A Guide To
Combustion Analyzers

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WARNING

Information contained is only for use by formally trained competent technicians practicing within the HVAC/R, building science and or weatherization 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.

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A Guide to Combustion Analyzers From TruTech Tools, LTD®

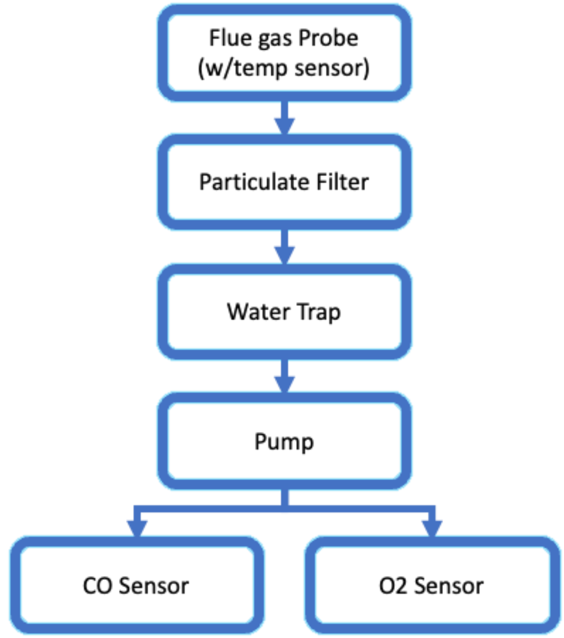
Using a Question and Answer format, this guide is designed to help all users gain knowledge about how to use and maintain combustion analyzers, as well as interpret values displayed by combustion analyzers when used on residential and light commercial appliances. The guide covers topics like operation of the analyzer, sample location, testing of combustion based appliances, basic interpretation for safety purposes, analyzer care/maintenance, and more.

What this Guide **does not** cover is identifying the source(s) of combustion safety issues, determining what repairs need to be made to return an appliance to safe operation, or performance tuning. For in-depth training covering these topics, TruTech Tools, LTD® recommends contacting National Comfort Institute, Inc (NCI) through their website at NationalComfortInstitute.com, or by phone at 800-633-7058, and scheduling to attend one of their combustion analysis training sessions where you can learn to perform in-depth combustion analysis and repairs.

Section Index

Section 1 - What is a Combustion Analyzer?

A combustion analyzer is a meter that measures properties an operator cannot otherwise see or feel, and displays information about what it measured to the operator in similar ways to a multimeter, manometer, or tape measure. To achieve this, a combustion analyzer measures the quantity of specific components of flue gas after the gas leaves an appliance, but usually before any dilution air is added. To measure these components of the flue gas, the analyzer uses a pump in the analyzer and a heat resistant probe inserted into the flue to continuously sample a small amount of the flue gas. Once the sample gas enters the analyzer, it passes through sensors inside of the analyzer, and the electronics display the values on the screen. Check out this flow diagram (some physical configurations, sensor types, and order of components may vary slightly by model and manufacturer, but the concept remains the same).



Section 2 - Why should I use a combustion analyzer?

This is an often asked question. As previously said, a combustion analyzer measures and displays things that cannot be seen in the field by other means. Measuring and displaying unseen things is done elsewhere in the HVAC/R field in places like refrigerant systems with surface temperature and pressure gauges, electricity with volt and amp meters, or airflow with a multitude of different instruments.

When combustion appliances were first made, instruments to measure combustion output were not available, so burner setup was done by means like flame shape, size and color. Just as many other things in our lives have evolved and advanced, so has instrumentation for measuring combustion. Because of these advances in instrumentation, we have learned new things, one of those being that flame color is not a reliable indication of a clean burning or safe appliance. Unfortunately, even though this new knowledge is widely available, field practices of setting up burners have largely relied on the old method of flame color.

Using flame color to evaluate equipment for safe operation can lead to things like equipment damage, liability claims, and unseen hazardous situations for technicians or building occupants.

Section 3 - What does a combustion analyzer measure, what does it calculate, and what do these values mean?

