrect orifices. These are considered defects or installation problems, and require mechanical correction rather than adjustment. It is the service technician's responsibility to determine if combustion problems are caused by improper adjustment, incorrect installation, component failure, or equipment defect. Therefore, it is important that the technician completely understands how each of the subsystems affects the chemical reaction called combustion.

It should be noted that there is not a national industry standard for calculating measured efficiency with a combustion analyzer. Manufacturers of analyzers use differing calculations to derive efficiency values. Oftentimes this discrepancy is due to values that have been extrapolated into the condensing range.

Heat removed from the flue gasses on a condensing furnace is latent or hidden heat. A combustion analyzer that measures only temperature and not volume of condensate cannot measure the quantity of heat removed from the flue gas during the condensing process. Although terms of thermal and combustion efficiency are often used interchangeably on non-condensing units, they cannot be used in the same manor on condensing appliances.

The thermal efficiency of a condensing appliance and combustion efficiency will be different. The only way to calculate the actual thermal efficiency of an appliance is to measure the exact airflow across the heat exchanger and the change in air temperature across the heat exchanger and input the measured values into the sensible heat formula to calculate the heat energy input into the conditioned air. There will be some minimal loss to the furnace cabinet by radiation and conduction. Depending on how much of the heat energy is extrapolated from the water in the flue gas, an average of 970 BTU per pound, the efficiency readings can differ by as much as 10%. This assumes that either all latent heat energy was extracted from the flue gasses after they reached the dew point or none of the latent heat energy was extracted.

This extrapolation of values is distorted, and has led manufacturers of appliances to inadvertently post higher than actual thermal efficiency numbers. Due to the readings achieved on their analyzer. (NOTE: This calculation does not affect the AFUE numbers,

which are derived by a different means.) By not taking this discrepancy into account, some in the industry have suggested that fuels are being delivered with low BTU levels. This leads them to suggest that fuel pressures be raised to provide the net heat output that the manufacturer has published. For this reason, Testo is recommending that the fuel pressure be set per the manufacturer's instructions. The combustion efficiency will then be a function of the actual dry flue gas and not of the thermal efficiency of a condensing appliance. This avoids use of a calculated rather than a measured parameter. Testo has chosen to use a combustion calculation that does not extrapolate the thermal efficiency values of flue gasses below the dew point, as those values are not representative of the heat that is removed from the flue gasses during the condensing process. Although this may result in the appearance of a lower thermal efficiency of the appliance, the science used for measuring combustion efficiency is not artificially high. Once differences in combustion and appliance thermal efficiency are understood, the methodology of scientific measurement versus extrapolation of measured values can be appreciated and applied, allowing manufacturers to publish combustion and thermal efficiencies that are representative of the actual efficiency of their appliance, thereby creating a standard that is based upon actual measurement rather than an extrapolation.

7 Common Combustion Measurements and Calculations

Measured

- ♦ **CO:** (Carbon Monoxide) Dangerous byproduct produced by incomplete combustion.
- ♦ **Stack Temperature:** (Gross Stack Temperature) Temperature of the flue gasses + combustion air temperature.
- ♦ **O₂:** (Oxygen) Measured oxygen in flue gasses after combustion has occurred.
- ♦ **NO:** (Nitric Oxide) Byproduct of combustion also called: mononitrogen monoxide or nitrogen monoxide. (Pollutant)

Calculated

- ♦ **EFF:** (Efficiency) a calculation of the maximum heat available in the combustion process minus the stack losses.
- ♦ **NO_x:** (Nitric Oxide) The mixture includes nitric oxide (NO), nitrogen dioxide (NO₂), nitrogen trioxide (N₂O₃), nitrogen tetroxide (N₂O₄), and nitrogen pentoxide (N₂O₅).

- ♦ **CO₂:** (Carbon Dioxide) Carbon Dioxide is byproduct of normal combustion, considered a greenhouse gas.
- ♦ **Excess Air:** The calculated air that passed through the combustion process without acting as an oxidizer in the combustion process. A certain amount is usually required to assure complete combustion. Excess air dilutes the flue gasses and should be kept to a minimum to keep combustion efficiency at its maximum.
- ♦ **CO Air Free:** A calculated measure of the undiluted CO in the flue gasses.
- ♦ **Dew point:** A calculated temperature below which the H₂O in flue gas will start to condense.

8 Common causes of CO, and CO related safety

In general when performing a combustion analysis, the service technician needs to look at three things. These are:

1. Safety
2. Efficiency
3. Pollution

Combustion testing of an existing appliance should be preformed prior to and also after servicing the appliance. This will provide the service technician pre and post results that can determine how equipment was operating before and after service. Combustion analysis should not be considered final until the complete commissioning procedure has been performed. This would include proper air or water flow across the heat exchanger, proper fuel pressures and draft. Additionally verification of combustion and ventilation air by performing the ventilation air test outlined in this manual, with all panels and or burner covers in place. Any mechanical or operational changes made after the combustion test is performed can affect the final combustion test results. Therefore a combustion test should always be the first and final test performed at the appliance.

8.1 Safety Considerations: *Carbon Monoxide (CO)*

Carbon monoxide is a pollutant that is readily absorbed in the body and can impair the oxygen-carrying capacity of the blood (hemoglobin). Impairment of the body's hemoglobin results in less oxygen to the brain, heart, and tissues. Even short-term over exposure to carbon monoxide can be critical or fatal to people with heart and lung diseases, the young or the elderly. It may also cause headaches and dizziness and other significant medical problems in healthy people.

During combustion, carbon in the fuel oxidizes through a series of reactions to form carbon dioxide (CO₂). However, 100 percent conversion of carbon to CO₂ is rarely achieved under field conditions and some carbon only oxidizes to the intermediate step, carbon monoxide or CO.

In today's equipment, high levels of carbon monoxide emissions primarily result from incomplete combustion due to poor burner design or firing conditions. Examples would include an improper air-to-fuel ratio or possibly a misaligned burner. Through proper burner maintenance, inspections, and operation, the formation of carbon monoxide can be controlled at an acceptable level. Upgrading equipment, performing regular inspections and combustion testing will also help keep the carbon monoxide levels under control.

No standards for CO have been agreed upon for indoor air. The U.S. National Ambient Air Quality Standards for outdoor air are 9 ppm (40,000 micrograms per cubic meter) for 8 hours, and 35 ppm for 1 hour (time weighted).

No CO (0 ppm) is the best level in the home. This cannot always be achieved due to smokers in the home and/or appliances like stoves that produce acceptable levels of CO during operation. When CO is present in the home, the source should be determined and corrective action taken. The goal is to assure occupant safety and minimize the occupants' exposure.

The local authority having jurisdiction should be consulted when determining the maximum safe level allowed in the home before shutting down the appliance and or making it inoperable. **An appliance with rising CO production should always be shut down no matter how low CO production is at the time of testing.** Rising CO problems are usually the result of improper venting and/or lack of combustion air.

Ambient CO Limits (Recommended)

- | | |
|-----------|--|
| 1-9 ppm | Normal levels within the home. If there are no smokers, investigation is recommended. These levels will be measured above ambient levels in most cases because the CO instrument has been zeroed in outdoor air. |
| 10-35 ppm | Advise occupants, check for symptoms, (slight headache, tiredness, dizziness, and nausea or flu like symptoms.) check all unvented and vented appliances, including the furnace hot water tank and or boiler, check for other sources including attached garages or small engine operation |
| 36-99 ppm | Recommend fresh air, check for symptoms, ventilate the space, recommend medical attention |

100+ PPM Evacuate the home (including yourself!) and contact emergency medical services (911). Do not attempt to ventilate the space. Short-term exposure to these levels can cause permanent physical damage.

8.2 Maximum CO Levels in Equipment

Vented (Note CO reading must remain stable and are measured on an air-free basis)

- ♦ 400 ppm (CO-Air Free: CO-AF) Stack ANSI Z 21.1
- ♦ 100 ppm CO Stack recommended

ALWAYS FOLLOW REQUIREMENTS of AUTHORITY HAVING JURISDICTION

Unvented

- ♦ 30-50 ppm stable
- ♦ Less than 10 ppm recommended

8.3 Light off CO levels:

Recently, light off levels of CO are being addressed by some as a topic of concern. Gas and oil appliances have no manufacturer-prescribed maximum CO level at light off. High CO levels at light off may be an indication of rough or delayed ignition warranting further investigation, but they are not considered by manufacturers or by most in the industry to pose health concerns due to low volume of CO produced (short times at this higher rate of CO production). The CO readings should peak under 400 ppm (there is no prescribed light off level), then drop below the prescribed level allowed in the stack. CO readings should stabilize within 10 minutes of operation and should never be rising during operation.

Technicians should also be aware that several manufacturers of combustion testing equipment do not filter out the Nitric Oxide (NO) from the combustion gas sample. NO is an acid gas which is a cross-interferant to all electrochemical CO sensors. (A cross-interferant will add "false CO" to the reading proportional to the amount of NO present. EG. 100 ppm of NO gas will show on an unfiltered CO sensor as an additional 25 to 50 PPM CO.) All Testo stack gas analyzers incorporate replaceable NO filters that remove NO_x gas from the CO sample to provide an accurate CO reading. Such filters are not important when measuring ambient CO as NO rapidly converts to NO₂ in ambient air. NO₂ is not a cross-interferant.

