Southface | Advanced Commercial Buildings Initiative

Small Commercial Building Assessment Combustion Appliance Guidelines

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Definitions

AHU	Air handling unit
AFUE	Annual fuel utilization efficiency, the measurement of the seasonal energy efficiency of a gas furnace.
Backdrafting	The undesired, sustained reverse-flow of combustion products back into the building instead of up and out the flue; backdrafting can be caused by negative pressures in the CAZ.
CAZ	Combustion Appliance Zone – the location in a building that contains combustion appliances
CO	Carbon monoxide, a colorless, odorless and tasteless gas that is a toxic by-product of combustion.
Draft diverter	A usually metal device designed to augment venting on a standard atmospherically vented appliance. This device allows surrounding air to be entrained by the flow of combustion gases and also minimizes risk of pilot blow out or flame rollout if a strong downward pressure spike occurs.
Spillage	The short-duration (typically < 5 minutes) undesirable reverse-flow of combustion products back into the building instead of up and out the flue pipe.
Stack effect	The natural buoyancy of heated gas (such as air) that causes it to rise. Stack effect is a function of height and temperature difference. In a building, it tends to be greater in the winter than the summer.

Executive Summary

The residential industry has recognized the need for assessing combustion safety and has developed testing protocols based on experience with energy and health audits. Sadly, very little information exists that targets the small commercial building sector.

Every year over 170 Americans die[1] and thousands of others are accidentally poisoned by carbon monoxide (CO)[2], some as a result of faulty combustion appliance operation and installation. Whenever combustion products from the appliance that produced them are not safely removed from the building, the result is a leading cause of CO exposure. This happens in commercial buildings as well as homes.

Testing provides some value but in the end is just a snapshot of the building and appliances on that day. Since many changes could occur in the future (occupant behavior, weather conditions, construction modifications, difference in type of occupancy, etc.), any chance to solve a problem or prevent a potential problem by designing it away is preferred.

Knowing whether an installed appliance is relatively safe and efficient and how it fits into whole building efficiency upgrades (e.g., air sealing and insulation) that may occur is critical to advancing safe and affordable improvements. The emphasis of this Guideline is to help an assessor to not just identify what the installed combustion appliance is but more importantly understand the context in which it is installed. Only then can whole building recommendations be properly applied.

1 Introduction

When assessing a commercial building, combustion equipment will often be encountered. Buildings are systems and how combustion appliances interact with the building is an important consideration that every commercial auditor should understand. In some buildings, combustion safety problems may already exist, but the occupants are unaware. In any building, when energy recommendations are made to improve the building thermal envelope (the insulation and air barriers) and/or the mechanical equipment, the energy upgrades could affect how safely the installed combustion appliances perform.

Combustion safety testing protocols do exist and can be helpful to the auditor, but they are only "snapshots" of the performance of the equipment on that day. The goal of an audit is to identify problems and opportunities regarding combustion appliances while maintaining a building-as-a-system mentality, and this goal may be met through a combination of visual inspection, testing and building performance experience.

These guidelines are intended to provide small commercial building auditors with a foundation in combustion safety fundamentals, and offer examples of real-world combustion safety issues and proposed solutions. To supplement these guidelines, Southface has also created a Small Commercial Combustion Assessment Workbook that may be used during site visits to aid in recording combustion appliance information.

Multiple resources have been created by the home performance industry for assessing combustion equipment in residential spaces and provide additional, valuable information relevant for small commercial building audits. (Appendix A)

2 Common Combustion Concerns

During the combustion process, appliances burn fuel using oxygen from the air and release exhaust gases and pollutants. When appliances are not properly vented or they malfunction, situations can develop which cause serious medical problems, and sometimes death.

Backdrafting occurs when combustion flue gases are unable to vent properly to outside the building envelope – often, though not always, a backdrafting combustion appliance will introduce carbon monoxide (CO) as well as moisture to the space around the appliance. After over 20 years of assessing thousands of buildings, in this author's opinion, there are **two rules** for safe combustion that, if followed, greatly minimize the risk of adverse health for the building occupants:

1. **Provide combustion air for the appliance that is separate from the occupants' breathing air**

2. **Make sure that the appliance combustion products are safely vented to the outside via a flue**

Combustion products that are more well-known for adversely impacting health include:

- carbon monoxide (CO),
- nitrous oxides (NOx, especially nitrogen dioxide),
- particles (such as fine soot),
- moisture, (moisture is not a contaminant on its own but excessive levels can lead to problems with dust mites, mold/mildew, and condensation/building decay).

