Combustion Safety & Testing: Do No Harm

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ADVANCING HOME PERFORMANCE

RESNET
Setting the Standards for Quality

RESNET 2009 CONFERENCE New Orleans February 15-18, 2009

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HOME PERFORMANCE WITH ENERGY STAR

Course Description

- Effective insulation and air sealing treatments can make a huge difference in the tightness of a home. In some cases, well-intentioned work can cause undesirable and dangerous consequences - and making customers sick is bad for business!
- Understand the conditions that contribute to back drafting, spillage, or carbon monoxide production.
- Find out how to recognize visual indicators of combustion problems.
- Learn how integrating combustion safety testing can lower your liability, separate you from competition, and increase your profit.
- Recognize the importance of inspecting and testing combustion safety in every home
- Learn how to identify common causes of carbon monoxide production
- Explore several types of diagnostic equipment and testing tricks
- Get your tricky combustion safety questions answered

Goals of this session

- Some Combustion Basics
- Recognize the need for combustion safety testing on gas fired equipment
  - Test In/Test Out
- Recognize the interaction and impact of various features of the home on combustion equipment
- Learn how and where to test for CO, draft spillage, and CAZ pressure
- Be familiar with testing protocols and equipment

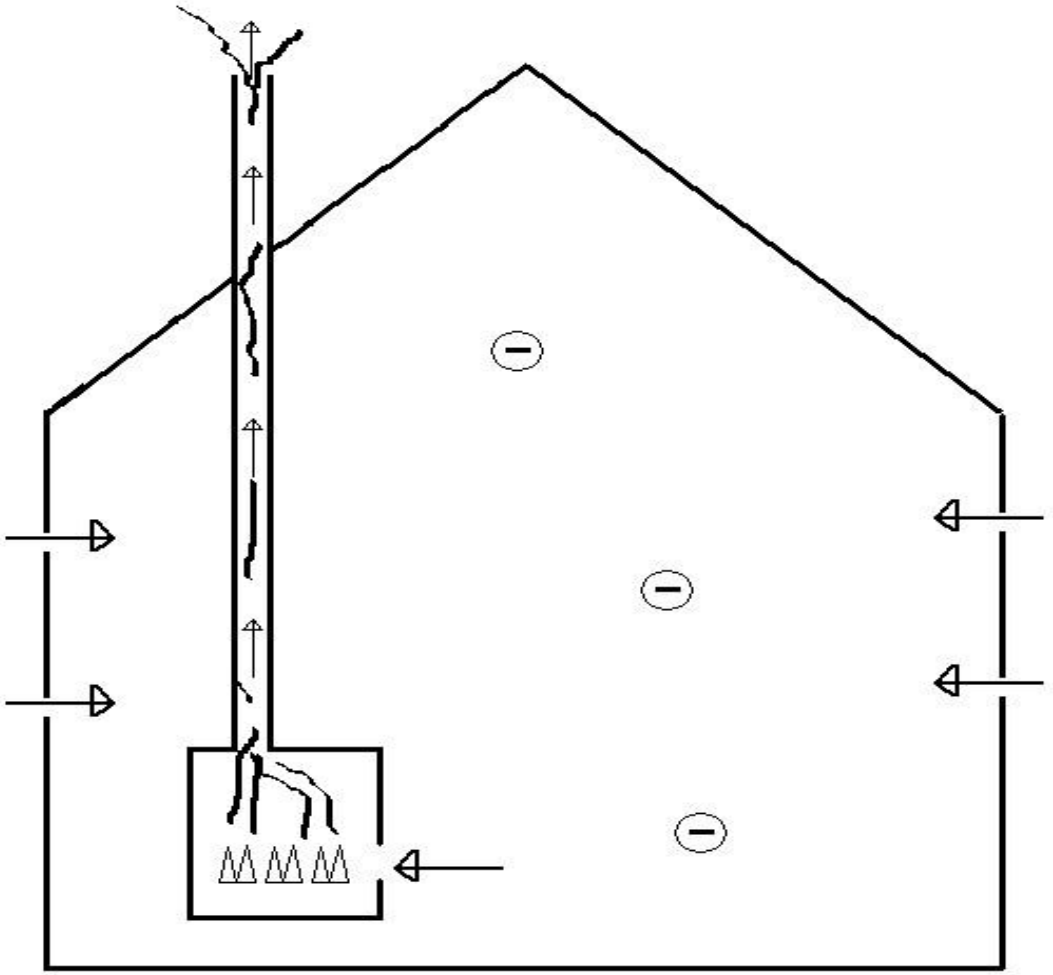
Introduction

- Who are you?
  - HERS Raters?
  - Weatherization Technicians?
  - Home Performance Contractors?
  - Home Improvement Contractors?
  - BPI Certifications?
- Is anyone doing combustion safety testing?
  - What protocol?
- Why do you feel the need for this testing?

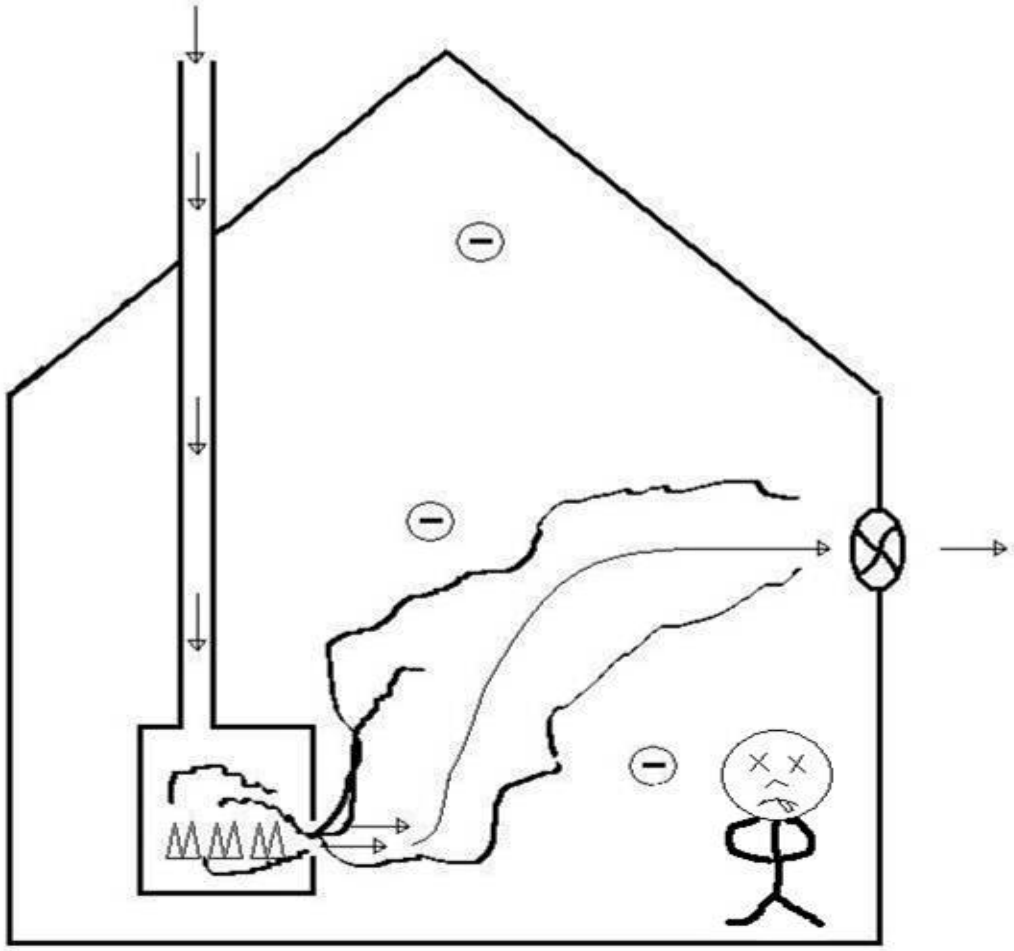
Finish this sentence…

- The house is a…

Systems Thinking-Before

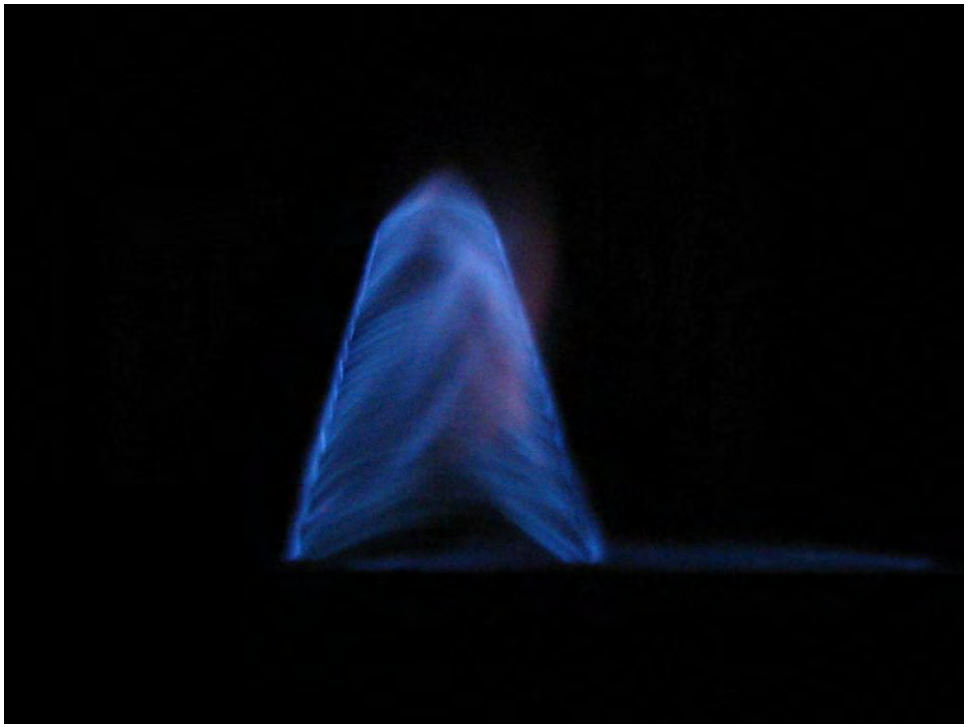


Systems Thinking-After



Combustion-How It Works

- Combustion of any fuel (natural gas, propane) requires three things:
  - Fuel
  - Air
  - Ignition Source
  - Equals…