A combustion analyzer both measures and calculates values that are displayed to the operator through a numerical display and recognized units of measure. Combustion analyzers typically have three basic sensors; temperature, carbon monoxide (CO), and oxygen ($O2$); other values like carbon dioxide ($CO2$), CO Air-Free (more on this later), efficiency %, excess air, dew point, etc. are a result of calculations unless extra sensors are added (Note: some analyzers substitute a $CO2$ sensor for the $O2$ sensor, and calculate the $O2$ level in the flue gas).

Some combustion analyzers will also measure draft pressure in a negative pressure flue, which is an important piece of information to know when working on appliances that rely on natural draft to remove combustion byproducts from the appliance.

Additional sensors can be added to specific analyzers for things like; nitric oxide (NO), nitrogen oxides (NOX), nitrogen dioxide ($NO2$), sulfur dioxide ($SO2$), hydrocarbons (CxHy), high CO (higher levels that a standard sensor can handle), volatile organic compounds (VOC), hydrogen sulfide ($H2S$), and other specialty gasses for emissions testing and/or monitoring of specific equipment in accordance with regulations or manufacturers requirements.

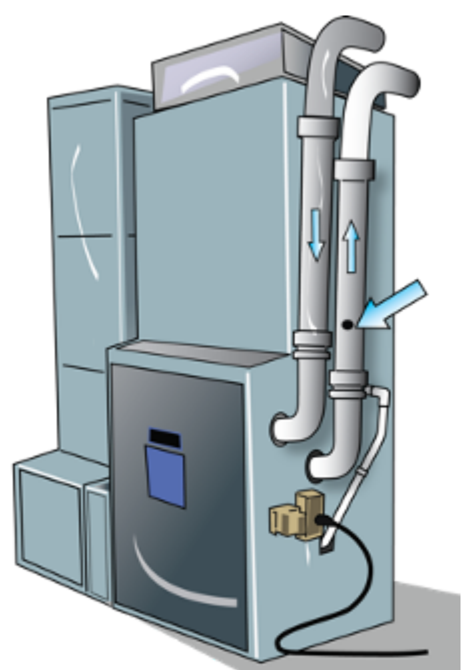
Designations on the screen for the various values do change between various manufacturers, so make sure to read all manufacturer's documentation to familiarize yourself with the way your analyzer displays values.

Displayed values have various units of measure. One of these units is "ppm", or Parts Per Million, which is used to tell the operator how much CO is in the sample of flue gas or air. This is saying that if there were one million parts in a box, and the displayed value is 55, this would indicate 55 of those million parts are what is being sensed. This is used instead of a percentage because using a percentage would result in a lot of decimal places. For example, 1% of 1,000,000 is 10,000. If an analyzer is reading 55 ppm of CO, that would read as 0.0055% concentration. Saying 55 ppm of CO is much easier than saying 0.0055% of CO.

Section 4 - Does sample location matter?

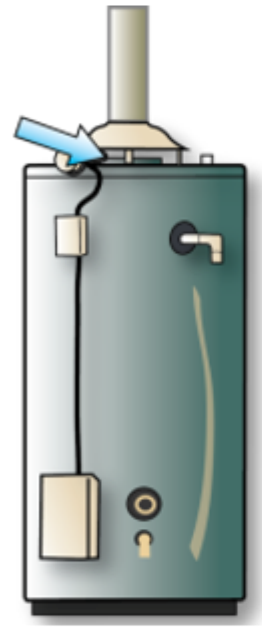
The short answer is yes. The long answer is that obtaining a flue gas sample from an incorrect location can result in the combustion analyzer displaying values that are inaccurate, which are not representative of actual equipment operation. If these inaccurate values are used to make decisions about equipment repairs or replacement, the company/person representing inaccurate data could be on the hook for that mistake.

Just like measuring refrigerant pressures and temperatures, or air temperatures in a duct system, location matters.