Other pollutants that are less studied in terms of human health impacts include elevated carbon dioxide levels, sulfur oxides (SOx), and polycyclic aromatic hydrocarbons and aldehydes.

3 Common Types and Categories of Combustion Appliances

The most common types of combustion appliances found in small commercial buildings typically include: furnaces, water heaters, boilers, ovens and cooktops. Other appliances that may occasionally be encountered include: gas logs, room space heaters, clothes dryers, generators, gas cooking grills, process heaters such as kilns, and fleet vehicles.

3.1 FURNACES

Perhaps the simplest way to understand combustion appliances and their interrelationship with the building is to study furnaces. Furnaces found in buildings today basically fit into one of three categories:

3.1.1 60-70% AFUE atmospheric venting furnaces –

a) Generally these older furnaces (which stopped being manufactured in 1992) include a standing pilot light,
b) feature a "scoop" (draft diverter) and use the air around the furnace for combustion air,
c) vent by the stack effect (warm air rising),
d) use a metal flue pipe – (typically single-wall vent pipe), and
e) are relatively easy to backdraft by small negative building pressures in the Combustion Appliance Zone (CAZ).

Figure 1: 60-70% furnace with louvered door for combustion air [Barcik photo]

3.1.2 80% AFUE induced draft furnaces –

a) These are the standard furnaces installed today and generally include a hot surface igniter (in lieu of a standing pilot) and may be found as split systems or as packaged units located on the rooftop or ground,
b) feature a mechanical inducer fan that helps suck the flue gases through the heat exchanger,
c) vent flue gasses by the stack effect via a metal flue pipe (typically double-wall B-vent),
d) use the air around the furnace for combustion air, and
e) are more difficult to backdraft by small negative building pressures in the CAZ but can still be backdrafted by a significant negative pressure in the CAZ.
f) Also, each burner is generally 20-25,000 Btu/hr, so counting burners can be used to estimate capacity.