Byproducts of Combustion

- Combustion byproducts-(complete combustion)
  - Oxygen
  - Carbon Dioxide
  - Water
  - Nitrogen
- Incomplete Combustion –Carbon Monoxide

Fuel-Natural Gas

- Composed mainly of methane (81%)
- Lighter than air (specific gravity .65)
- BTU content/cu.ft. =700 to 1200
- Ignition temperature of 1100° to 1200°F
- Typical manifold pressure = 3.5" WC

Propane

- Composed mainly of propane (95%)
- Heavier than air (specific gravity 1.53)
- BTU content/cu.ft. =2500 to 2700
- Ignition temperature of 920° to 1020°F
- Typical Manifold pressure = 11" WC

Heating Oil

Grade Heating Value(*Btu/gal*)

- Fuel Oil No. 1 132,900 - 137,000 Small Space Heaters
- Fuel Oil No. 2 137,000 - 141,800 Residential Heating
- Fuel Oil No. 4 143,100 - 148,100 Industrial Burners
- Fuel Oil No. 5 (Light) 146,800 - 150,000 (preheating in general required)
- Fuel Oil No.5 (Heavy) 149,400 - 152,000 (heating required)
- Fuel Oil No. 6 151,300 - 155,900

Air

- Combustion Air
  - Primary
  - Secondary
  - Dilution
  - Excess
- Natural gas appliances needs 10 cubic feet of combustion air for every 1 cubic foot of fuel.
- Propane appliances needs 25 cubic feet of combustion air for every 1 cubic feet of fuel.

Combustion Air Guidelines

- Uniform Mechanical Code Chapter 7:
  - "Two openings, with each opening having one square inch/4000 btu"
  - Other variations on this, depending on jurisdiction (local codes), equipment type and location.

How much air is needed

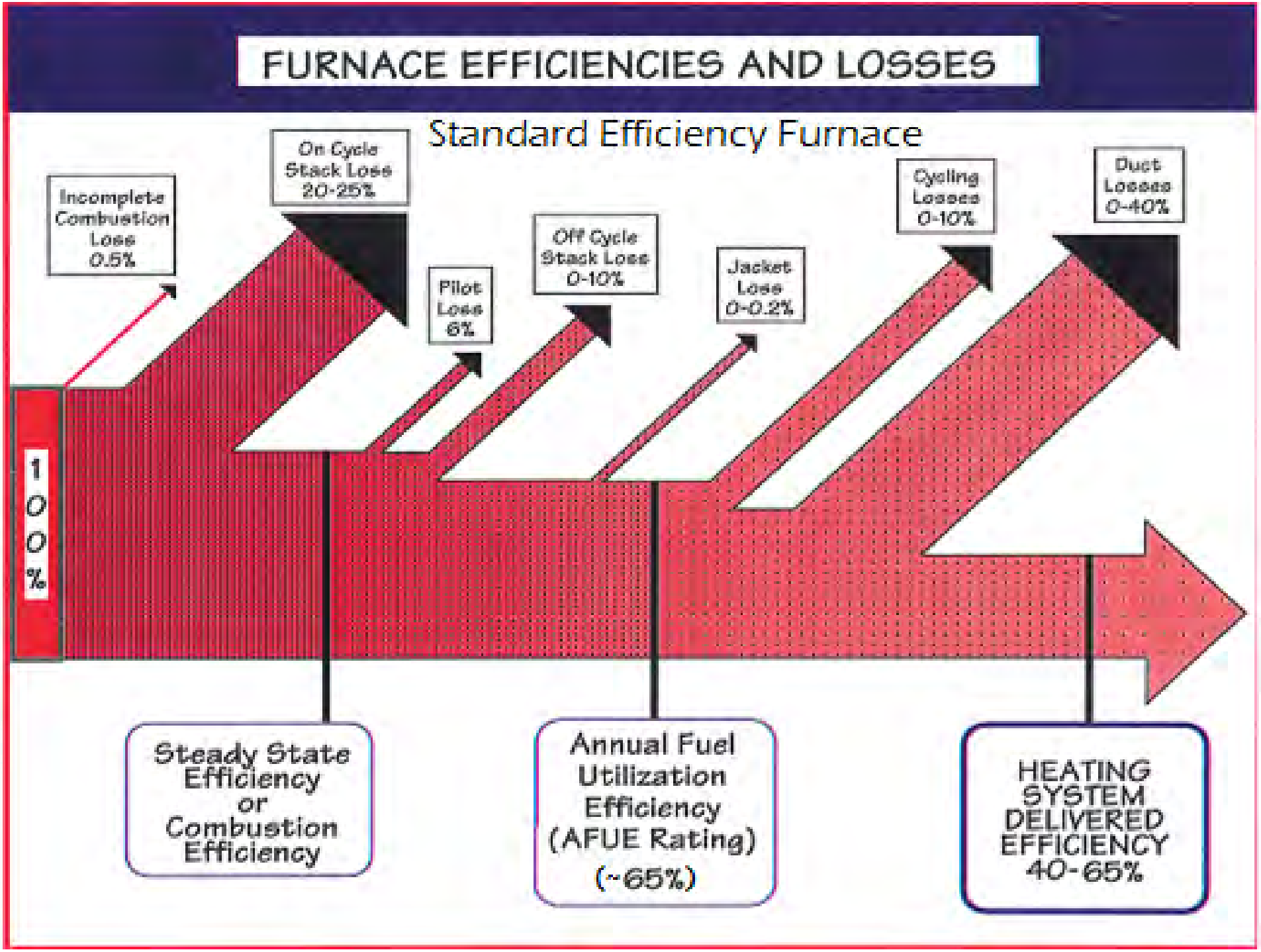
- Assuming 1000 btu/cubic foot of gas, then:
- A 100,000 btu furnace requires 1000 cubic feet of air for every hour it burns.
  (100,000 btu = 100 cubic feet of gas x 10 cubic feet of combustion air/ft = 1000 cubic feet of air)
- Where is this air coming from? How is combustion air allowed to the appliances?

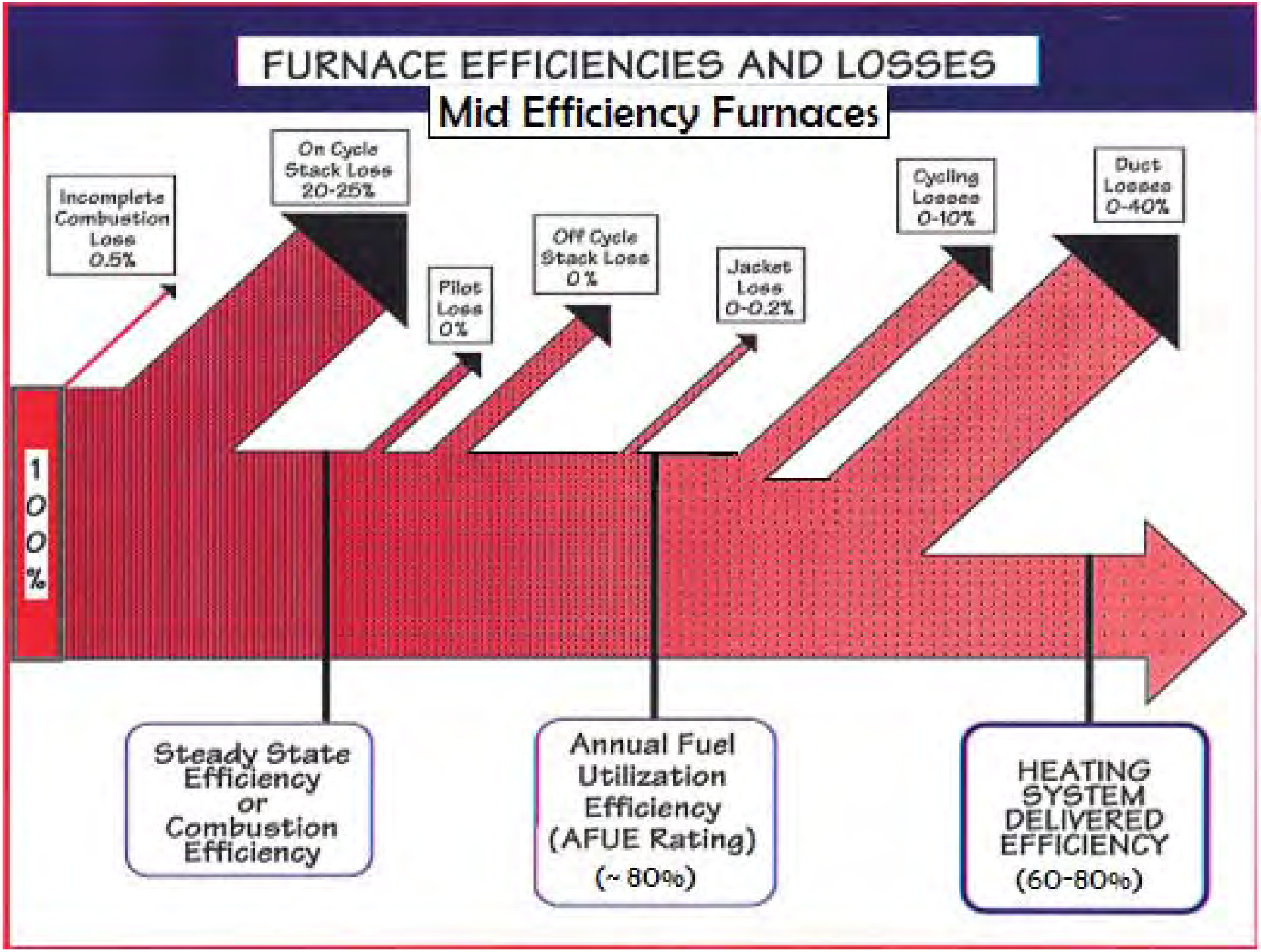
How much air is present?