Make sure the equipment you are using is specifically designed to measure low levels of CO and incorporates a NO filter. Many combustion analyzers manufactured today and

some methods used for low-level CO detection have inherent error in instrumentation or the measurement process. While Testo is a leader in this technology, other manufacturers are following suit.

8.4 Mechanical Problems and CO

Many times there is sufficient combustion/ventilation and infiltration air, but the appliance being tested is still producing higher than acceptable CO air-free levels. Normally this is the result if a mechanical problem. Burners should be inspected for cleanliness and proper alignment. Gas pressures should be checked and set to manufacturer's specified levels; the flame should be closely examined for evidence of impingement.

Impingement occurs when the flame hits an object that has sufficient mass, or can transfer enough heat from the flame to lower flame temperatures and cause incomplete combustion. This can be as simple as a screw poking into the heat exchanger or as major as a warped heat exchanger cell. Burners should always be carefully removed and reinserted to assure proper placement and alignment.

Missing burner covers, improper air band adjustment on fuel oil or improper manifold pressure or oil pressures can also contribute to higher than normal CO levels. Too much excess air can cool the flame lowering the flame temperature creating higher than acceptable levels of CO. This is one of the reasons two stage furnaces produce slightly higher CO levels on low fire. The excess air on a two-stage appliance is often significantly higher by percentage than required for safe combustion.

9 Performing a Complete Combustion Test

Prior to entering an existing home installation, ambient CO levels should be checked and the equipment should be run through a complete cycle.

9.1 CO Ambient Air* Testing - The First Step (*Combustion Air Zone & Living Space)

For your safety and for your customer's safety do not skip this step!!

WARNING: If at any time during this test ambient CO levels exceed 100 ppm evacuate occupants and ventilate the dwelling immediately.

*For lower CO concentration levels consult the Ambient CO Limits in **Section 8.1 of this guide** or contact the local authority having jurisdiction over these matters. Perform this test **prior** to entering any home, boiler room, basement or crawl space where or near where an appliance is located. The CO level in the home should always be verified prior to entering the space and prior to zeroing the analyzer for a combustion test of the appliance. If an ambient combustion air temperature probe is not used, the analyzer must be re-zeroed with the probe in air similar in temperature that used for combustion if CO is present.*

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Safety of the appliance should be the primary goal of all technicians. The production of CO in the flue gasses should be kept below 100 ppm air free, even though the allowable limit in the stack is 400 ppm air free. Anytime CO is rising and unstable at any level from 1 ppm to 400 ppm during the combustion process, the burner should be shutdown and/or immediately repaired. A burner with rising CO under operation is far more dangerous than a stable reading because the CO can continue to rise far above dangerous levels. Levels above 400 ppm are not permissible and require immediate repair and or shutdown of the appliance.

CO levels in ambient air are not normally from a cracked heat exchanger. More often than anything else it is the result of auto exhaust from an attached garage, and or depressurization of the home resulting in insufficient air for combustion. If CO is detected, all possible sources of CO should be checked including but not limited to hot water tanks, gas ovens and stoves, the furnace, (non-electric) space heaters, vented or unvented appliances like gas logs.

9.2 Performing a Draft Test:

Verifying draft is an important safety consideration, Draft is required to remove the flue gasses from the heat exchanger or draft hood on all atmospheric and draft induced appliances, and most power burner equipped appliances.

All appliances requiring draft are required to have and maintain draft during operation. An appliance has 5 minutes under the ANSI standards to prove draft. During steady state operating conditions, the draft should be stable. The draft will increase as the flue warms until it reaches maximum flue temperature and stabilizes. The analyzer will record and store the draft reading for the flue gas measurement screen and printout.

Note: *If the appliance and chimney are cold it can take up to ten (10) minutes to establish draft. A system that has been under operation should have or establish draft very quickly. If draft induced and atmospheric appliances are common vented, always verify the atmospheric appliance is not spilling when both appliances are operating. Verify that flue gasses are not spilling through the draft hood on the atmospheric appliance when it is operating by itself. If both appliances are common vented, both should be draft tested. Kitchen exhaust fans, basement doors opening or closing etc, should not affect draft. If multiple draft-induced appliances are common vented, assure that spillage does not occur through the heat exchanger and out through the burner openings of the adjoining appliance while it is in its stand-by position (OFF)*

9.3 Efficiency Measurement and Considerations:

Since it is not possible in the field to measure the theoretical temperature of a combustion process due to dilution of the gases and absorption of the heat by radiation to the surrounding areas, the combustion equation has been developed to determine

whether a combustion process is being properly handled. The efficiency calculation is based from the theoretical heat value of the fuel being burned minus the stack losses. See the Section 6 for additional information on the efficiency calculation.

9.4 Oxygen (O₂) Reading:

The O₂ reading is by far the most important reading an analyzer measures with regard to combustion. The oxygen level in the atmosphere remains constant (20.9%), and is the only true constant in the combustion process we have. The O₂ reading should be monitored to produce a flame with the lowest excess air reading possible while maintaining a safe level of CO in the stack. Excess air readings should always fall within the manufacturer's published guidelines. Always make sure that all burner shields are in place to avoid the entry of excess secondary air. Residential furnaces often do not provide combustion air adjustment provisions because manufacturers have determined that the safety gained by providing additional air to assure complete combustion outweighs any potential savings that adjustment might provide. Also, excess air lowers the dew point of the flue gasses by dilution, thereby lowering the probability of condensation in the stack.

9.5 Carbon Dioxide (CO₂)

The carbon dioxide level in the flue gas provides an indication of the efficiency of the burner. If the production of CO₂ is as high as possible with slight excess air (complete combustion), the flue gas heat losses are at their lowest. The CO₂ reading is calculated from the O₂ reading by the analyzer.

For each fuel there is a maximum possible CO₂ level (CO_{2max}), which is determined by the chemical composition of the fuel. This maximum theoretical level is never reached in practice.

CO_{2 max} values for different fuels:

- Light Fuel Oil - 15.4% by volume CO₂
- Natural Gas - 11.8% by volume CO₂

9.6 Ambient Air Temperature

The ambient air temperature is measured at the burner inlet. Often this measurement requires an additional probe to measure inlet air temperature when combustion air comes into the burner directly from the outside as in the case of a sealed combustion furnace. The ambient air temperature is used for the efficiency calculation and will not affect other combustion gas calculations.

9.7 Stack Temperature

"The Hot Spot": The flue gas temperature should be measured in the flue gas hot spot. This is the point in the flue where the stack temperature and the CO₂ are at the highest level and the O₂ is at its lowest level. The primary importance of stack temperature is to provide enough heat in the flue to prevent water formation. Water can be a byproduct of combustion from condensing in the flue and or the chimney. Condensing on non-condensing appliances can cause chimney deterioration liner failure and rusting of the appliance.

Reducing the temperature of the flue gasses provides only a small benefit in the appliance efficiency. For every 50° the stack temperature is lowered, there is less than a 1% gain in efficiency. The stack temperature should be 270-370° above the supply air temperature or supply water temperature on non-condensing atmospheric appliances, and 170-270° above supply air temperature on draft induced appliances. On condensing appliances, ideally the stack temperature will be approaching the return air temperature and always below 125° F. The lower the return air temperature the higher the efficiency will be on a condensing appliance. Until the flue gasses are lowered to the condensing range, there is not a significant increase in thermal efficiency of the appliance. Remember the analyzer is looking at a modified equation that considers combustion efficiency and stack losses of the dry gasses. The efficiency calculation is not reflective of the thermal efficiency of a condensing appliance.

9.8 Dew Point Temperature

The dew point temperature is the temperature below which the water vapor contained in the flue gas would turn into a liquid state. This change is often referred to as condensation. Below the dew point temperature, moisture exists; above the dew point temperature vapor exists. If the chimney or venting material falls below the dew point temperature, condensation in the flue will occur. The dew point temperature is a calculated value the technician can use to reference if condensation of a non-condensing appliance is suspected.

9.9 Smoke Spot Number

The smoke spot number is determined by using a smoke spot tester. A standard quantity of flue gas is drawn through a filter paper by a certain number of strokes. The degree of blackening of the resulting spot on the filter paper is compared to a scale of gray tones with different numbers. The smoke spot number derivative determined in this way (according to ASTM D2156) is between 0 and 9. The smoke spot number is not measured in gas burners. Ideally the smoke spot number will be a 0 to 1 with a trace of soot. Smoke numbers above this will result in poor combustion and formation of soot on the heat exchanger.

Yellow spotting on the filter paper is an indication of incomplete combustion due to insufficient atomizing of the fuel. This condition is usually accompanied by high CO readings and is often eliminated by reducing the amount of excess air to the burner.

9.10 Fuel Pressures

Only two factors affect the input to an appliance, fuel pressure and orifice or nozzle size. The fuel pressure should always be measured and set to the manufacturer's prescribed settings. Under no circumstances should fuel pressures be adjusted outside of the designed range or over firing or under firing will result which could lead to premature equipment failure.

10 Pollution Parameters

Oxides of Nitrogen (NO_x) Optional Measurement

Measurement of NO_x and other pollutants are required in some jurisdictions on certain types of equipment. As a safety factor to assure complete combustion, appliances are fired with excess air. One of the factors influencing NO_x formation in a furnace or boiler is the excess air level. High excess air levels (>45%) may result in increased NO_x formation because the excess nitrogen and oxygen in the combustion air entering the flame will combine to form thermal NO_x. Low excess air firing involves limiting the amount of excess air that is entering the combustion process in order to limit the amount of extra nitrogen and oxygen that enter the flame. This is accomplished through burner design and can be optimized through the use of oxygen trim controls on commercial applications. Low excess air firing is used on most appliances and generally results in overall NO_x reductions of 5-10% when firing natural gas.