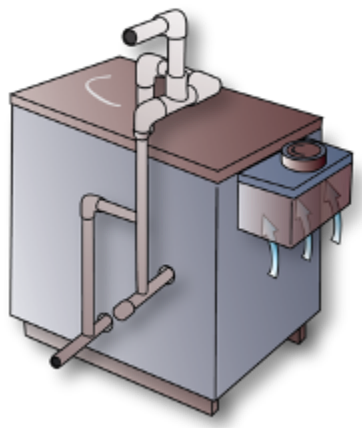


90% Furnace Condensing

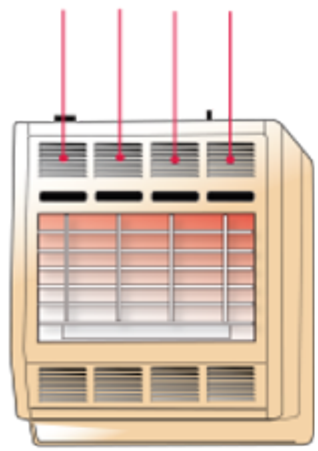
When analyzing combustion of an appliance, the basic goals are to determine: if the fuel is being burned as completely as possible, if there is excessive excess air passing through the combustion process, and if the correct amount of heat is being transferred from the flue gasses into the heat transfer fluid (fluids exist as gas or liquid).



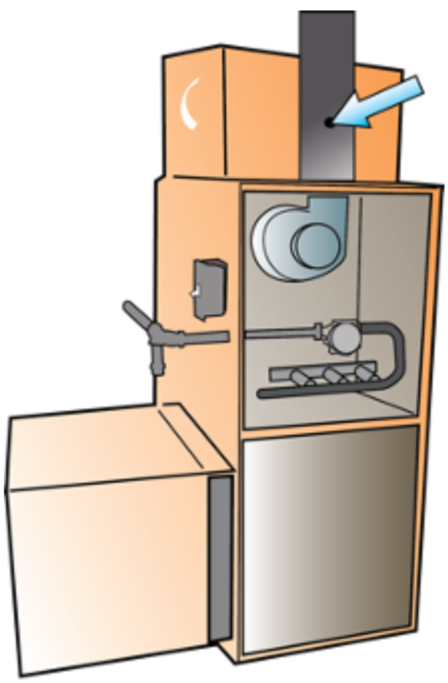
Water Heater



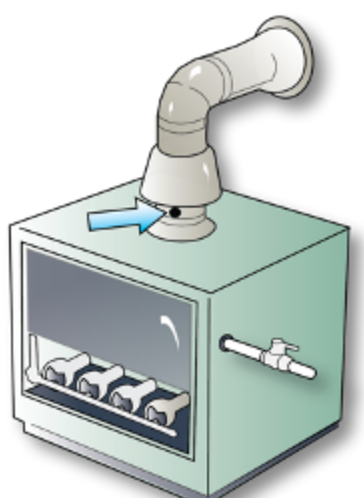
Natural Draft Boiler Rear Drafthood



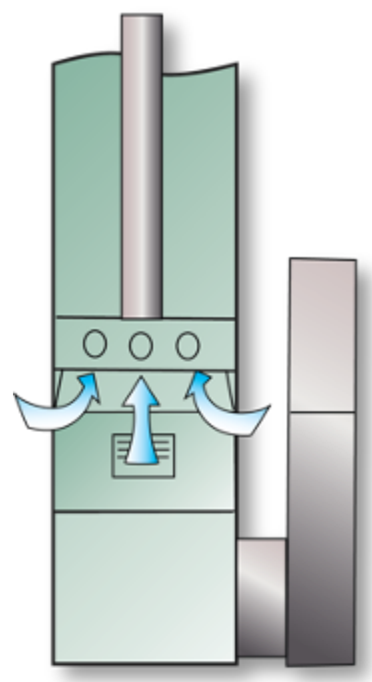
Space Heater



80% Induced Furnace

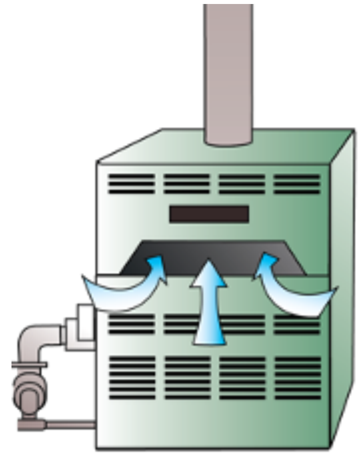


Natural Draft Boiler Top Draft Hood



Natural Draft Furnace

With the previous guidelines in mind, the sample location for combustion analysis needs to be prior to any dilution air being added to the flue gas, but after the flue gas has passed completely through the heat exchanger. The included equipment images (courtesy of NCI) indicate test locations on common appliances (if your appliance type is not shown, just remember to get your sample after the heat exchanger, but prior to any dilution air being added).