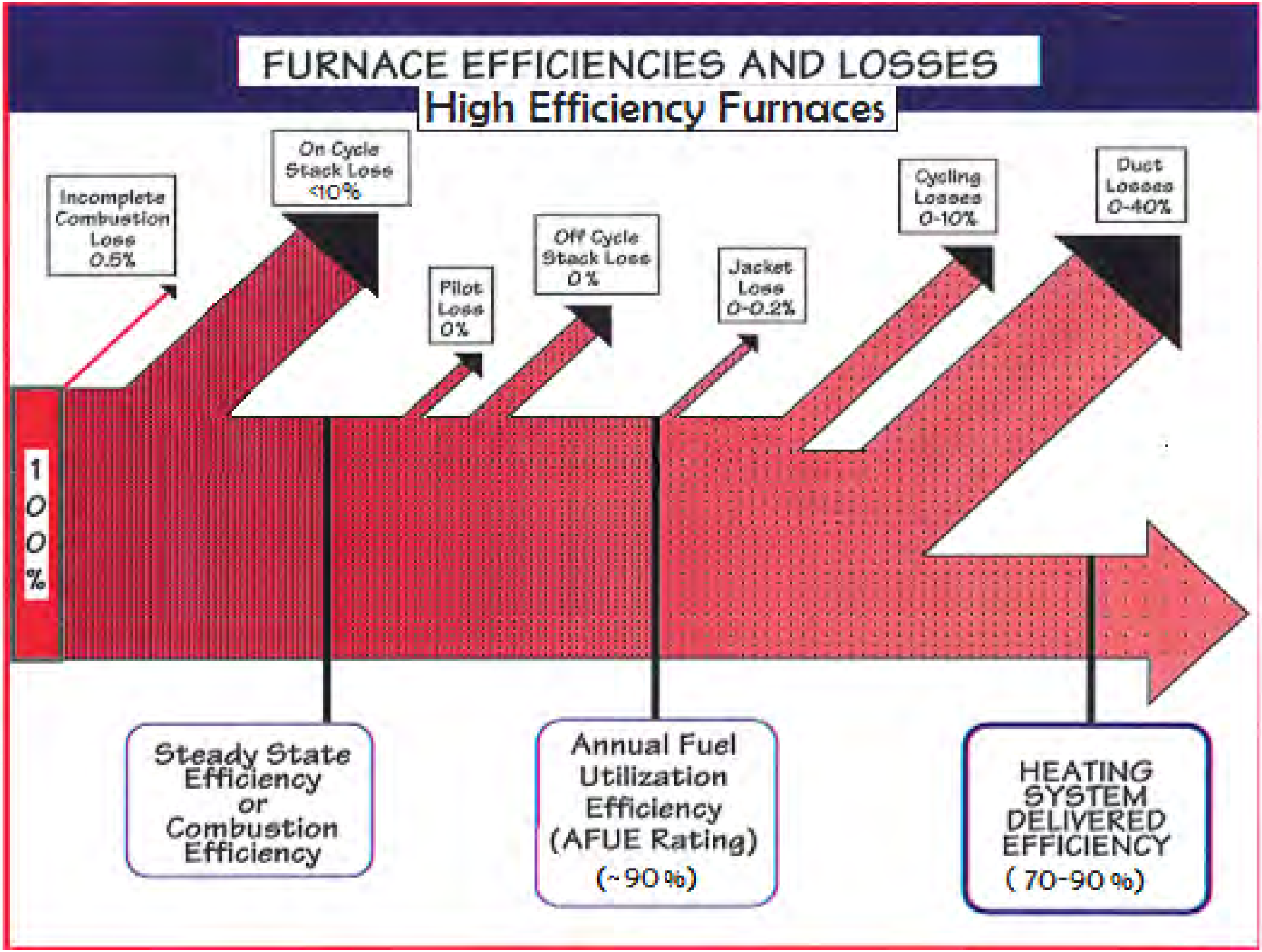
- 1000 square ft. home, 8’ ceilings = 8000 cubic ft. volume.
- Total appliances =160,000 btuh.
  - Furnace = 75,000 DHW = 40,000
  - Dryer = 25,000 Oven = 20,000
- Need 50 cubic feet/1000 btu
- Need 8000 cubic feet (enough is present)

Ignition Sources

- Standing Pilots
- Electronic
  - Spark Ignitors
  - Hot Surface Ignitors
- Others
  - Matches, candles…"manual" ignition!
  - (Not a good idea!)


FURNACE EFFICIENCIES AND LOSSES
Standard Efficiency Furnace
Incomplete Combustion Loss 0.5%
On Cycle Stack Loss 20-25%
Pilot Loss 6%
Off Cycle Stack Loss 0-10%
Jacket Loss 0-0.2%
Cycling Losses 0-10%
Duct Losses 0-40%
100%
Steady State Efficiency or Combustion Efficiency
Annual Fuel Utilization Efficiency (AFUE Rating) (~65%)
HEATING SYSTEM DELIVERED EFFICIENCY 40-65%


FURNACE EFFICIENCIES AND LOSSES
Mid Efficiency Furnaces
Incomplete Combustion Loss 0.5%
On Cycle Stack Loss 20-25%
Pilot Loss 0%
Off Cycle Stack Loss 0%
Jacket Loss 0-0.2%
Cycling Losses 0-10%
Duct Losses 0-40%
100%
Steady State Efficiency or Combustion Efficiency
Annual Fuel Utilization Efficiency (AFUE Rating) (~ 80%)
HEATING SYSTEM DELIVERED EFFICIENCY (60-80%)


FURNACE EFFICIENCIES AND LOSSES
High Efficiency Furnaces
Incomplete Combustion Loss 0.5%
On Cycle Stack Loss <10%
Pilot Loss 0%
Off Cycle Stack Loss 0%
Jacket Loss 0-0.2%
Cycling Losses 0-10%
Duct Losses 0-40%
100%
Steady State Efficiency or Combustion Efficiency
Annual Fuel Utilization Efficiency (AFUE Rating) (~90%)
HEATING SYSTEM DELIVERED EFFICIENCY (70-90%)

Open & Closed Combustion Appliances

- Open Combustion:
  - An appliance that gets its combustion air from the same area as the unit is located
    (you could reach in and touch the flame)
- Closed Combustion: (aka Sealed Combustion)
  - An appliance that gets its combustion air from the outdoors, piped directly to the unit's burner area (the combustion chamber is completely sealed and isolated from the zone it is located in)

Draft / Venting

- Since all combustion appliances create combustion byproducts, they must be removed to the outside via a venting system (masonry chimney, single or double wall metal pipe, or plastic vent, etc.).
- Drafting:
  - (Negative pressure) A current of warm exhaust gasses. This effect creates a slight negative pressure, carrying the gasses out of the home via a chimney or vent stack.
  - Positive pressure venting involves the use of a fan to push exhaust products out of the home.

Drafting

	Negative-pressure Venting	Positive-pressure Venting
Non-condensing	**I** Combustion Efficiency **83% or less** Use standard venting: masonry or Type B vent	**III** Combustion Efficiency **83% or less** Use only pressurizable vent as specified by manufacturer
Condensing	**II** Combustion Efficiency **over 83%** Use only special condensing-service vent as specified by manufacturer	**IV** Combustion Efficiency **over 83%** Use only pressurizable condensing-service vent as specified by manufacturer

American Gas Association Vent Categories

Most residential furnaces are either Category I (standard or mid-efficiency) or Category IV (high efficiency).

Four Factors for Good Drafting

- Delta T = Delta P
  - The greater the temperature difference, the greater the pressure difference (draft)
- Vent Height
  - The greater stack height, the greater the draft
- Friction
  - Venting design & installation
- Air Flow
  - Is there enough combustion air?