High flame temperatures and intimate air/fuel mixing are essential for low CO emissions. Some NO_x control technologies used on residential, industrial and commercial burners reduce NO_x levels by lowering flame temperatures through modification of air/fuel mixing patterns, or creation of intentional flame impingement. The lower flame temperature and decreased mixing intensity can result in higher CO levels.

Section 17 details the typical operating characteristics of specific categories of appliances.

11 Infiltration Air and Ventilation Air Testing

Ventilation Air: Total air, which is the combination of the air brought inside from outdoors and the air being re-circulated within the building. Sometimes, used in reference only to the air brought into the system from the outdoors. This document defines ventilation air as "indoor and outdoor air ventilation."

Infiltration Air: A term used to describe the outdoor air that enters a building through cracks or unintentional openings.

Combustion Air: The air supply brought into the furnace's combustion chamber and supplied from within the basement or from the outdoors. Combustion air is necessary to burn fuel.

Dilution Air: Air that enters a draft hood or draft regulator and mixes with the flue gasses. Dilution air enters through the burners on modern furnaces and is measured as excess air in the stack. If the dilution air level is too low, condensation of the flue gasses will occur.

Natural and induced draft gas appliances use air from inside the building to burn the fuel. If air used during the combustion/ventilation process from inside the building is not replaced by outdoor air, the following may occur:

- A. There will be insufficient air in the building for proper combustion.
- B. There is a very high probability that carbon monoxide (CO) will be generated due to the lack of air (Oxygen) inside of the building.
- C. Poor ventilation/infiltration can cause a negative pressure inside of the building.
- D. If the building is under a negative pressure, the chimney will not draft. The higher pressure outdoors will force air down the chimney or flue vent spilling the flue gasses into the building.
- E. Vent spillage will increase the probability that the flue gasses will contain Carbon Monoxide (CO) due to poor combustion.

The Ventilation Air Test:

- A. The ventilation air test is a worst-case test used to determine whether or not enough indoor air and infiltration air is coming into the building; used to test for proper ventilation/infiltration under actual operating conditions.
- B. The procedure for the ventilation air test is outlined in the International National Fuel Gas Code. (ANSI Standard Z223.1)
- C. It should be performed on every gas appliance installation and every gas appliance service call **prior to servicing the appliance.**

Background Information: The Ventilation Air Test

This procedure should be performed **prior to any attempt** at modification of the appliance or of the installation. This includes servicing, clean and checks, and/or mechanical changes.

If it is determined there is a condition that could result in unsafe operation, the appliance should be shut off and the owner advised of the unsafe condition.⁵ If there is not sufficient air for combustion and/or ventilation, the homeowner and/or technician will be at risk by operating the appliance under worst-case conditions.

This test is performed to insure that the building into which you are going to install, or have installed, a fossil fuel appliance has enough ventilation/infiltration air to replace the air used in the combustion and venting process. As homeowners are constantly making changes to the home (remodeling, caulking windows, and adding weather stripping) this test should be performed on an annual basis.

Modern buildings are much tighter than old buildings; some do not allow enough leakage for the infiltration air to enter the building from the outdoors. Winterization practices on older homes have sealed many of the openings that formerly provided combustion and ventilation air.

If the building does not allow enough infiltration air in, provisions must be made to bring in the outdoor air to replace the air used in the combustion and ventilation process. This could mean the installation of natural or mechanical combustion air to assure proper combustion and venting.

This test should be performed even if you are installing a 90+ furnace that takes all of the combustion air directly from the outdoors. This test is recommended by the International Fuel Gas Code since you are making changes in the venting system by removing the old appliance.

This test should be performed on all furnaces, boilers, hot water tanks, or other fuel burning appliance inspections or installations including the installation of woodstoves or other fossil fuel appliances.

⁵ If conditions can be changed to temporarily correct the condition, for example removing the door from the adjoining space, cracking a window in the basement, or locking out another appliance that is not deemed critical for heating the structure, the heating appliance can be left in operation provided the corrections to the combustion/ventilation system are incorporated prior to returning to normal conditions. Any changes made should be noted on the work order and signed off by the customer before any changes are made. Any appliance left in operation must not show any signs of combustion/ventilation problems.

**RECOMMENDED PROCEDURE FOR SAFETY INSPECTION OF AN
EXISTING APPLIANCE INSTALLATION AS OUTLINED IN THE
2003 INTERNATIONAL FUEL GAS CODE™**

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Note: If appliance fails this test, do not proceed until repairs are made.

The following procedure is intended as a guide to aid in determining whether an appliance has been properly installed and is in a safe condition for continued use. This procedure is predicated on central furnace and boiler installations, and it should be recognized that generalized procedures cannot anticipate all situations. Accordingly, in some cases, deviation from this procedure is necessary to determine safe operation of the equipment.

- (a) This procedure should be performed prior to any attempt at modification of the appliance or of the installation.
- (b) If it is determined there is a condition that could result in unsafe operation, the appliance should be shut off and the owner advised of the unsafe condition. The following steps should be followed in making the safety inspection:
 - 1. Conduct a test for gas leakage. (See Section 406.6 IFGC)
 - 2. Visually inspect the venting system for proper size and horizontal pitch and determine there is no blockage, restriction, leakage, corrosion, or other deficiencies that could cause an unsafe condition. (This will require removal of the vent from the chimney in most cases)
 - 3. Shut off all gas to the appliance and shut off any other fuel-gas-burning appliance within the same room. **Use the shutoff valve in the supply line to each appliance.**
 - 4. Inspect burners and crossovers for blockage and corrosion.
 - 5. **Applicable only to furnaces.** Inspect the heat exchanger for cracks, openings, or excessive corrosion.
 - 6. **Applicable only to boilers.** Inspect for evidence of water or combustion product leaks.
 - 7. Insofar as is practical, close all building doors and windows and all doors between the space in which the appliance is located and other spaces of the building. Turn on clothes dryers. Turn on any exhaust fans, such as range hoods and bathroom exhausts, so they will operate at maximum speed. Do not operate a summer exhaust fan. Close fireplace dampers. **If, after completing Steps 8 through 13, it is believed sufficient**

combustion air is not available, refer to Section 304 of this code for guidance.

8. Place the appliance being inspected in operation. **Follow the lighting instructions.** Adjust the thermostat so appliance will operate continuously.
9. Determine that the pilot(s), where provided, is/(are) burning properly and that the main burner ignition is satisfactory by interrupting and reestablishing the electrical supply to the appliance in any convenient manner. If the appliance is equipped with a continuous pilot(s), test the pilot safety device(s) to determine if it is operating properly by extinguishing the pilot(s) when the main burner(s) is/are off and determining, after 3 minutes, that the main burner gas does not flow upon a call for heat. If the appliance does not have a pilot(s), test for proper operation of the ignition system in accordance with the appliance manufacturer's lighting and operating instructions.
10. Visually determine that the main burner gas is burning properly (i.e., no floating or lifting of flames, or flashback). Adjust the primary air shutter(s) as required. If the appliance is equipped with high and low flame controls or flame modulation, check for proper main burner operation at low flame.
11. Test for spillage at the draft hood relief opening after five minutes of main burner operation. Use the flame of a match, a candle or smoke.
12. Turn on all other fuel-gas-burning appliances within the same room so they will operate at their full inputs. **Follow lighting instructions for each appliance.**
13. Repeat Steps 10 and 11 on the appliance being inspected.
14. Return doors, windows, exhaust fans, fireplace dampers, and any other fuel-gas-burning appliance to their previous conditions of use.
15. **Applicable only to furnaces.** Check both the limit control and the fan control for proper operation. Limit control operation can be checked by blocking the circulating air inlet or temporarily disconnecting the electrical supply to the blower motor and determining that the limit control acts to shut off the main burner gas.

16. **Applicable only to boilers.** Determine that the water pumps are in operating condition. Test low water cutoffs, automatic feed controls, pressure and temperature limit controls, and relief valves in accordance with the manufacturer's recommendations to determine that they are in operating condition.

NOTES:

1. To properly burn 1 Ft³ of natural gas, 15 Ft³ of air is needed for combustion and to meet excess air requirements.
2. If the gas appliance is a natural draft appliance, an additional 15 Ft³ feet of dilution air is vented through the draft hood.
 - A. A mid efficiency furnace will consume 15 Ft³ of air/1Ft³ of natural gas. (1 Ft³ of natural gas = 1,000 BTUH)
 - B. A natural draft appliance will need 30 Ft³. of air/1 Ft³ of natural gas burned.

This means a 100,000 BTUH furnace would require 3000 Ft³ of ventilation/combustion air for each hour of continuous operation. If make-up air provisions are not made, the air must be replaced through infiltration air openings.

12 Three-Part Procedure for Checking a Heat Exchanger

CAUTION: If appliance fails this test, do not proceed until repairs are made.

The Gas Research Institute (GRI) funded a study to determine the most effective method for checking a heat exchanger.