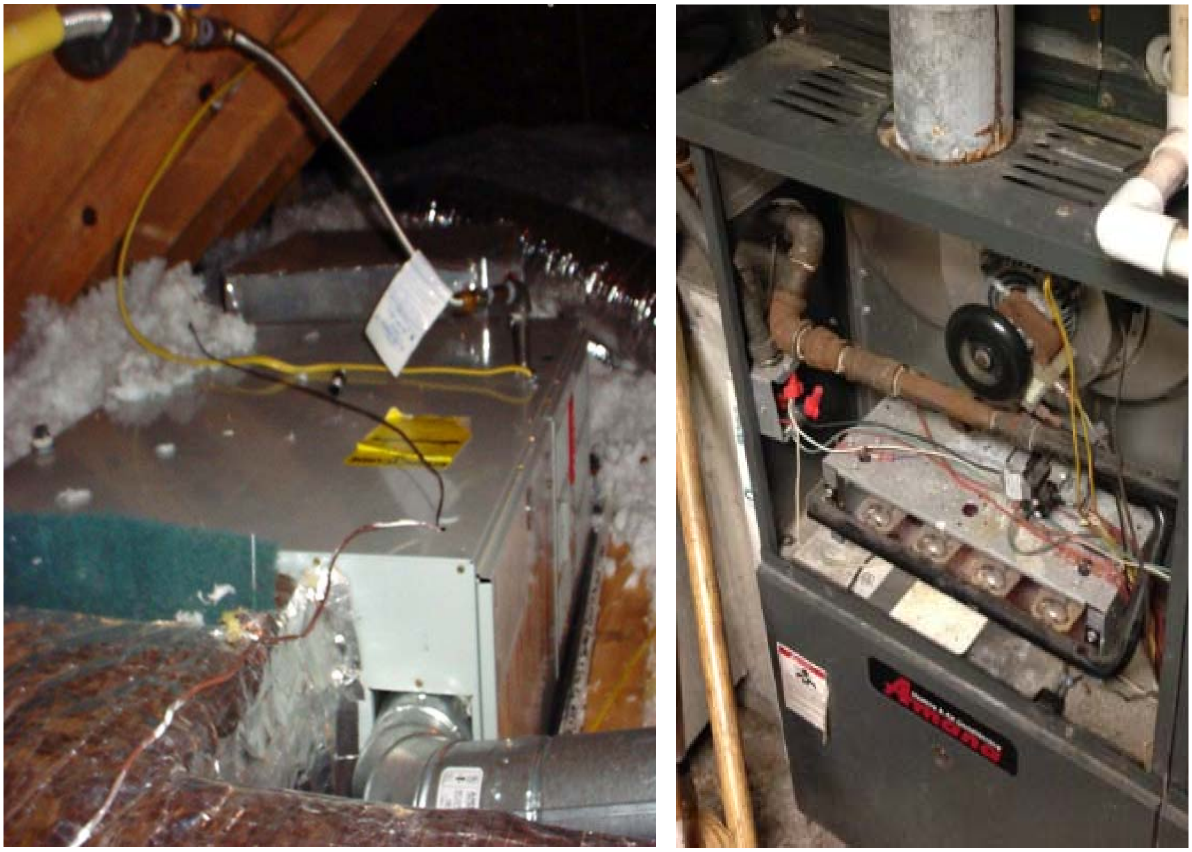


Figure 2: Horizontal 80% furnace with double-wall B-vent flue pipe (left), Vertical 80% mechanically induced furnace with four burners (right) [Barcik photos]

3.1.3 90+% AFUE sealed combustion, direct vent (condensing) furnaces –

a) These high efficiency furnaces include a hot surface igniter (no pilot),
b) remove so much heat from the combustion process that the exhaust gases are cool and will condense water vapor requiring a plastic flue pipe,
c) do not rely on the stack effect to vent as the inducer fan helps pull combustion air in and push the combustion gases out, and
d) can be vented horizontally.
e) In a two-pipe configuration, they do not use the air around them for combustion (unless the inlet pipe has been omitted) and feature a sealed combustion chamber where outside air is pulled in and combustion gases are pushed out through direct-vent piping, and
f) are nearly impossible to backdraft and are considered safe to locate inside the building thermal envelope (when plumbed in a two-pipe configuration).

Figure 3: 90% furnace with 2-pipe configuration (PVC combustion air inlet and flue) (left), 90% furnace with 1-pipe configuration (combustion air drawn from room and PVC flue) (right) [Barcik photos]

3.2 WATER HEATERS

Combustion water heaters are similar to the three types of furnaces with some additional options:

3.2.1 Standard gas water heaters –

a) These are usually tank-type and contain a pilot light,
b) feature a draft diverter and use the air around them for combustion air,
c) vent by the stack effect,
d) use a metal flue pipe which must always slope upwards – (typically either single wall vent pipe or double-wall B-vent pipe), and
e) are relatively easy to backdraft by small negative building pressures.
f) They sometimes feature electronic ignition and a motorized flue damper to reduce standby losses.

Figure 4: Atmospherically vented water heater with standing pilot (top left), atmospherically vented water heater with electronic ignition and motorized damper on flue (top right), close-up of motorized damper shown open while system is firing (bottom photos) [Barcik photos]

3.2.2 Direct vent gas water heaters –

a) These are usually tank-type and contain a pilot light,
b) feature a concentric venting system (often run horizontally) that exhausts hot gas through a center pipe while an outer pipe introduces outside air to the burner for combustion air,
c) vent by the stack effect,
d) are nearly impossible to backdraft by negative building pressures because the exhaust flue is continuous with the combustion chamber and combustion air comes from outside.

Figure 5: Direct vent gas water heaters – do not use air around them for combustion air (Youth Activity Center 1, garage demo) [Barcik photos]

3.2.3 Power vented gas water heaters

a) are usually tank-type but have an electric blower fan and do not contain a pilot light
b) are higher efficiency combustion and so must be vented with plastic (usually PVC) pipe,
c) can be vented horizontally, or vertically,
d) use the fan to assist the flue gases in exiting the building,
e) use the air around them for combustion but are very difficult to backdraft because they feature a pressure switch that prevents burner operation in case of insufficient venting pressure.

Figure 6: Power Vented gas water heater - uses surrounding air for combustion air; no pilot [internet image]

3.2.4 Sealed combustion, direct vent (condensing) water heaters

a) these high efficiency water heaters include a hot surface igniter (no pilot), and remove so much heat from the combustion process that the exhaust gases are cool and will condense water vapor requiring a plastic flue pipe,

b) feature a sealed combustion chamber where outside air is piped into and combustion gases are expelled out from via plastic (usually PVC) pipes,

c) do not rely solely on the stack effect to vent as the blower fan helps pull combustion air into and push the gases out (and can be vented horizontally),

d) In a two-pipe configuration, do not use the air around them for combustion (unless the inlet pipe has been omitted), and

e) are nearly impossible to backdraft and are considered safe to locate inside the building thermal envelope (when plumbed in a two-pipe configuration).