Open Combustion Appliances

These are both open combustion appliances. Air for combustion is drawn from the same area (zone) as the appliance. It is often house air.

Category I Furnaces

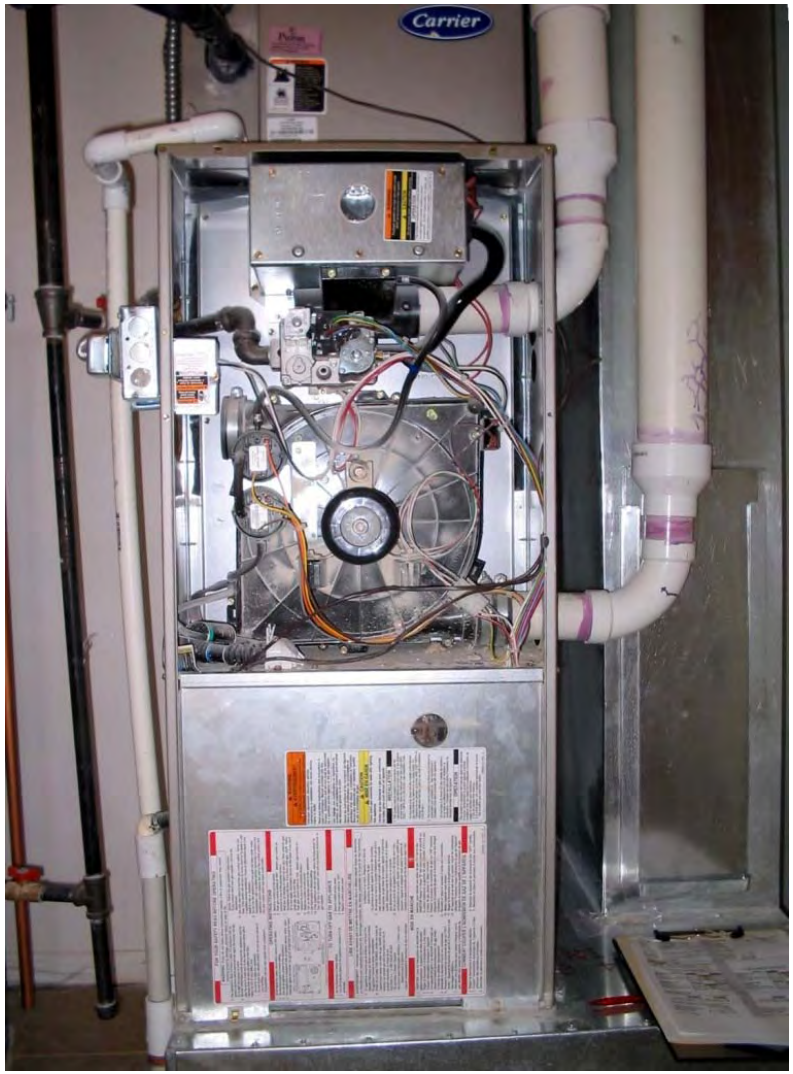
Each of these furnaces, though different AFUEs, are Category I appliances.

(The left unit is ~ 65%, the right is 80%. Each has negative pressure venting, non-condensing)

Open or Closed? High Efficiency?

- This is a Category I open combustion furnace. The combustion air source is house air, as it the hot water tank next to it.
- AFUE = 80%

Category IV Furnaces

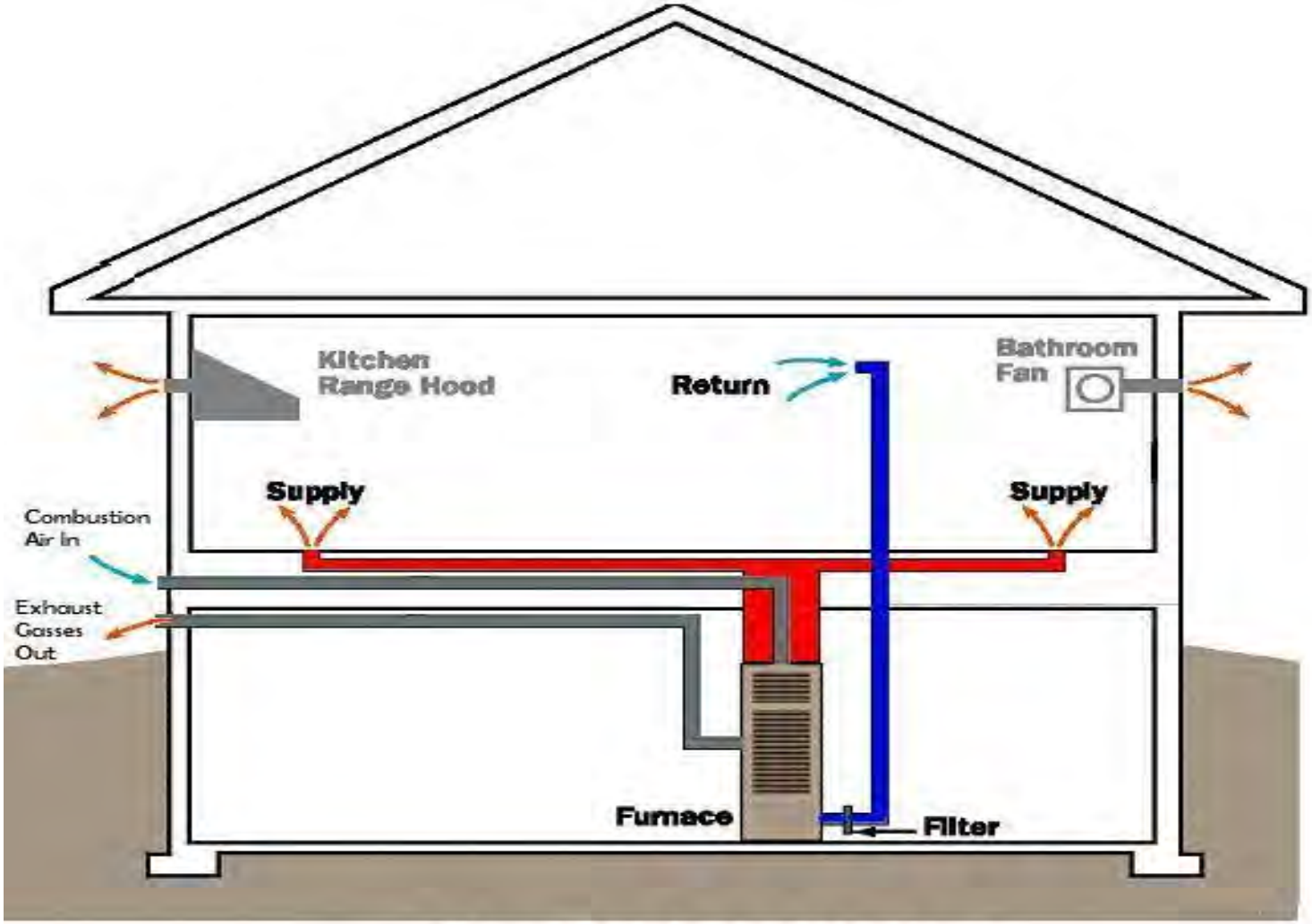


This 90+ AFUE (condensing) is a Category IV, with a positive pressure vent system

Closed Combustion Appliance

- Both the hot water heater and furnace shown here are closed combustion appliances. They each draw combustion air from outdoors, not the living space.

Closed Combustion Appliance



Sealed Combustion

So What… (moving on)

- If code is met, will the appliance work properly?
- If a new home has a CO, is everything OK?
- If the air changes are above .35 NACH, is there enough air for combustion?
- Can I tighten a house below .35 and have enough air for combustion?

Air Sealing

- Taking a House as a System look, what are some typical improvements made to reduce air leakage in the home?
  - Attics-top plates, open walls, drop ceilings, plumbing and electrical penetrations, etc.
  - Wall insulation (dense pack)
  - Basements
    - Rim joists. Wall penetrations, windows, etc.
  - Ductwork

Pressure Problems

- Know the impact of air sealing on combustion appliances:
  - Over-tightening a home
  - Exhaust appliances
    - fans, dryers, fireplaces
  - Duct Leakage