1. That study and the recommendations for the testing procedures were published in the RSES Publication 630-92 9/86.
2. They determined that:
 - A. A three part testing was necessary to determine the integrity of a heat exchanger.
 - B. The three-part procedure they recommended is summarized as follows:
 1. Watch the flame when the blower comes on. The blower operation should not affect the flame pattern.
 2. Perform a visual inspection of the heat exchanger. (This may be limited by the shape of the heat exchanger and by visual obstructions such as an evaporator coil.)⁶
 3. Perform a chemical test on the heat exchanger. (Introduce a chemical that can be detected into the inside of the heat exchanger, then use an instrument that can sense that chemical in the supply air stream)
 - C. The International National Fuel Gas and Oil Codes say that you should check the heat exchanger on all service calls.
They do not specify the method.

A more modern alternative to the trace gas test is the O₂ test using a combustion analyzer. The O₂ test has several advantages over the trace gas test including testing during normal operation under normal temperatures. Leaks below the burner will be evident. Multiple tests can be performed at once including combustion air testing, heat exchanger testing, CO testing, and efficiency testing. A combustion analyzer can be used to determine unacceptable leakage, atmospheric draft appliances and draft-induced appliances using O₂ as the trace gas. The O₂ will be below 21% and stable during normal operation. When performing this test, it should be noted that as of this writing, there has been no formal field study to document the correlation of minimum leakage rates and O₂ changes. However, during lab testing, we were able to determine

⁶ The chemical test was performed with a tracer gas (nitrogen and methane) and a calibrated detector usually calibrated to 1200cc of tracer gas. The study was performed in 1986, and although validated and recommended by GRI to become part of the appendix for heat exchanger testing in the Nation Fuel and Gas Code, no method has been officially adopted into the code.

leakage through a single 1/8" test hole drilled in several locations in the heat exchanger. After each test the hole was plugged with a screw and an additional location was tested. Multiples of holes were also tested to simulate pin holing in a heat exchanger. Locations were specifically selected that avoided air blowing directly in the heat exchanger, and rather depend upon system static pressure to force additional air from the supply side into the heat exchanger. If the O₂ changes when the blower starts, there is likely leakage into the heat exchanger, and further investigation is warranted. Closing main dampers will increase supply side static pressure and further amplify the leakage rate. If cracks or holes cannot be found, the customer should still sign off in writing that they have been notified there is a potential problem with the operation of their furnace.

PERFORMING the O₂ TEST

A flue gas combustion analyzer can be used effectively for finding leaking cracks or holes in a furnace heat exchanger. **Not all cracks or holes will leak.** Smaller cracks and holes found only by a thorough visual inspection may not be leaking during the time of testing. They still pose a potential danger to your customer, as cracks will continue to open over time due to the tremendous thermal forces on the metal at the ends of the crack due to appliance cycling.

On all furnaces the static pressure achieved by the system blower can usually overcome any positive pressure in an atmospheric draft appliance. On draft-induced appliances, the pressure within the heat exchanger is always negative, causing them to leak in rather than out. Any leakage in a heat exchanger in or out poses a danger to your customer. Leaks out can allow flue gasses that may contain CO into the living space, and pressurization of a draft induces appliance heat exchanger can result in a rollout and possible fire. With all combustion, the readings on the analyzer should be stable after several minutes. When the stack temperature stabilizes, all other gas readings on the analyzer should also remain stable. ***CAUTION Readings that change during operation after stabilization has taken place are indicative of a combustion air, venting, or mechanical problem such as a cracked heat exchanger.***

Important notes:

1. Oil furnaces and older gas appliances can have leaking cleanouts that will test positive for leakage. This is not a heat exchanger failure. Inspection gaskets should be replaced and properly sealed following the manufacturer's recommendations. If the manufacturer's recommendations are not available, an industry-approved method should be used to seal the cleanout.
2. No inspection method is "fool proof." The three-part method should always be performed to maximize the safety of the appliance.

PROCEDURE:

1. Follow the manufacturer's instructions to properly zero the combustion analyzer.
2. Insert the combustion analyzer in the appropriate test position in the furnace.
 - a. For atmospheric draft appliances this would be directly in the heat exchanger cell.
 - b. For 80+/90+ furnaces this would be in the stack.
3. Start the furnace and observe the oxygen reading for stability. (1-3 minutes)
4. When the blower starts, watch for a change in the O₂ reading. If the blower starts prior to stabilization of the O₂ reading, a piece of cardboard can be inserted and removed during operation to observe if any changes in the combustion readings take place.

Corrective action:

Attempt to visually find the crack or hole.

- A. If you can find the defect, show it to the customer.
- B. On the service invoice, write that your testing indicates presence of a leak in the heat exchanger. (Do this even if you cannot find the leak.)
- C. Inform the customer, in writing, that the heat exchanger has a defect and poses a potential danger. (Do this even if you cannot find the leak.)

CAUTION: *Using the word POTENTIAL is very important. If the technician tells a customer that they will get CO poisoning, or that they are going to get sick, they can be accused of trying to scare the customer.*

- D. Explain the potential health risk:
 1. The defective heat exchanger is allowing the flue gases to enter the home/building.
 2. If poor combustion takes place, there is the potential to allow Carbon Monoxide into the structure.
 3. Carbon Monoxide is a deadly gas. It is colorless, odorless, and displaces Oxygen in the blood stream. High levels of Carbon Monoxide can cause brain damage and/or death.
 4. Ask the customer if you can shut down the furnace for their safety. Open the safety disconnect at the furnace. Record this request on your service invoice.

5. Possible solutions:
 - A. Replace the heat exchanger.
 - B. Replace the furnace.

Note: You should NEVER attempt to repair a heat exchanger.

(See the Section 20 for a format that your company may want to use if a heat exchanger shows a defect).

13 Field Modifications

13.1 Adjusting Gas Pressure Outside of Manufacturers' Recommendations

Although not published in a field or scientific study, some in the industry have recommended adjusting appliance input to improve appliance operation.

CAUTION: Testo does not recommend adjusting the fuel input outside of the manufacturer's recommended manifold pressure (usually 3.5" WC) in attempt to lower the excess air reading and or increase the combustion efficiency on appliances with or without adjustable primary air shutters.

While this may result in a slightly (2-5%) more efficient appliance due to increased radiant heat transfer, lower excess air readings, and or a lower CO levels, ***it can and usually will result in over firing the appliance and possibly condensing problems and can cause premature heat exchanger failure*** and leave unnecessary liability for the technician and company by not setting up the equipment to manufacturer's specifications. With the large variance in heat content of fuel, and factors that affect air density like temperature and humidity, excess air is a necessary evil. It should be carefully controlled and kept to a minimum whenever possible. Excess air is a required by all commercial and residential burners.

13.2 Modification of Draft hood equipped appliances to Control Draft

On furnaces with or without air shutters on the burner, controlling the draft can control the combustion air and in turn the secondary air to the furnace. This would only be true where excess draft is apparent. The addition of a double acting barometric damper to a flue that does not properly draft will not correct a low or no draft problem.

If there is no or low measured draft, the chimney and the vent pipe should be inspected for blockage, shifted tiles and or improper installation or height. Report NO. FT-C-07-93 On Performance of Drafthood Equipped Gas appliances Modified by the Addition of Barometric Dampers. A.G.A. Laboratories Field Test Program details a procedure to control draft and increase efficiency. Although this is a field report and not equivalent to a design certification, the factual information is intended to assist the code enforcing authorities and others involved in judging acceptance of the device for use in their jurisdiction. The field-testing suggested that addition of draft controls on draft hood equipped appliances can improve performance, lower CO production and improve overall operation. Testo cannot recommend this course of action because of the number of factors that must be determined in the field, but we do believe you should be aware of its findings.

Under Section 503.12.4 of the IFGC, the addition of a draft regulator is allowed provided the code requirements are followed. An important factor to remember when installing draft control devices is they control draft, not create it. The addition of a draft control device is only desirable when the draft would prove to be in excess of 31

manufacturer requires at the vent connector. If the draft hood is modified as suggested in the A.G.A. study, the installation shall be in accordance with recommendations of the equipment manufacturer and shall be approved IFGC 503.12.2.2 .

In the case of an atmospheric burner, the combustion air is drawn in by buoyancy of the heated flue gasses and mixes with the gas as it enters the combustion chamber. The fuel/air mixture burned in the combustion chamber quickly releases its heat to the heat transfer surfaces surrounding it, and the hot flue gas escapes through a draft hood into the flue.

The role of the draft hood is to prevent excessive flue draft or a back draft in the flue system from affecting the combustion process. Because flue gasses have natural buoyancy, it is not necessary for the appliance to be connected directly to the flue by design of natural draft appliances. As warm air rises and moves toward the vent connector, fresh air will be required to replace it.

So long as draft is provided at the vent connector, the low-pressure zone created in the draft hood will direct all of the flue gasses and the proper amount of dilution air into the vent pipe and chimney. If a negative pressure is created in the appliance combustion/venting zone that is greater than the draft provided at the vent connector, spillage will occur. The flue gasses will always move to the area of lowest pressure. This will occur whether a draft hood or barometric damper is installed; hence the requirement of spill switches on both to improve safety.

14 Classification of Equipment (Gas Furnaces- AFUE)

Determination of the exact equipment Annual Fuel Utilization Efficiency (AFUE) is not possible in the field. There are several types of efficiency ratings including Annual Fuel Utilization Efficiency (AFUE), Combustion Efficiency, Thermal System Operating Efficiency, and Steady State Operating Efficiency. An older furnace can have 85% combustion efficiency yet have an AFUE of 60% because of the amount of heat going up the stack, which is heat not being transferred by the heat exchanger. A 95% AFUE furnace can be operating in the 60% range due to poor installation or operation. In general; furnace efficiency (AFUE) can be generalized by the following chart and guidelines provided the installation is adequate.