Natural Draft Boiler
Front Draft Hood

Section 5 - How is a combustion analysis performed?

Combustion analysis is a process that begins with the equipment in standby (power applied, but no call for the burner). Start at the beginning and complete the whole process to make sure all data is gathered.

During this process the user should be observing values displayed on the screen almost constantly to understand what is happening. Your job is to observe and interpret the values being displayed on the screen.

- ☐ Start the combustion analyzer outside the testing area in the cleanest air available (the sensors zero themselves to whatever is in the air at startup, so make sure there are no combustion exhaust sources like a running vehicle nearby)
- ☐ Identify the type of appliance being tested
- ☐ Identify the sample location in the flue or appliance as shown in Section 3
- ☐ Insert the sample probe into the sample location, start the analyzer pump, then start the appliance
- ☐ Observe (or record) the displayed values on the screen through the startup, run, and shutdown processes
- ☐ Remove the analyzer probe from the sample location after the burner(s) are completely shut down
    - This is done so to evaluate seals in the gas valve for leakage (we encourage you to seek out further education opportunities about this and other topics)
- ☐ Leave the analyzer pump running until the readings on the screen return close to normal air values
    - Removing any residual combustion gasses from sensors will allow them to last as long as possible

Section 6 - What levels are acceptable?

One of the primary concerns that combustion analyzer operators look for when performing an analysis is elevated CO levels. The presence of elevated CO levels in flue gas samples indicates that not all of the fuel is being burned (converted to heat energy) before it leaves the appliance. If CO levels become high enough, visible soot starts to form, which creates more problems (occupant safety risks, reduced heat transfer, impeding flow of flue gasses, etc.).

To ensure equipment is operating correctly and safely, flue gas levels are set by manufacturers, regulators and the industry. Always follow manufacturer recommended levels if they are provided, otherwise you may need to follow industry limits for safety. Table 1 (below) shows industry accepted standard maximum levels for safety purposes.

The US EPA National Ambient Air Quality Standards limit CO exposure to 35 ppm average for 1 hour, or 9 ppm average for 8 hours. These are not to be exceeded more than once per year.

From: ANSI/BPI-1200-S-2017, Section 7.9.7, Table 1

Carbon Monoxide (CO) Thresholds for Fossil-Fuel Fired Combustion Appliances

Appliance	Threshold Limit
Central Furnace (all categories)	400 ppm air free
Boiler	400 ppm air free
Floor Furnace	400 ppm air free
Gravity Furnace	400 ppm air free
Wall Furnace (BIV)	200 ppm air free
Wall Furnace (Direct Vent)	400 ppm air free
Vented Room Heater	200 ppm air free
Unvented Room Heater	200 ppm air free
Water Heater	200 ppm air free
Oven/Broiler	225 ppm as measured
Clothes Dryer	400 ppm air free
Refrigerator	25 ppm as measured
Gas Log (gas fireplace)	25 ppm as measured in vent
Gas Log (installed in wood burning fireplace)	400 ppm air free in firebox

In addition to acceptable CO levels provided by the industry, NCI has done extensive testing and determined safe and effective levels for Oxygen in flue gas samples for most heating equipment on the market.

From NCI:

Oxygen (O2) levels in undiluted flue gas	
All appliances	6-9% (Unless otherwise specified by the manufacturer)

Note: Some equipment manufacturers specify CO2 values in the flue gas instead of O2 values. If a CO2 value is specified, follow the manufacturer instructions for proper burner setup.

Section 7 - What is the difference between “air-free” and “as-measured” CO?