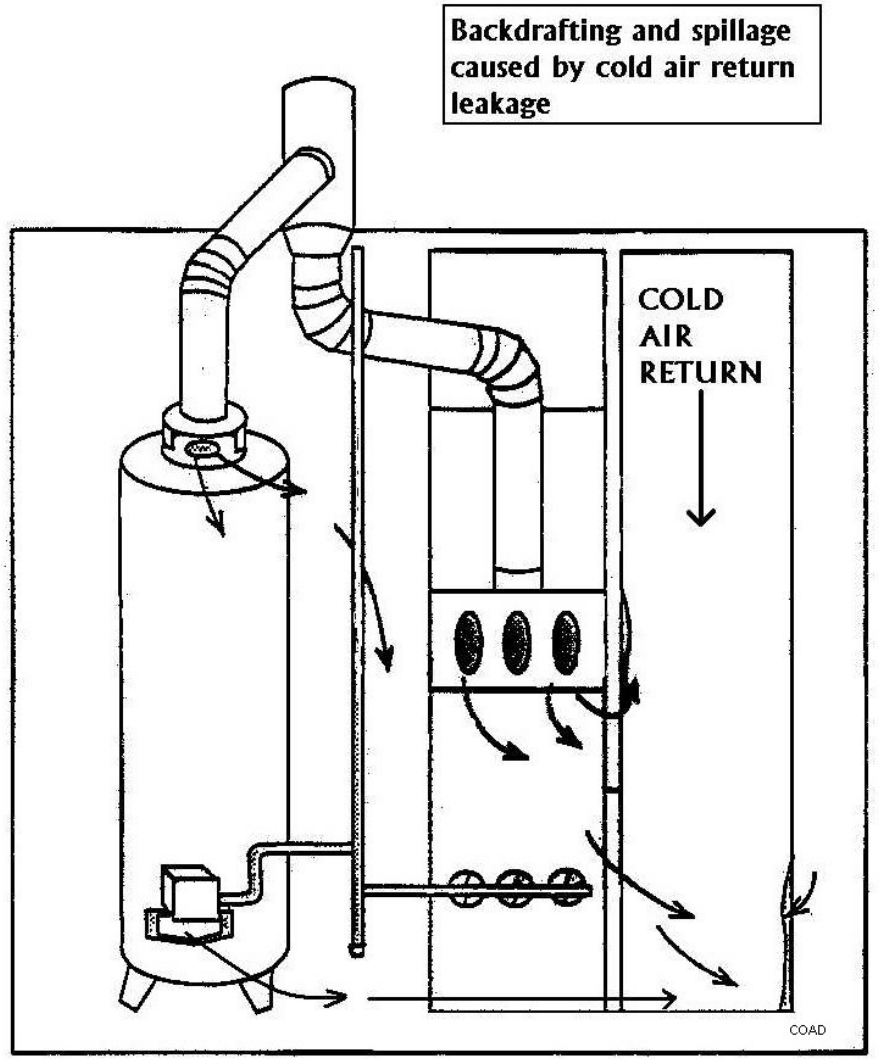
Pressure Problems

- A HOME MAY NOT HAVE HAD A PRESSURE PROBLEM *BEFORE* YOU BEGAN IMPROVEMENTS.
- THE EFFECTS OF TIGHTENING A HOME MAY CREATE ADVERSE CONDITIONS *AFTERWARDS.* (BACKDRAFTING, PRESSURE IMBALANCES, ETC.)
- Don't assume anything. Test In, Test Out.

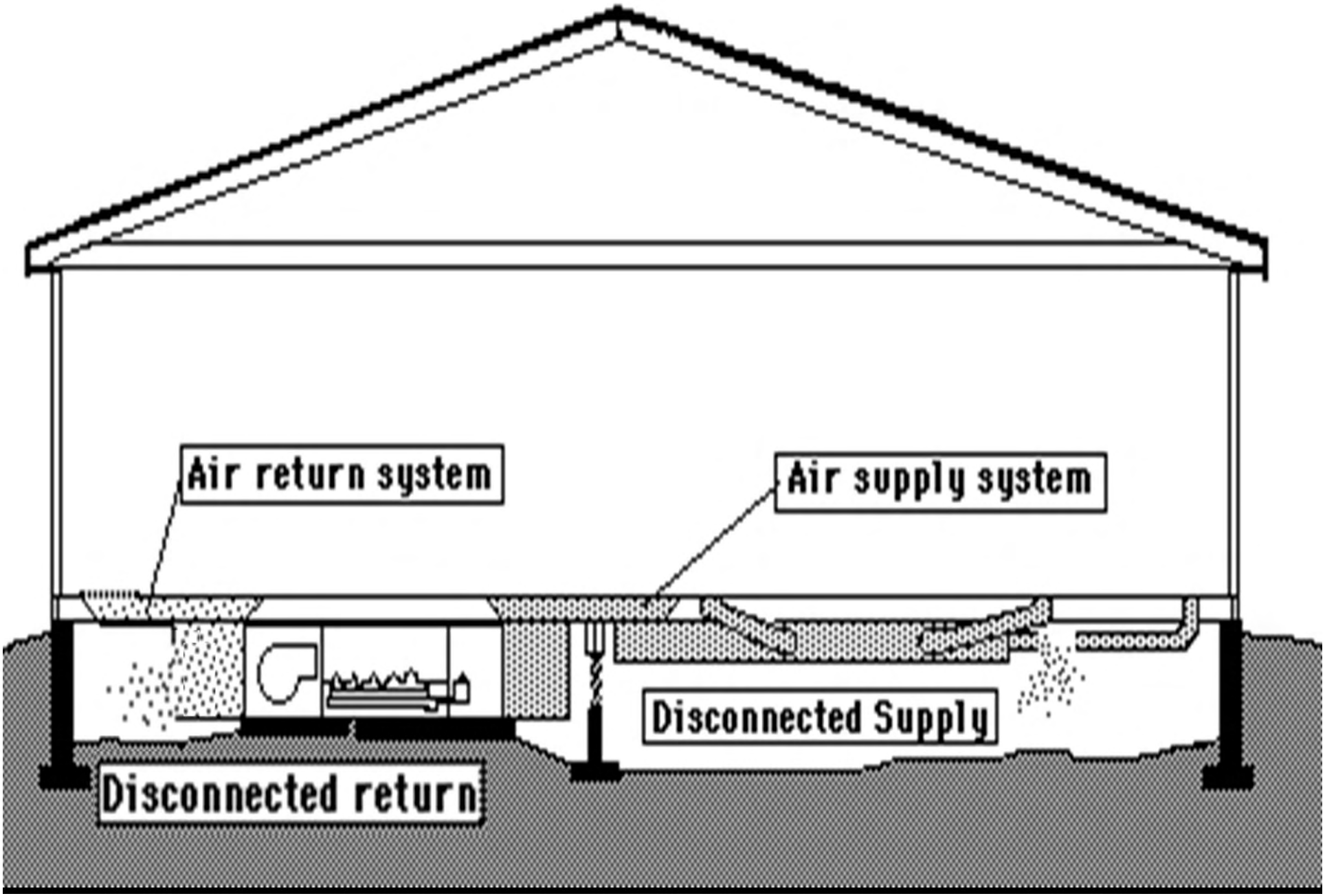
Ductwork

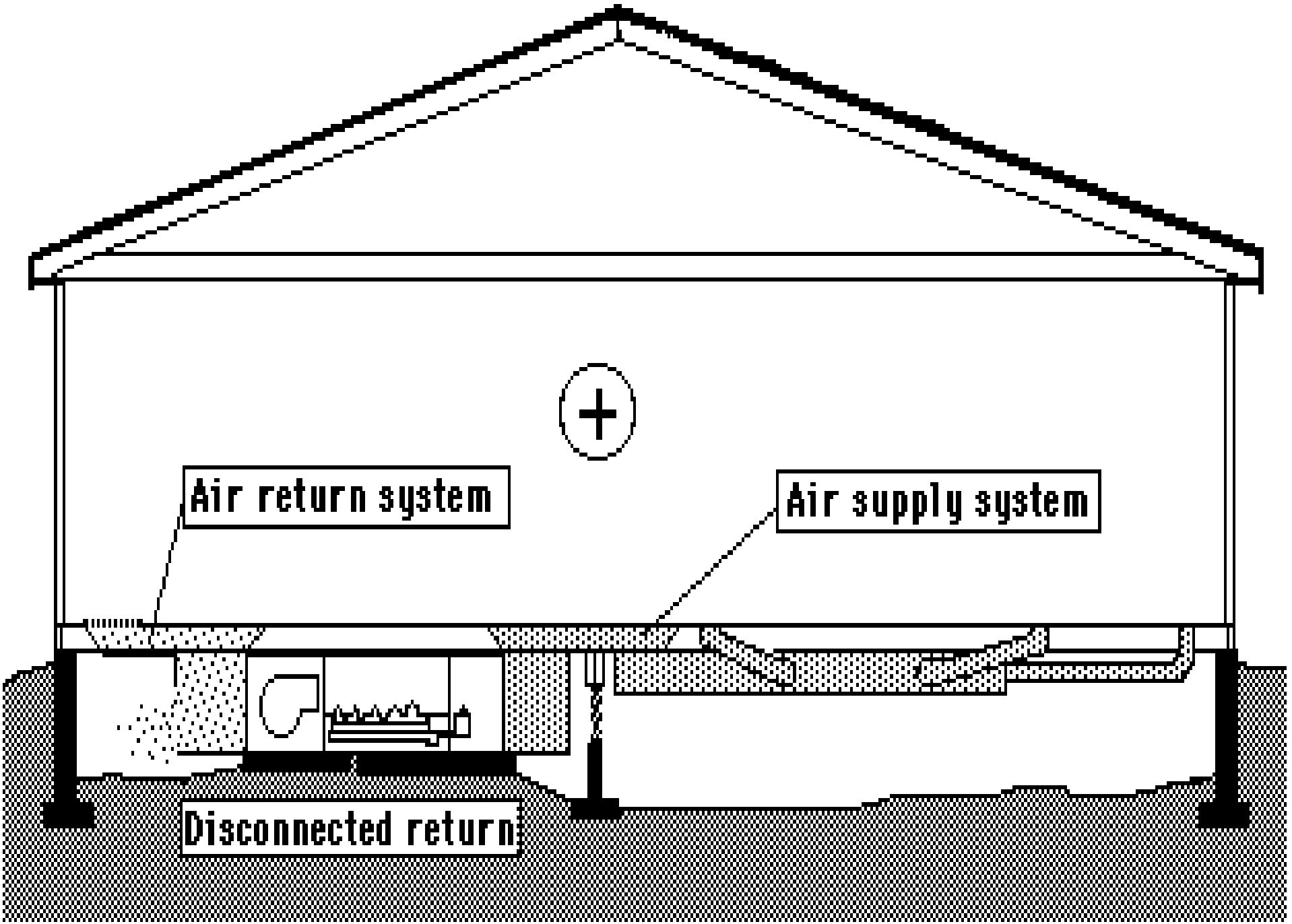
- The impact of leaky ductwork can never be emphasized enough.
- Sealing only supply ductwork can lead to catastrophic results, including backdrafting in the CAZ, or excessive positive pressure in the core of the home