60-70% AFUE range:	Standing pilot, draft diverter, belt drive blower, and a single upshot burner. Single wall flue pipe
70-78% AFUE range:	Intermittent pilot direct spark or Hot Surface Igniter (HSI), draft diverter, with/without flue damper, direct drive blower, multi cell construction with ribbon, slotted, or ported burners. Single wall flue pipe
80-89% AFUE range:	Intermittent pilot direct spark or HSI, induced draft, direct drive blower, could be multistage and/or variable speed, jet or in-shot type burners, single or double wall flue pipe. If vented in masonry chimney, chimney must be lined.
90-97% AFUE range:	Intermittent pilot direct spark or HSI, induced draft, direct drive blower, could be multistage or modulating and or variable speed, jet or in-shot type burners, secondary heat exchanger, plastic flue pipe

Thermal efficiency can be field-calculated provided the heating value of the fuel being burned is known, and accurate measurement of the airflow across the heat exchanger is made. The values should be input into the sensible heat formula and then divided by the appliance input.

15 Calculating Field Thermal Efficiency or BTUH Output

To calculate field thermal efficiency or BTUH output, measure airflow across the heat exchanger, preferably using a mini-vane anemometer such as a Testo 416. Or measure total external static pressure using a Testo 506-3 or 506-2 and using a manufacturer's chart to determine CFM. Measure the temperature rise across the heat exchanger, being careful not to let radiant energy affect the temperature reading. It is preferable to take your temperature measurements in several locations and average them. Enter the results into the sensible heat formula.

This is the heat added that causes a change in temperature of the air without adding or removing humidity to the air.

Total Sensible Heat Formula $TSH=1.08 \times CFM \times \text{delta } t$

Where: TSH = Total sensible heat in BTU per hour
CFM = Airflow in cubic feet per minute
delta t = Change in temperature (°F) across the heat exchanger

If the heat content of the natural gas is verified, the meter can be clocked and the actual input can be divided into the measured output to calculate the actual operating thermal efficiency.

Table 1: Average BTU Content of Fuels

Fuel Type	Energy Density
Fuel Oil (No. 2)	140,000 BTU/gallon
Electricity	3,412 BTU/kWh
Natural Gas	1,027 BTU/cubic foot
Propane	91,330 BTU/gallon 2,500 BTU/cubic foot
Wood (air dried)*	20,000,000 BTU/cord or 8,000 BTU/pound
Pellets (for pellet stoves; premium grade)	16,500,000 BTU/ton
Kerosene	135,000 BTU/gallon
Coal	28,000,000 BTU/ton

From U.S. Department of Energy

16 Principals of Heat and Heat Transfer

Once the fuel has been burned and the BTUs (or heat) released, the heat must be transferred to the heat exchanger or directly to the air. There are three basic types of heat transfer: convection, radiation, and conduction.

Convection is the form of heat transfer whereby the temperature of a gas or liquid, passing across another object, normally a heat exchanger, results in a transfer of energy (temperature) from the (flue) gas to the heat exchanger. We normally think of this form of heating as going from a hot gas to a cold, solid object. The more turbulent the flow, the greater the heat transfer by convection.

Convection heating is the most commonly used and important method of heat transfer in the HVAC industry since the hot gases to come into contact with most surfaces of the heat exchanger. To transfer energy to the heat exchanger, the heat energy must penetrate multiple layers of air that are electrostatically bonded to the heat exchanger surface. Air, an excellent insulator, makes this transfer difficult. Therefore, the faster that a fluid (gas stream) passes across the surface, the more rapidly these air layers will be swept away, to be replaced by hotter gases. This continuing process is convective heat transfer, and it has been made more efficient for the heating industry through the development of more complex heat exchanger designs and better burners. Excessive draft will decrease heat transfer by convection and lower the system efficiency.

Radiation is the transfer of energy (heat) between surfaces at different temperatures without the two being in physical contact with each other. The most common example is the sun and the earth. The amount of heat transfer via radiation is proportional to the fourth power of the temperature difference between the heat source (emitter) and that which is being heated (receiver).

Only those surfaces that "see" the heat source will receive the heat waves and have their temperature raised. At the higher temperatures, radiation is the most intense form of heat transfer - but only in straight-line radiation. In a furnace heat exchanger, while a significant amount of heat is transferred through radiation, more complex heat exchanger designs have increased the heat transferred by convection and conduction. For maximum radiant heat transfer, the gas pressure must be set to the maximum recommended pressure level prescribed by the manufacturer.

Conduction is the mode of heat caused by the increased activity of molecules within a body. An object heated at one end (by convection and/or radiation) will cause the opposite end to get hot by the molecules passing along the heat (energy). The speed at which this transfer occurs is a function of:

- ♦ The thermal resistance of the material (the inverse of the conductivity),
- ♦ The mass of the object,
- ♦ The temperature differential between the energy source and the surface of the body being heated.

While conduction is generally the slowest of the heat transfer mechanisms and depends on the molecular structure of the material, it is the only way to completely heat an object once the energy has been transferred by convection and radiation to the surface of the object being heated. With newer heat exchangers being low mass, the time required to reach steady state efficiency or the point at which a constant rate of input produces a constant rate of output has been significantly reduced.

NOTE: Low mass heat exchangers do come at a cost. Stresses produced on a low mass heat exchanger due to loss of airflow or low airflow, over-firing, and/or excessive short cycling can cause premature failure of heat exchanger material, and/or mechanical and or welded connections. Careful inspection should be done on an annual basis. Inspection of the heat exchanger is required if the furnace has been cycling on the high limit control, experiencing blower motor failure or has been over-firing no matter how short the length of time.

17 Combustion Testing Specific Appliances and Other Industry Practices/Procedures and Pertinent Information

CAUTION: *The following operating characteristics are given as typical. Every manufacturer should have published standards for the operating characteristics of all appliances they manufacture. The manufacturer should always be consulted prior to changing the operating characteristics of any fuel-burning appliance. No matter how good-intentioned one is when practicing field adjustment of equipment, it is not possible to consider the varied and many operating characteristics and conditions that the manufacturer has taken into account when designing and testing the appliance. Therefore, the typical operating characteristics listed here are secondary to the manufacturer's published guidelines and are intended only as a reference to typical operation of the particular appliance being tested. Commentary contained in the rest of this document is provided to increase awareness of standards and practices common to the HVAC industry.*

Since there is always 20.9% oxygen in normal air, this can be used a measure of combustion efficiency. Ideally, a flue gas analysis of 0% combustibles would be achieved with no excess oxygen in the flue gas. Manufacturers of residential appliances normally require a minimum of 20-40% excess air (5-9% O₂) to assure enough air is available for complete combustion and dilution of the flue gasses even if an appliance is dirty and suffering from neglect. If homeowners had their appliances checked on a regular basis, excess air requirements could be more tightly controlled, provided there is ample air for dilution to avoid condensing in the stack. Where clean air is taken from the outdoors as in a two pipe 90+ furnaces, air requirements are more tightly controlled. Additionally, 90% efficient appliances are condensing appliances and the air normally used for dilution of the flue gasses is undesirable for maximum efficiency of the appliance. In all cases the higher excess air requirements and the associated losses in efficiency and cost to the consumer are outweighed by the increase in safety and product reliability.

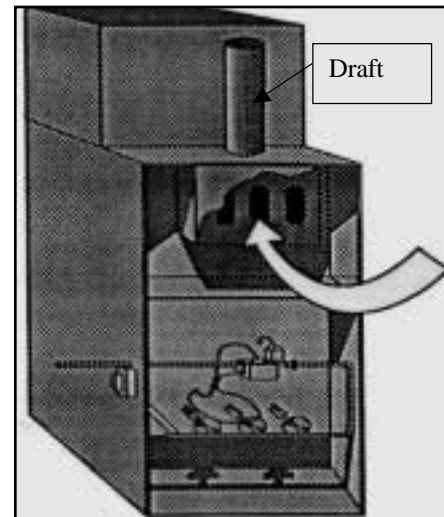
It is possible for a system to have large quantities of excess air in the area of the flame. This can come from secondary air sources or can be caused by running the burners at high excess air rates. This is particularly true in oil powered burner applications. The excess air can cause the flame to be quenched before combustion is completed, forming CO and aldehydes (CH₃CHO) as the resultant products of combustion. With oil furnaces, lowering the excess air by closing the draw band can decrease CO production. This is a required and permissible practice by burner and appliance manufacturers using oil power burners. Provisions are made by the manufacturer for this specific adjustment. Excess air requirements should be carefully controlled and within the manufacturer's specifications to assure optimum performance while minimizing the chance of condensing the flue gasses in non-condensing appliances.

17.1 Typical Readings: Atmospheric Draft Gas Fired Burners

- ♦ Efficiency 75-80%
- ♦ Oxygen: 7% - 9%
- ♦ Carbon Dioxide: 6.5% - 8.0%
- ♦ Stack Temp: 325° F to 500° F
- ♦ Draft: -0.02"WC to -0.04"WC
- ♦ Carbon Monoxide: < 100 ppm (undiluted)

Always Follow Manufacturer's Specifications

Atmospheric draft appliances tend to have higher excess air readings and higher stack temperatures due to less complex heat exchanger designs. Remember there is a positive pressure in the heat exchanger and a negative pressure in the vent connector and stack. A heat exchanger crack in this style furnace will be shown with an increase in excess air readings when the blower starts and a decrease when the blower stops. If the primary air shutters or gas pressure are adjusted, it is imperative that a combustion analysis is performed, as operating characteristics of the furnace have changed. For proper combustion and venting approximately 30 cubic feet of air is required per 1000 BTUH. This means a 100,000 BTUH furnace would require 300 cubic feet of ventilation for every hour of operation.