“As-measured” Carbon Monoxide is indicated on the display of a combustion analyzer with “CO” next to the value. The “air-free” CO (Displayed as: COAF, COun, CO Air-Free, COa, depending on the analyzer manufacturer) value is calculated from the “as-measured” CO value, and the Oxygen percentage value displayed on the screen. Almost all modern analyzers today will calculate CO Air-Free and display it on the screen. In case you have an older analyzer that doesn’t do the calculation, the math is shown below (tip: after calculation the COAF value will always be higher than the displayed CO level).

$$COAF\ ppm = \left(\frac{20.9}{20.9 - O2}\right) \times COppm$$

Example: Displayed CO = 152 ppm, Displayed O2 = 11%

20.9 - 11 = 9.9
20.9 / 9.9 = 2.111
2.111 x 152 = 321 ppm COAF

If you would like to learn more about CO air-free calculations and why this value is used, a great resource is available as a PDF from karg.com titled, Air-Free Measurement of Carbon Monoxide Emissions from Gas Ranges: Analysis and Suggested Field Procedure
By Richard Karg, R.J. Karg Associates

Section 8 - Can a combustion analyzer identify a failed heat exchanger?

The answer to this question is not straightforward. Because a combustion analyzer takes measurements after the heat exchanger in the combustion gas path, indications of a failed heat exchanger can be displayed if the right conditions exist. This does not mean that a combustion analyzer is the only tool that should be used to determine if a heat exchanger has failed, because a combustion analyzer will only indicate an issue exists if the normal combustion process is affected by the failure. If the combustion process is not affected, it is possible to have a failed heat exchanger with no indication of the failure during combustion analysis. For this reason, we recommend obtaining additional knowledge and tools to identify failures in heat exchangers using visual or other means.

Section 9 - What safety concerns exist when performing a combustion analysis?

When performing combustion analysis, technicians should be aware of hazards like flue gas spillage, hot surfaces, condensate leakage, nearby controls, and other hazards. Personal Protective Equipment appropriate for the situation such as gloves, safety glasses, and long sleeves are recommended.

Section 10 - If a combustion analyzer is used, should I also wear a personal CO monitor?

The simple answer is that carrying a personal CO monitor whenever you are around combustion appliances is always a best practice, and carrying one when traveling has shown that CO shows up in some very unexpected places.

Personal CO monitors and combustion analyzers serve two very different purposes. A personal CO monitor is there to continuously monitor the air you are breathing and sound an alert if levels in that air become elevated (think of a personal CO monitor like a smoke detector, turn it on and leave it on until the sensor goes bad), where a combustion analyzer is designed for measuring levels in flue gas. Yes, an analyzer can measure ambient CO in spaces, but the pump must be running, and a large analyzer is not nearly as convenient as a personal monitor clipped to a belt.

When worn constantly, a personal monitor also protects the wearer when an analyzer is not being used, and can be a great conversation starter with a homeowner if an alarm occurs while a technician is in their home. If a personal CO monitor with an adjustable alert threshold is set at 10-15 ppm, an early warning is in place to notify of a potentially hazardous situation prior to someone getting injured.

Section 11 - Do combustion analyzers require maintenance?

Just like the equipment being serviced, combustion analyzers require regular care and maintenance. The following are general recommendations based on field experience. Always refer to the manufacturer's operation manual for best practices compatible with your specific analyzer.

Daily maintenance:

- [ ] Empty the water trap regularly to keep moisture from entering the sensors
- [ ] Inspect and replace inline particulate filters regularly
- [ ] Protect the instrument from freezing (take it inside at night)
- [ ] After a test, allow the pump to run with the probe in a clean environment until the CO reading reaches 0-1 PPM
- [ ] Check external hoses and/or gaskets for cracks or damage (some analyzers have the ability to evaluate their sample path for integrity)

Annual maintenance:

- [ ] Send analyzer to an authorized servicer or factory for calibration and performance checks (visit TruTechTools.com for information on combustion analyzer calibration and minor service tasks)
- [ ] Detailed physical inspection of internal hoses and gaskets
- [ ] Sensor replacement on a regular basis
    - Most sensors used in combustion analyzers are electrochemical based, which means they wear out over time, and therefore require regular replacement
    - Replacing sensors at manufacturers recommended regular intervals can prevent breakdowns in the field

Section 12 - What are the different vent types used on appliances?

There are 4 different vent types used on gas appliances, these are defined as Categories (Cat) I, II, III, and IV by the International Fuel Gas Code (IFGC). These descriptions refer to the pressure in the flue when measured in reference to the surrounding area near the appliance outlet, and the relationship of flue gas temperature to dew point temperature inside of the vent system.