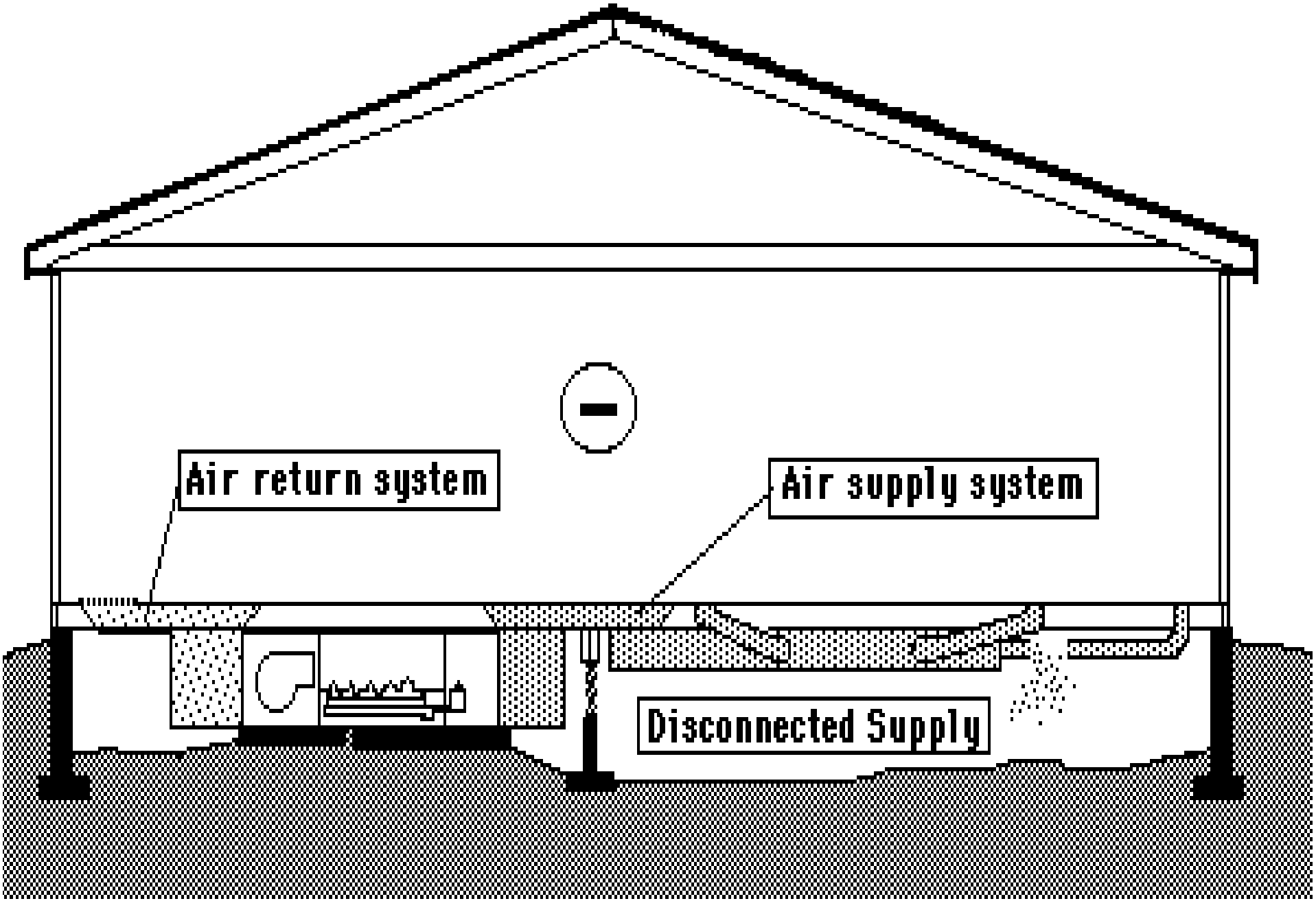
Effect of Duct Leakage On Open Combustion Appliances



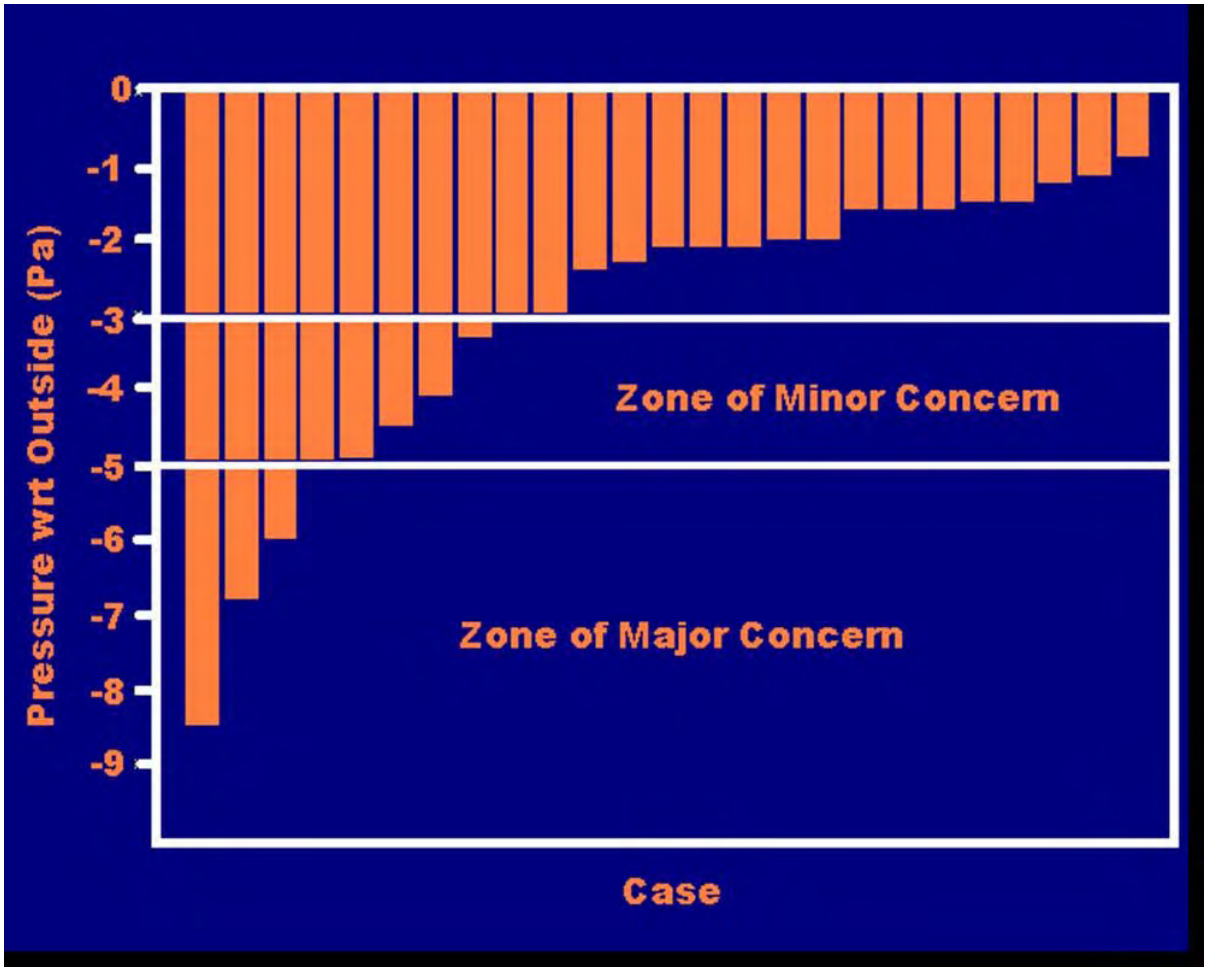
- The leaky cold air return on this furnace can draw combustion products down the flue and into the ductwork, for delivery into the living space.
- In addition, it robs the appliances of necessary combustion air, possibly leading to CO production.