Measurement Procedure

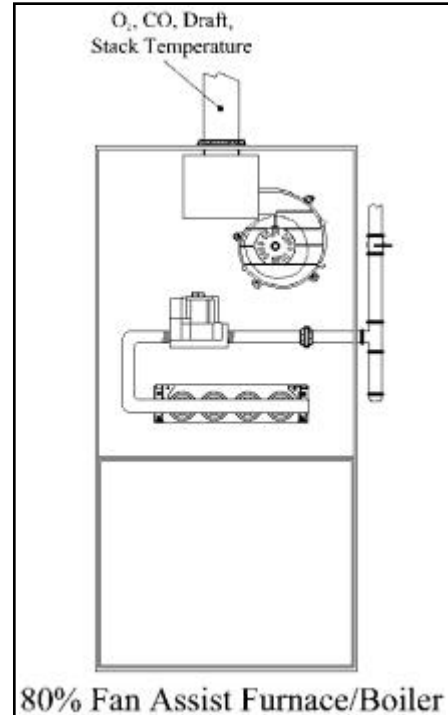
- 1) Set up the combustion analyzer per manufacturer's instructions.
- 2) Verify combustion analyzer condensate/water trap plug/access is properly sealed, there is no water in the water trap and thermocouple tip is not touching side of probe tube.
- 3) In uncontaminated air (outdoor) start the analyzer and allow unit to complete zeroing process. Never allow the analyzer to zero in the stack unless the manufacturer's design allows this, as in Testo model 330-2.
- 4) Measurements **must be made in each cell** of the heat exchanger. If needed a 5/16" hole can be made in the front of the draft diverter to allow measurement access.
- 5) Allow furnace to operate for ten minutes or until stack temperature stabilizes. The furnace must establish draft (measured in the flue pipe) with ten minutes of operation.
- 6) Measure and print combustion results for each cell in the furnace.
- 7) Compare results for each cell

17.2 Typical Readings: Draft Induced Gas Fired Burners

- ♦ Efficiency 80-82%
- ♦ Oxygen: 7.0% - 9.0%
- ♦ Carbon Dioxide: 6.5% - 8.0%
- ♦ Stack Temp: 325° F to 400° F
- ♦ Draft: -0.02"WC to -0.04"WC
- ♦ Carbon Monoxide: < 100 ppm (undiluted)

Always Follow Manufacturer's Specifications

Draft induced appliances have similar operating characteristics to atmospheric draft appliances with the exception of lower flue gas temperatures. The stack draft operates identically, but the heat exchanger pressure is now negative. The function of the draft inducer is to pull combustion byproducts through the heat exchanger, **not** to create a positive pressure in the vent. If the vent pressure is positive the flue pipe is clogged. These furnaces characteristically do not leak flue gas into the house when heat exchanger failure occurs due to the negative heat exchanger pressure. Combustion ventilation air requirements are reduced to 15 cubic feet/1000 BTUH. No dilution air is required for venting other than the excess air required by the appliance manufacturer.



Measurement Procedure

1. Set up the combustion analyzer per manufacturer's instructions.
2. Verify combustion analyzer condensate/water trap plug/access is properly sealed, there is no water in the water trap and thermocouple tip is not touching side of probe tube.
3. In uncontaminated air (outdoor) start the analyzer and allow unit to complete zeroing process. Never allow the analyzer to zero in the stack unless manufacturer's design allows this, as in Testo model 330-2.
4. Measurements must be made in the vent connector or stack.
5. Allow furnace to operate for ten minutes or until stack temperature stabilizes. The furnace must establish draft (measured in the flue pipe) with ten minutes of operation. **Verify flue gasses are not spilling from the draft hood of the hot water tank if common vented!!**
6. Measure and print combustion results prior to and after making any adjustment to the furnace.

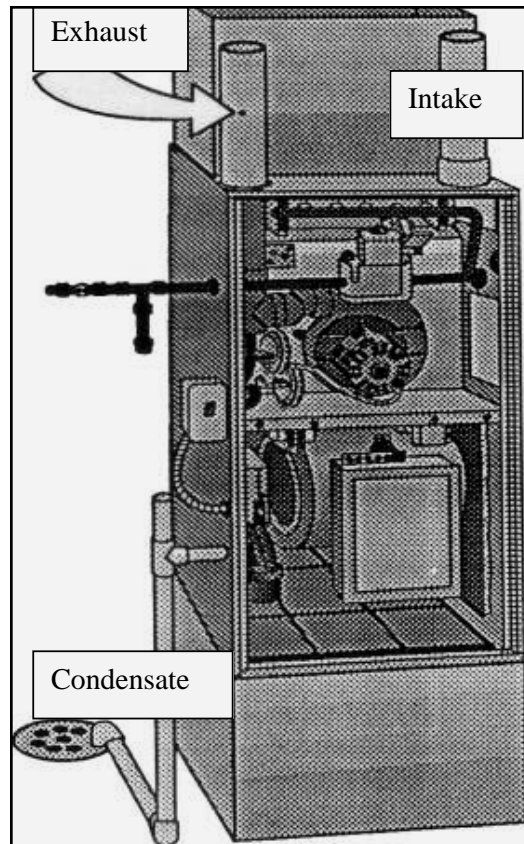
Note: If furnace is multi-stage or modulating, each stage must be checked independently to assure safe operation through the entire operating range.

17.3 Typical Readings: Draft Induced Sealed Combustion Gas Fired Burners 90+

- ♦ Efficiency 88 - 92%
- ♦ Oxygen : 5.0% - 7.0%
- ♦ Carbon Dioxide: 7.0% - 8.5%
- ♦ Stack Temp : Less than 125° F
- ♦ Draft: +0.02"WC to 0.08"WC
- ♦ Carbon Monoxide: <100 ppm (undiluted)

Always Follow Manufacturer's Specifications

High efficiency appliances are considerably different in operation. Heat exchanger pressure is negative, vent pressure now becomes positive. Flue gas temperatures drop below 125° F. Often outdoor air is used for combustion, allowing these furnaces to operate without indoor air ventilation requirements. If used with two-pipe configuration the combustion air temperature must be referenced to get an accurate combustion test result. All burner shields and doors must be in place. The high efficiency of these appliances is achieved by removing the latent heat or hidden heat from the flue gasses by condensing the water from the byproducts of combustion. This additional removal of heat through a secondary heat exchanger lowers the flue gas temperature below 125° F. High heat extractions in conjunction with careful control of combustion air allow these furnaces to operate with high combustion efficiencies and very high thermal efficiencies. Combustion air required by these furnaces is reduced to 10 cubic feet/1000 BTUH. Provisions for condensate removal must be made during the installation of condensing type furnaces and boilers.



Measurement Procedure

1. Set up the combustion analyzer per manufacturer's instructions.
2. Verify combustion analyzer condensate/water trap plug/access is properly sealed, there is no water in the water trap and thermocouple tip is not touching side of probe tube.
3. In uncontaminated air (outdoor) start the analyzer and allow unit to complete zeroing process. Never allow the analyzer to zero in the stack unless manufacturer's design allows this, e.g. Testo 330-2.
4. Measurements must be made in the PVC flue pipe, and temperature of combustion air must be properly referenced in the intake pipe (with an auxiliary temperature probe or other process) to get accurate combustion efficiency results.

5. Allow furnace to operate for ten minutes or until stack temperature stabilizes.
7. Measure and print combustion results prior to and after making any adjustment to the furnace.

Note: If furnace is multi-stage or modulating, each stage must be checked independently to assure safe operation through the entire operating range.

17.4 Typical Readings: Gas Fired Power Burners

- ♦ Oxygen: 3.0% - 6.0%
- ♦ Carbon Dioxide: 8.5% - 11.0%
- ♦ Stack Temp (gross): 320° F to 570° F
- ♦ Draft: -0.02"WC to -0.04"WC Over fire
- ♦ Draft: Positive pressure (Manufacturer's specifications)
- ♦ Carbon Monoxide: <100 ppm (diluted)

Always Follow Manufacturer's Specifications

Power burner appliances tend to have lower excess air readings and higher stack temperatures due to less complex heat exchanger designs, although some do approach condensing. Remember there could be a positive pressure in the heat exchanger and a negative pressure in the stack depending on the design. A heat exchanger crack in this style furnace may not show an increase in excess air readings when the blower starts or a decrease when the blower stops. If the primary air shutters/air band or gas pressure is adjusted, it is imperative that a combustion analysis is performed, since operating characteristics of the furnace have changed. For proper combustion and venting approximately 20 cubic feet of air is required per 1000 BTUH. This means a 100,000 BTUH furnace would require 200 cubic feet of ventilation for every hour of operation. Always set gas manifold pressure per manufacturer's specifications.