- Cat I - negative pressure, non-condensing
    - These flue types are common, made from single or double wall metal pipe, and the flue gas is hot enough to burn a human if we come into contact with it or the metal pipe that contains it.
- Cat II - negative pressure, condensing
    - Appliances using this category are non-existent because when the flue gas is cooled enough to condense moisture inside of the pipe, it does not have enough heat content to create a natural draft to remove flue gas from the appliance.
- Cat III - positive pressure, non-condensing
    - Appliances using this category are rare, but a few examples can be located in some areas.

    - These systems will be constructed of metal with gas-tight sealed connections so that flue gas does not escape

- Cat IV - positive pressure, condensing
    - This category is very common, and typically uses plastic pipe of some type due to the condensation that forms inside of the flue pipe.
    - This category requires special considerations to get rid of the condensation.
    - Make sure to follow manufacturers instructions for flue installation.

Section 13 - How should a test port be sealed?

Understanding which vent type is present plays a part in choosing a strategy to close/seal the sample location when testing is complete.

In the case of a Cat I vent system with a single-wall flue pipe, a small amount of dilution air will be pulled in through an open test hole, and while this really doesn't hurt anything in the grand scheme, many customers will not understand this, so best practice is to plug the hole with something removable for future access.
In single-wall flue pipes a small metal plug is generally considered acceptable (foil tape is not designed for the high temperatures encountered on non-condensing single-wall flue pipes). *Note: because the flue is under a lower pressure than the surrounding spaces, this plug does not need to be sealed any tighter than the joints in the single-wall flue pipe.*

In the case of a Cat IV vent, if a test port is left unsealed there are a couple of immediate concerns. First being that flue gas could be introduced into the occupied space, and second that condensate is often present and could lead to water damage of equipment or other personal property. With these concerns in mind, a positive pressure flue test location needs to be sealed air and water tight. When installing a new flue it is a good idea to also install a sample location that can be easily sealed now and opened later for testing. If an existing flue is being tested it may be necessary to drill a test port through the flue pipe (*follow code requirements*). When drilling into a plastic flue to make a test port, know the size plug that will be used to seal the hole, and drill at a slight downward angle so condensate will naturally run back into the pipe. Silicone plugs (similar to the red one shown in the image) work well for sealing test ports in condensing flue pipes, and can be easily removed for regular testing.

Section 14 - How are test ports installed and sealed in Type-B vent systems?

Combustion testing in Cat I Type-B vent systems requires drilling through the inner and outer wall of the vent material. This has been approved by multiple manufacturers, as long as the AHJ is accepting of the practice, and any recommendations for sealing the test port are met. This generally means that the inner hole must be as small as possible and be sealed with a high temperature flexible sealant, while the outer hole can be slightly larger to allow access and be sealed with the same sealant as the inner hole or aluminum tape.

Letters from Type-B vent system manufacturers detailing their recommended processes and concerns are hosted for your convenience by TruTech Tools, LTD® and can be viewed at http://www.bit.ly/B-Vent

Section 15 - What happens if the CO level on the analyzer screen goes close to or above the upper measurement limit?

If the CO ppm displayed on the screen goes up suddenly when it should not (any time other than the ignition period), or gets above the upper limit of the sensor, disconnect the probe from the analyzer or remove the probe from the flue to get fresh air into the gas path immediately.

If a CO sensor is exposed to excessive amounts of CO for even a short time, permanent damage can occur. Some sensors are more resilient than others, and some manufacturers have built protection features into their analyzers, but it is a good idea to keep a close eye on the levels during a test so that damage to the analyzer does not occur.

Section 16 - What if CO alarms go off, but no source of CO is located?

This happens periodically. Most CO sensors have cross sensitivity to a few other gasses, one of which is Hydrogen, which can be expelled at low levels while lead-acid batteries are charging. If no other source of CO can be located, look for a battery being charged in a location that could have an air pathway to the alarming CO sensor. If the Hydrogen is present your combustion analyzer will likely indicate a low level of CO, just like the alarm. Some common sources are a golf cart, or a sump pump backup power source. Depending on the situation, a CO sensor measuring Hydrogen may be an indication of a lack of ventilation, or an unintended air path between two spaces.

Hydrogen compensated CO sensors are available on some higher end combustion analyzers, so knowing what type of sensor your analyzer contains is important should you encounter this situation.