Air return system
Air supply system
Disconnected Supply
Disconnected return


Air return system
Air supply system
Disconnected return

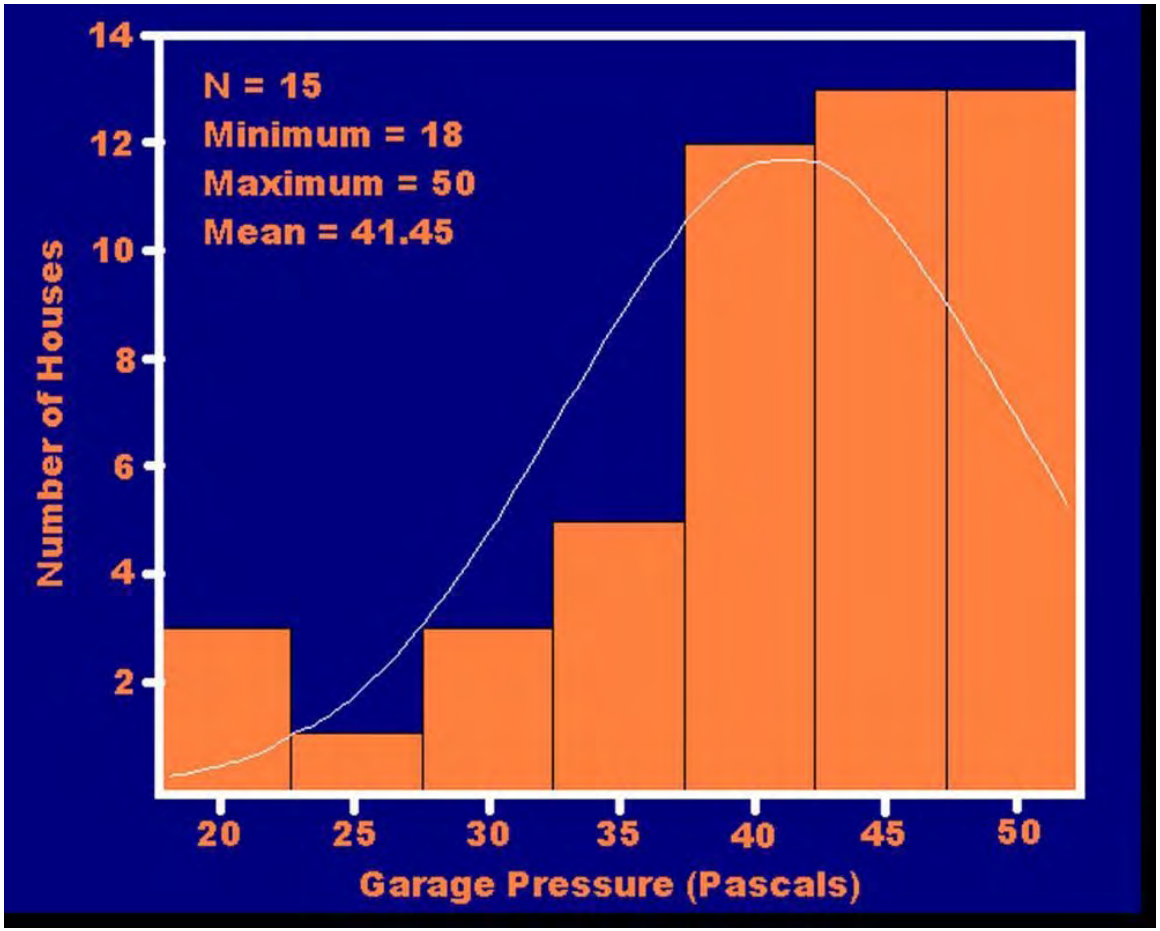

Air return system
Air supply system
Disconnected Supply

Combustion Appliance Zone Pressures



Combustion appliance zone (CAZ) pressures may overcome the draft pressure needed to safely exhaust hot water tanks and furnaces.
Typical draft pressures may be -5 pa or less.

House to Garage Connections



If air sealing is performed throughout the home,
makeup air for appliances may now only be available via the house-garage connection.
Be careful!

Please Note…

- IN NO CASE SHOULD ANY HOME IMPROVEMENTS BE MADE IF THERE ARE UNVENTED APPLANCES IN THE HOME.

- THIS INCLUDES FREE STANDING SPACE HEATERS AND COOKING APPLIANCES*.
  - *These should have exhaust fans installed as an upgrade

Carbon Monoxide

- An odorless, colorless, tasteless toxic gas that can be lethal at high concentrations.
  - Low level poisoning contributes to health problems.
  - Has distinct odor when combined with byproducts of incomplete combustion.
  - Is caused by *incomplete* combustion

Carbon Monoxide

Myth:

- All furnaces and hot water tanks always produce deadly amounts of Carbon Monoxide

Fact:

- Properly tuned equipment produces little or no measurable levels of CO

Carbon Monoxide

- Other byproducts of combustion can be dangerous including:
  - Carbon Dioxide (CO_2)
  - Moisture
  - Oxides of Nitrogen (NOx)

Testing Overview, before the CAZ setup and test

- Check all accessible fuel lines for leaks
- Check the venting systems to see that they are safe and intact.
  - Be sure the vent is cool to the touch
  - Hand check venting integrity
- Check for carbon in the heat exchanger, draft hood and gas vent(s) of all appliances being tested.
  - Another hand check
- Visually check for cracks in the heat exchanger.
- Drill test holes in the gas vent(s) of atmospheric drafting appliances.

Combustion Safety Testing (CAZ)

- Testing is performed to determine the CAZ (Combustion Appliance Zone) pressure
  - This test ultimately determines the potential of an appliance backdrafting exhaust gasses into the home.
  - Measurements of CO, draft , spillage
- Other items to be tested
  - Cracked heat exchanger
  - Gas leaks
  - High limit operation
  - Pilot safety controls
  - Combustion Efficiency
    - Stack Temp, O_2, excess Air

CAZ….HELP!!!

- Some ideas to help CAZ and Mechanical testing go smoothly
  - Do this test first.
    - If you find that there are serious mechanical system or CAZ problems, you may not be able to/need to proceed with further home testing.
  - Determining "Worst Case" can be tricky. While doing your client interview and house walkthrough, close and lock all exterior windows and doors. Open all interior doors. Start setting up the test as you take notes on the home, while listening to the homeowner (that's right…multi-task)

COMBUSTION SAFETY TEST PROCEDURE FOR VENTED APPLIANCES

1. **Measure the Base Pressure.** Start with all exterior doors and windows closed and the fireplace damper closed. Set all combustion appliances to the pilot setting or turn off the service disconnect. Combustion appliances include: boiler, furnace, space-heaters, and water heater. With the home in this configuration, measure and record the baseline pressure of the mechanical room WRT outside.

2. **Establish the Worst Case.** Turn on the dryer and all exhaust fans. Close all interior doors that make the CAZ pressure more negative. Turn on the air handler, if present, and leave on if the pressure in the CAZ becomes more negative, then recheck the door positions. Measure the net change in pressure from the CAZ to outside, correcting for the base pressure. Record the "worst case depressurization" and compare to the CAZ Depressurization Limit Table.

3. **Measure Worst Case Spillage, Draft, CO.** Fire the appliance with the smallest Btu capacity first, test for spillage at the draft diverter with a mirror or smoke test, and test for the CO at the flue at steady-state (if steady state is not achieved within 10 minutes, take the CO readings at the 10 minute mark). If the spillage test fails under worst case, go to Step 4. If spillage ends within 1 minute, test the draft in the connector 1' - 2' after the diverter or first elbow. Fire all other connected appliances simultaneously and test the draft diverter of each appliance for spillage. Test for CO in all appliances before the draft diverter.

4. **Measure Spillage, Draft, CO under Natural Conditions.** If spillage fails under worst case, turn off the appliance, the exhaust fans, open the interior doors and allow the vent to cool before re-testing. Test for CO, spillage, and draft under "natural conditions." Measure the net change in pressure from worst case to natural in the CAZ to confirm the "worst case depressurization" taken in Step 2 outside. Repeat the process for each appliance, allowing the vent to cool between tests.

5. **Ambient CO.** Monitor the ambient CO in the breathing zone during the test procedure and abort the test if ambient CO goes over 35 ppm. Turn off the appliance, ventilate the space, and evacuate the building. The building may be reentered once ambient CO levels have gone below 35 ppm. The appliance must be repaired and the problem corrected prior to completing the combustion safety diagnostics. If the ambient levels exceed 35 ppm during testing under natural conditions, disable the appliance and instruct the homeowner to have the appliance repaired prior to operating it again.

6. **Action Levels.** Make recommendations or complete work order for repairs based on test results and the Combustion Safety Test Action Level Tables.

RANGES AND OVENS*

1. Remove any items/foil in or on oven/range top
2. Make sure self-cleaning features are not activated
3. Test oven in vent sleeve, before dilution air
4. **100 ppm to 300 ppm** as measured you must install a carbon monoxide detector and recommendation for service must be made to the consumer.

   Greater than 300 ppm as measured—the unit must be serviced prior to work. If greater than 300 ppm after servicing, exhaust ventilation must be provided with a capacity of 25 CFM continuous or 100 CFM intermittent.

Continually monitor ambient CO levels during test

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Updated: 4/07

This is the BPI protocol for CAZ Testing. If you are doing a Home Performance with Energy Star job, it is a required step. Other approved protocols may be used in other programs.

Combustion Safety Test Procedure for Vented Appliances

- 1. **Measure the Base Pressure.**
  - Start with all exterior doors and windows closed and the fireplace damper closed. Set all combustion appliances to the pilot setting or turn off the service disconnect. Combustion appliances include: boiler, furnace, space-heaters, and water heater. With the home in this configuration, measure and record the baseline pressure of the mechanical room WRT outside.