Measurement Procedure

1. Set up the combustion analyzer per manufacturer's instructions.
2. Verify combustion analyzer condensate/water trap plug/access is properly sealed, there is no water in the water trap and thermocouple tip is not touching side of probe tube.
3. In uncontaminated air (outdoor) start the analyzer and allow unit to complete zeroing process. Never allow the analyzer to zero in the stack, unless manufacturer's design allows this, e.g. Testo 330-2.
4. Measurements must be made in the stack before the barometric damper if equipped.
5. Allow furnace to operate for ten minutes or until stack temperature stabilizes. The furnace must establish draft (measured in the flue pipe) with ten minutes of operation.
6. Measure and print combustion results prior to and after any adjustments are made.

17.5 Typical Readings: Oil Fired Power Burners

- ♦ Oxygen: (Cast iron cone) 5.0 - 9.0%
- ♦ Oxygen: (Flame Retention) 3.0 - 6.0%
- ♦ Carbon Dioxide: 10.0% - 12.5%
- ♦ Stack Temp: 60 - 79% AFUE 400° F to 600° F
- ♦ Stack Temp: 80+ AFUE 330° F to 450° F
- ♦ Stack Temp: 90+ AFUE less than 125° F
- ♦ Draft: -0.02"WC Overfire
- ♦ Draft (Stack) -0.02"WC/0.04"WC
- ♦ Carbon Monoxide: < 50 ppm (diluted)
- ♦ Smoke spot #0 to #1
- ♦ Oil Pressure 100-150 psi (Per manufacturer)

Always Follow Manufacturer's Specifications

Oil power burner appliances tend to have lower excess air readings and higher stack temperatures, due to less complex heat exchanger designs. Some high and ultra-high efficiency models do approach and operate in condensing mode. Remember these furnaces must operate with a negative pressure in the heat exchanger and a negative pressure in the stack unless otherwise specified by the manufacture. A sizable heat exchanger crack in this style furnace will be indicated by an increase in excess air readings when the blower starts, and a decrease when the blower stops. If the primary air shutters/air band or oil pressure is adjusted, it is imperative that a combustion analysis is performed, since operating characteristics of the furnace have changed. For proper combustion and venting approximately 25 cubic feet of air is required per 1000 BTUH. This means a 100,000 BTUH furnace would require 250 cubic feet of ventilation for every hour of operation.



Measurement Procedure

1. Set up the combustion analyzer per manufacturer's instructions.
2. Verify combustion analyzer condensate/water trap plug/access is properly sealed, there is no water in the water trap and thermocouple tip is not touching side of probe tube.
3. In uncontaminated air (outdoor) start the analyzer and allow unit to complete zeroing process. Never allow the analyzer to zero in the stack unless manufacturer's design allows this, e.g. Testo 330-2.
4. Measurements must be made in the stack before the barometric damper if so equipped.
5. Allow furnace to operate for ten minutes or until stack temperature stabilizes. The furnace must establish draft (measured in the flue pipe) with ten minutes of operation.

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18 Understanding Air and Airflow

If the airflow is not set correctly, the system cannot operate as designed!

Airflow is one of the most overlooked yet the most important parts of verifying proper operation of heating and air conditioning systems. Low airflow can cause symptoms like heat exchanger damage, evaporator freezing, low system capacity, poor distribution and high-energy consumption. High airflow can cause symptoms of poor heat transfer, poor humidity removal, higher energy costs, noise, drafts and water/equipment damage due to water droplets blowing from the evaporator coil from excessive air velocity.

To operate with the designed capacity the airflow has to be set to the manufacturer's design criteria at the heat exchanger. Temperature drop across a coil will vary therefore it is imperative to set the airflow to the proper range and not to rely on the temperature drop across the heat exchanger to verify system performance.

The most common and easiest way to verify and set airflow is to use one of the following methods:

- 1) Rotating Vane Anemometer
- 2) Pressure drop across the heat exchanger or dry evaporator coil
- 3) Total external static pressure method
- 4) Pitot tube and digital manometer
- 5) Velocity Stick (Hot Wire Anemometer)
- 6) The temperature rise method (Sensible heat formula)
- 7) RPM and manufacturers fan curve (Belt or VF Drive)

The airflow must first be set according to the equipment design not to the register delivery. While the design of the duct system is imperative for proper air distribution to the conditioned space, air measurements are only to be measured at the appliance for the equipment commissioning procedure. Due to leakage inherent with all ducting systems, airflow cannot be measured at the registers to verify correct airflow across an evaporator coil or heat exchanger. If the system will not heat or cool the home after the airflow is properly set at the appliance and the equipment operation is verified to be correct, the problem is not with the operation of the equipment. The ducting system should then be evaluated for excessive leakage, proper sizing and proper design. A review of the load calculations may be required to verify the equipment selection was correct if the system still will not perform properly. *Do not adjust the airflow to change system-operating characteristics like air noise or low register airflow or decreased capacity and or system damage could result.*

Approximately 50 CFM per ton is lost due to leakage from poorly sealed duct systems.

When making any air flow/quantity measurements for cooling or heating all dampers must be in their normal operating position, all equipment panels and doors must be in place. Many manufacturers have a removable base pan for bottom return. If a

is used, make sure the bottom return is properly sealed, the return airdrop is securely fastened, and a proper sealant, (like Mastic®) is used to seal the connections. A digital-manometer can be used to check for pressure differential between the bottom side of the base pan and the surrounding air. The fan must be operating using the speed that will be operating when the heating is in operation. The condensing unit should not be in operation during the measurement process, as moisture that will accumulate on the evaporator coil will significantly affect the pressure differential readings. It is usually easiest to pull the service disconnect for the condensing unit, locking out the condenser.

Rotating Vane Anemometer

For highly accurate quick measurement the rotating vane anemometer is the best way to measure airflow. Vane anemometers have several advantages over any other method. The primary advantages are speed, accuracy, and ease of use. Vane anemometers do not require air density compensation due to air temperature, humidity, or atmospheric pressure. The mini vane allows for a full duct traverse with an automatic calculation of the CFM in the duct if the dimensions are input into the instrument before the measurement is taken. It is imperative that the ducting attached to the appliance, and the base pan, if side returned is used, is sealed. Air leaks up-stream of where the measurements are made will significantly alter the actual reading obtained with this method. If done carefully the measurement error will be less than 3%. Changes in yaw and pitch of the probe head in the duct as much as 10% will result less than 1% error in the measurement making the mini-vane an ideal probe for field air measurement.

Pressure drop across the dry evaporator coil

An easy way to quickly verify airflow is to measure the static pressure drop across the evaporator coil, and compare the reading to that specific evaporator coil in the manufacturer's literature. With a digital manometer, and a pressure drop vs. CFM chart, close airflow can be set across a dry coil in a matter of minutes. The positive probe should be inserted ahead of the air entering the coil and the negative probe immediately downstream of the coil. The reading obtained will be the pressure drop in inches of water column or Pascal. While this measurement is accurate enough for setting up equipment, it is not accurate enough to make a field measurement of the system capacity.

Total external static pressure method

The total external pressure method is preformed in the same manner by measuring the pressure difference across the furnace (supply to return) and using the manufacturer's chart. The CFM can also be set quickly and accurately using this method, but again, the measurement process is not precise enough to use for verification of the system capacity.

Pitot tube and digital manometer

While very time consuming, if the return airdrop is tall and straight enough, the airflow can also be very accurately verified into the appliance using a Pitot tube and a digital manometer. By traversing the duct, (making several pressure measurements in predefined locations) and performing a couple of simple calculations to convert

pressure to speed in feet per minute, the air flow is then determined by multiplying the average air velocity by the cross sectional area of the duct to obtain CFM. It is imperative that the ducting attached to the appliance, and the base pan, if side returned is used, is sealed. Air leaks up-stream of where the measurements are made will significantly alter the actual reading obtained with this method.

Velocity Stick (Hot Wire Anemometer)

A hot wire anemometer can also be used in the return air duct to verify flow. With method, (Pitot tube or anemometer), it is important to carefully traverse the duct in order to get accurate results. Until the development of the mini-vane anemometer, the Pitot tube and velocity stick were the most precise field measurement of airflow in a duct. Both however are sensitive to changes in air density outside of standard air conditions. If done carefully most technicians can achieve accuracy within 5%.

The temperature rise method (Sensible heat formula)

The temperature rise method is a last resort, and may be used for fossil fuel and electric furnaces. Because the heat content of natural gas varies from day to day and hour to hour, the temperature rise method should only be used to get the airflow close to the manufactures recommended, and can not be used for system capacity verification.

To verify CFM in a natural gas furnace, let the furnace run for ten minutes or until the stack temperature stabilizes, allowing the appliance to reach steady state efficiency. Using a combustion analyzer determine the steady state operating efficiency of the appliance and multiply it times the BTUH input to get the output BTUH of the furnace. *(Remember, if the heat is not going up the stack, it is going into the house.)*

If a combustion analyzer is not available, alternatively, the manufacturer's literature could be used to determine the output BTUH of the furnace provided the manifold pressure is correct set and the BTU content of the fuel used is consistent. (The manufacturer's tag is a good place to look for this.)

CAUTION: *Do not use efficiency information from the yellow energy guide label, as this is AFUE, (Annual Fuel Utilization Efficiency) and takes into account the efficiency losses at start-up of the equipment.*

Second measure the temperature rise across the heat exchanger. It is important to be out of the line of sight of the heat exchanger when making these measurements as the temperature probe can be affected by radiant heat from the heat exchanger. If the furnace has a bypass humidifier, make sure the bypass is closed. Then enter your results into the sensible heat formula (shown below). This is an approximate method as the heat content of natural gas varies across the United States and even from the same meter from hour to hour, and there is additional heat added from the blower motor. Heat added by the motor can be as much as 300 watts or 1024 Btu.