CAZ Testing

- Measuring Baseline
  - Find an easy spot to run a reference tube to the outdoors from the CAZ.
    - Rim joist penetrations (Line Set, Gas line, Electric penetrations, etc.)
    - Under the sill plate?
    - Use a window and tape over the remaining gap.
    - Use time averaging feature if windy.

Combustion Safety Test Procedure for Vented Appliances

- 2. **Establish the Worst Case.**
  - Turn on the dryer and all exhaust fans. Close all interior doors that make the CAZ pressure more negative. Turn on the air handler, if present, and leave on if the pressure in the CAZ becomes more negative, then recheck the door positions. Measure the net change in pressure from the CAZ to outside, correcting for the base pressure. Record the "worst case depressurization" and compare to the CAZ Depressurization Limit Table.

CAZ Testing

- Turn on "regular" fans and dryer first, then proceed with air handler. The air handler must be run at the *highest* speed used.
  - If possible, observe CAZ change with *each* fan.
  - Gourmet Cooktop Exhaust? Add separately.
  - Dryer…Don't forget to clean lint filter.
  - Is air handler's filter clean?
- Cooling present? Run cooling from thermostat, with outdoor unit off. (You are only concerned about air pressure, not temperatures.)
- No cooling? Run air handler with fan control ("summer switch"), or you may have to run heating.

CAZ Testing

- Positioning interior doors-use smoke. Rooms that are positively pressurized should have doors closed. Negatively pressurized rooms should have doors open.
  - A good rule of thumb is: If the smoke comes toward you, the door comes toward you. If the smoke goes away from you, the door goes away from you". (Note – this only applies to bedroom or other doors that open *in* to the room, away from the CAZ.
- Worst case CAZ pressure is the strongest *negative* pressure in the appliance zone, of whatever configuration the fans/doors, etc. It does *not* include baseline the stack effect.

Combustion Safety Test Procedure for Vented Appliances

- 3. **Measure Worst Case Spillage, Draft, CO.**
  - Fire the appliance with the smallest Btu capacity first, test for spillage at the draft diverter with a mirror or smoke test, and test for the CO at the flue at steady-state (if steady state is not achieved within 10 minutes, take the CO readings at the10 minute mark). If the spillage test fails under worst case, go to Step 4. If spillage ends within 1 minute, test the draft in the connector 1' - 2' after the diverter or first elbow. Fire all other connected appliances simultaneously and test the draft diverter of each appliance for spillage. Test for CO in all appliances before the draft diverter.

Combustion Safety Test Procedure for Vented Appliances

- 4. **Measure Spillage, Draft, CO under natural conditions (if spillage fails under worst case).**
  - If spillage fails under worst case, turn off the appliance, the exhaust fans, open the interior doors and allow the vent to cool before re-testing. Test for CO, spillage, and draft under "natural conditions." Measure the net change in pressure from worst case to natural in the CAZ to confirm the "worst case depressurization" taken in Step 2 outside. Repeat the process for each appliance, allowing the vent to cool between tests.

Combustion Safety Test Procedure for Vented Appliances

- 5. **Ambient CO.**
  - Monitor the ambient CO in the breathing zone during the test procedure and abort the test if ambient CO goes over 35 ppm. Turn off the appliance, ventilate the space, and evacuate the building. The building may be reentered once ambient CO levels have gone below 35 ppm. The appliance must be repaired and the problem corrected prior to completing the combustion safety diagnostics. If the ambient levels exceed 35 ppm during testing under natural conditions, disable the appliance and instruct the homeowner to have the appliance repaired prior to operating it again.

Test Equipment

Fix Venting Problems

Learn to observe!

Combustion spillage

This is from a new home!

Brother-in-law installation

What's wrong with these pictures?

Remember…

- Houses with central returns vs. returns in every room may quite likely change your door arrangement.
- Leaky ductwork can cause a zone to go positive, negative, or remain neutral.
- If there is an operable fireplace, it may be necessary to run a blower door at a low (~200 to 400 cfm or higher) flow in order to simulate its drafting.

Test Locations-65% Furnaces

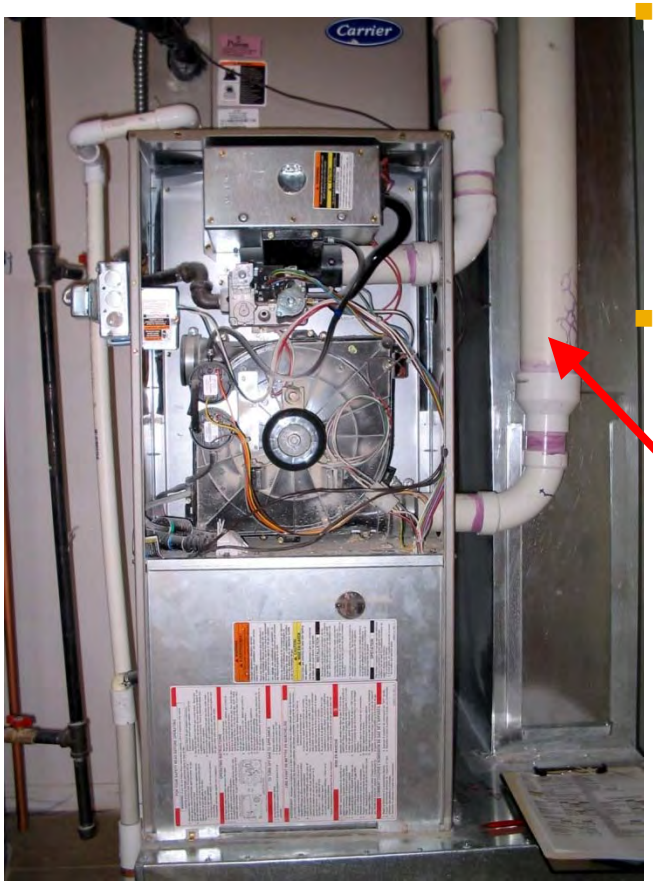
The vent on this furnace should be drilled approximately 18" from the top of the draft hood. This hole is for testing the draft, not CO.

Test Locations-80% Furnaces

The test hole on this furnace should be in the adaptor section above the combustion blower. Avoid drilling into double wall vent. This test hole is for measuring draft *and* CO.

Spillage tests are not usually taken on furnaces like this. (They do not have a draft hood, but sometimes a test can be done at the burner area.)

Test Locations-90+ Furnaces



- It is preferred that PVC venting not be drilled. Always try to test at the vent termination. Some manufacturer's will allow drilling of the vent pipe, however it must be completely sealed after testing is done, with approved material.
- CO only is measured on 90+ furnaces (positive pressure venting).

Test Locations-CO testing 65% Furnaces

This

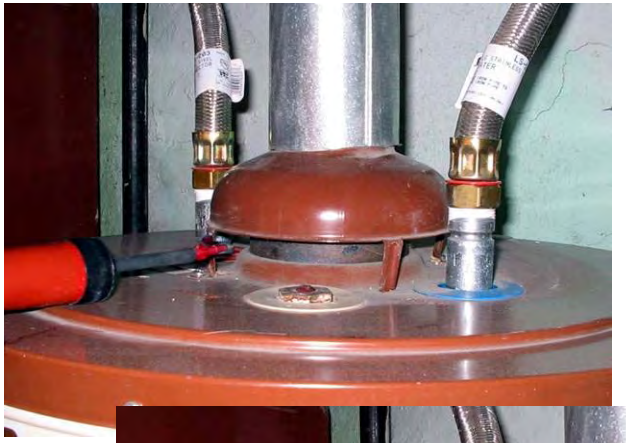
Not this

- The top picture shows the correct location for CO measurement on a 65% efficiency unit. Do not measure CO in the vent pipe when a draft hood is present.
- One CO reading is taken at *every* port under the draft hood; one for each burner. The numbers are *not* averaged.

Test Locations-Spillage

- On a draft hood furnace, spillage is tested using smoke, matches, or a mirror, to check for the presence of combustion products.
  - If spillage is present, the CO_2 will extinguish a flame.
  - A mirror will fog over from the moisture content of the gasses.

Test Locations – Hot Water Tanks



- An atmospheric water heater is tested for spillage around the base of the draft hood, again using smoke, matches or a mirror.
  - CO is measured *inside* the draft hood, underneath it, before dilution air enters. There are two readings taken, one from each side of the baffle

CAZ Testing

- (Optional) While running furnace in the "Heat" mode, install thermometers to measure heat rise at 5 minutes.
  - Supply air minus return air.
- While running furnace (whatever speed), use smoke to find duct leaks. (You've got ~ 5 minutes to get the equipment to Steady State!)
- Listen for air flow noises, duct popping, or whistling. These are signs of leakage, excessive pressures, or other duct problems.
- At steady state, measure the CO, draft & spillage. **Appliances must remain ignited for the entire test!**

Ovens & Cooktops

Stove courtesy of Warp 8 Model courtesy of Compass Records

- Oven CO levels are tested at the outlet port, usually located at the top/back of the unit. Testing is done after 15 minutes of operation, and levels should not exceed 800 ppm air free.

Finally…

- Don’t get in over your head
- Know what you are doing. Get hands-on training
- If you are lost, ask for help

Save the Dates!

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