NATURAL GAS/LIQUEFIED PETROLEUM (PROPANE)

$$\text{CFM} = (\text{Input BTU} \times \text{steady state efficiency}) / (1.08 \times \text{delta T})$$

Delta T is the temperature rise across the heat exchanger in degrees Fahrenheit

This will give you an approximate CFM; although it will be very close to the actual if the measurements are made accurately and the heat content of the natural gas is near 1000 BTU/cf (BTUs per cubic foot of gas).

ELECTRIC HEAT

For an electric furnace the procedure is the same. Allow the appliance to operate until the temperature rise stabilizes. Measure the temperature rise again out of the line of sight of the electric heater, along with the incoming volts and current draw in amps to the electric strip heaters. Enter the information into the following formula.

$$\text{CFM} = (\text{Volts} \times \text{Amps} \times 3.41) / (1.08 \times \text{deltaT})$$

FUEL OIL

For fuel oil the procedure involves verifying the nozzle size and the correct fuel pressure. After the Nozzle size in GPM (gallons per minute) is known and fuel pressure set, the combustion efficiency must be measured with a stable stack temperature, and the temperature rise across the heat exchanger recorded.

$$\text{CFM} = ((\text{Btu/gal oil}) \times (\text{Nozzle size GPM}) \times (\text{combustion efficiency})) / (1.08 \times \text{deltaT})$$

For fuels other than those listed above see the chart in Section 19. For residential applications the standard values will be sufficient as small changes in the heat quantity of fuel will have a very small impact on final calculations.

19 BTU Content of Fuels

Since the actual heat content of different types of fuels varies, the approximate average values are often used. The table below provides a list of typical heating fuels and the BTU content in the units that they are typically sold in the United States. The figures below are general references for residential heating applications only. Commercial and industrial users should obtain more precise values from their fuel vendors.

Table 1: Average BTU Content of Fuels

Fuel Type	No. of Btu/Unit
Fuel Oil (No. 2)	140,000 per gallon
Electricity	3,412 per kWh
Natural Gas	1,027 per cubic foot
Propane	91,330 per gallon 2500 per cubic foot
Wood (air dried)*	20,000,000 per cord or 8,000 per pound
Pellets (for pellet stoves; premium grade)	16,500,000 per ton
Kerosene	135,000 per gallon
Coal	28,000,000 per ton

From U.S. Department of Energy

20 Sample form: Heat Exchanger / Venting / Combustion Problem

(COMPANY NAME HERE)

Heat Exchanger / Venting / Combustion Problem

While inspecting your furnace performing the three-part inspection procedure as outlined in Refrigeration Service and Engineering Society publication 630-92 9/86, and adopted by the Gas Appliance Manufacturers Association, and or during venting/combustion air testing outlined in the National Fuel and Gas Code, we found the following:

1. _____ The heat exchanger has a visible crack, hole, or opening that may allow the flue gasses to enter the home.
2. _____ Testing of your heat exchanger using the salt spray test (Chemical Test) gave a positive result. This indicates that the flue gasses may be entering the home through a crack, hole, or opening that is not visible to the eye.
3. _____ There is a venting or combustion air problem

Any breach in the heat exchanger or a venting/combustion air problem may allow the flue gasses to enter the home creating a potentially dangerous situation for the homeowner.

We highly recommend that you allow us to turn off the furnace until this problem can be corrected.

If you wish to continue operation of the above cited appliance, please read and sign the statement below:

I understand that by operating this appliance without correcting the problem, I assume full responsibility for any harm or damage that may result from my decision. I will not hold COMPANY NAME its heirs, or any of its employees liable for my decision.

Customer Name: _____ Date: _____

Customer Signature: _____ PRINTED _____

Technician Signature: _____ PRINTED _____



Date _____

Technician _____

Gas Furnace Inspection Procedures: Information contained in this check sheet follows a specific set of instructions outlined in: **Servicing Gas Appliances Applications Guide And Gas Heating Reference Guide for the Advanced Technician.**

Information contained is only for use by formally trained competent technicians practicing within the HVAC/R community. The manufactures' installation, operation, and service information should always be consulted, and should be considered the first and best reference for installing, commissioning and servicing equipment. The publisher/Testo assumes no liability for typographical errors or omissions of information contained herein.

Unit completed full operating cycle? Y <input type="checkbox"/> N <input type="checkbox"/> Combustion Ventilation Air Test Pass / Fail Furnace <input type="checkbox"/> 60% <input type="checkbox"/> 70% <input type="checkbox"/> 80% <input type="checkbox"/> 90 %	Burner Compartment Btu input _____ Burners clean Y <input type="checkbox"/> N <input type="checkbox"/> Carry over clean Y <input type="checkbox"/> N <input type="checkbox"/> Incoming Pressure _____ "WC Manifold Pressure _____ "WC Pilot Clean Y <input type="checkbox"/> N <input type="checkbox"/> Flame Rod μ amps _____ T-couple/PP MV _____	REQUIRED CORRECTIONS Combustion /Ventilation Air: Venting:
Venting Vent proper size Y <input type="checkbox"/> N <input type="checkbox"/> Correct vent pitch Y <input type="checkbox"/> N <input type="checkbox"/> Blockages/restrictions Y <input type="checkbox"/> N <input type="checkbox"/> Corrosion/pin holes Y <input type="checkbox"/> N <input type="checkbox"/> Condition of liner Good <input type="checkbox"/> Poor <input type="checkbox"/> Number of elbows _____ Established draft within 5 minutes Y <input type="checkbox"/> N <input type="checkbox"/>	Operation Temperature Rise Range _____ to _____ Actual Temperature Rise _____ Measured Heating CFM _____ Calculated Btuh Output _____ Total External Static Pressure _____ "wc Supply Static _____ "wc Return Static _____ "wc	Thermostat: Filter:
3 Part Heat Exchanger Test Type _____ Visual Inspection <i>Pass / Fail</i> Blower Test <i>Pass / Fail</i> Chemical Test <i>Pass / Fail</i>	Limit Circuit High Limit C/O _____ °F _____ °F Actual C/O _____ °F C/I _____ °F Pressure Switch C/O _____ "WC Actual C/O _____ "WC Auxiliary Pressure Switch G <input type="checkbox"/> P <input type="checkbox"/> Spill Switch G <input type="checkbox"/> P <input type="checkbox"/> C/O _____ Min Roll Out Switch s G <input type="checkbox"/> P <input type="checkbox"/>	Blower: Wiring: Limit circuit:
Thermostat Type _____ Model # _____ Location _____ Anticipator Setting _____ Level Y <input type="checkbox"/> N <input type="checkbox"/>	Combustion Analysis Ambient CO _____ Stack CO _____ Combustion air temperature _____ CO ₂ _____ O ₂ _____ Excess Air _____ % Stack Temperature _____ °F Combustion Efficiency _____ % Draft _____ "wc	Burner Compartment: Combustion Analysis: Operating:
Filter Size _____ Good <input type="checkbox"/> Poor <input type="checkbox"/> Replaced <input type="checkbox"/> Perm <input type="checkbox"/> Filter door in place	NOTES: 	Heat Exchanger:
Blower Voltage _____ Amps _____ Clean <input type="checkbox"/> Aligned <input type="checkbox"/> Bearings Good <input type="checkbox"/> Poor <input type="checkbox"/> Belt Good <input type="checkbox"/> Poor <input type="checkbox"/>	Manufacturer _____ Unit M/N _____ Unit Serial Number _____	
Wiring Breaker Size _____ A Good <input type="checkbox"/> Loose connections <input type="checkbox"/> Service Switch Y <input type="checkbox"/> N <input type="checkbox"/> Polarity Correct Y <input type="checkbox"/> N <input type="checkbox"/> Properly Grounded Y <input type="checkbox"/> N <input type="checkbox"/> Proper Wire Sizes Y <input type="checkbox"/> N <input type="checkbox"/> Door Switch Good Y <input type="checkbox"/> N <input type="checkbox"/> Incoming Volts _____ V Amps _____ A		

22 REFERENCES

GAMA-An Association of Appliance & Equipment Manufacturers

2107 Wilson Boulevard, Suite 600

Arlington, VA 22201

Telephone: (703) 525-7060

Fax: (703) 525-6790

www.gamanet.org

info@gamanet.org

ASHRAE

American Society of Heating Refrigerating and Air Conditioning Engineers

1791 Tullie Circle, N.E.

Atlanta, GA 30329

Telephone: (800) 527-4723

Fax: (404) 321-5478

Web: www.ashrae.org

Email: ashrae@ashrae.org

ANSI

American National Standards Institute

1819 L Street, NW

Suite 600

Washington, DC 20036

Telephone: (202) 293-8020

Fax: (202) 293-9287

Web: www.ansi.org

Email: info@ansi.org

RSES

Refrigeration Service Engineers Society

1666 Rand Road

Des Plaines, IL, 60016-3552

Telephone: 800-297-5660

Web: www.rses.org

Email: info@rses.org

International Fuel Gas Code

American Gas Association

400 North Capitol Street, NW

Suite 400

Washington, DC 20001

Telephone: (202) 824-7000

Web: www.aga.org

Email: jranfone@aga.org

Testo, Inc.
35 Ironia Rd.
Flanders, NJ 07836
+1 800-227-0729
+1 973-252-1720
Fax +1 973-252-1729
www.testo.com
info@testo.com

PART NO.: 400554 3200