Figure 7: High Efficiency 2-pipe condensing gas tank water heaters - do not use the surrounding air for combustion air and contain no standing pilot (Fire1, Day Care) [Barcik photos]

Tankless gas water heaters are either non-condensing (standard efficiency) or are condensing (high efficiency). They usually have electricity provided to them and thus no pilot. They can be installed with a one-pipe configuration (which uses the air around them for combustion) or the much preferred two-pipe configuration (which brings combustion air from the outside to the appliance). While appearing to be one larger pipe, concentric venting (exhaust flue located in the center of a larger intake pipe), may be used so confirm by checking the outside termination.

Figure 8: Tankless gas water heaters - can usually be installed to not use surrounding air for combustion (Fire3), (left, center); concentric vents allow for only one wall or roof penetration (right) [Barcik photos, internet image]

3.3 BOILERS

Boilers are water heating devices that usually heat water for space conditioning rather than just potable water supply. Similar to furnaces, boilers generally come in standard and high efficiency (condensing) units.

Figure 9: Two views of a standard boiler and circulation pump (Youth Activity Center 2) [Barcik photo]

3.4 UNVENTED APPLIANCES - OVENS/COOKTOPS, GAS LOGS AND ROOM HEATERS

Gas ovens and cooktops almost always use combustion air from the space around them and exhaust to the same space. They should only be operated in conjunction with an exhaust hood that vents to the outside. One of the more significant improvements is to switch to electronic ignition, getting rid of the pilot lights that many older units use to ignite each burner.

Figure 10: Always hot - Gas cooktop with pilots and no functioning exhaust hood (left), Missing fan and hood mechanism (right) (Fire1) [Barcik photos]

Figure 11: Undesirable - Gas oven and cooktop with recirculating hood (T. Germick)

Kitchen hoods and proper make-up air are important design considerations that become more relevant as buildings get tighter. Maintaining desirable building pressures during times of both off and on hood operation is important[3]. Consult IMC Chapter 5 Exhaust Systems for details – even domestic hoods over 400 cfm require makeup air. Generally, it is desirable that the hood area is kept at the highest negative pressure, the kitchen is a little negative while the dining room and most other parts of the building should be maintained at a slight positive pressure[4].

Finally, any other unvented combustion appliances should be eliminated before any envelope upgrades are made. Examples include gas logs and room space heaters. Even though newer appliances have oxygen depletion sensors (ODS), they can still create hazardous conditions and clearly violate both rules for safe combustion.

Figure 12: Unvented gas log insert kits at rough in and at final (EarthCraft Training, T.Barcik) [Barcik photos]

3.5 RADIANT HEATERS

In large volume spaces with high ceilings, it is usually more effective to heat the surfaces with radiant heaters versus trying to heat all of the air in the large space.

Figure 13: It is typically more efficient to use surface-warming radiant heaters in high bay applications (left, Fire1) versus hanging space heaters that attempt to heat the large volume of air (right, Fire4) [Barcik photos]

3.6 GENERATORS

Fuel powered engine-driven generators can also produce copious amounts of CO.

Figure 14: A massive diesel generator resides behind these doors – this space must be carefully air sealed from the rest of the building and confirmed through diagnostic testing. Is this an Outside Air (OA) intake located above the window that is so close to the diesel exhaust? (Fire4) [Barcik photo]

3.7 CO MONITORS

Any building with combustion appliances or an attached garage (that may contain CO-producing vehicles) should have some form of CO indicator installed. UL2034-listed CO detectors are commonly available in battery, plug-in, or hard-wired versions. However, these devices only alert and display at higher sustained levels of CO. For measurement and alarm notification of lower CO concentration, particularly for at-risk individuals such as elderly or infirm, a low level CO monitor is recommended[5].

Low level CO monitors are ***not*** UL-listed due to their high sensitivity; they can provide alerts at levels down to less than 10 ppm over a short period of time and are much more sensitive than standard detectors / alarms. Many of these units are multi-year battery-operated devices that must be discarded at the end of the battery life which coincides with the end of the sensor life.

Two manufacturers are George Kerr's device (COexperts.com), and Defender (entechsupply.com) which is more economical but still detects as low as 10 ppm. CO is roughly the same molecular weight as air (it doesn't really float or sink) so follow the manufacturer's guidelines on where to locate the unit.

Figure 15: Two good CO monitors [internet images]

4 Means of Supplying Combustion Air

The IRC and IBC codes dictate that combustion air must be provided to the appliance and reference the International Fuel Gas Code for combustion and dilution air requirements (Note: although similar to gas appliances, oil-fired appliances are not covered by this guideline – see NFPA 31 for more information). Unfortunately, in this author's opinion, the codes provide both safe ways as well as risky and antiquated ways of delivering combustion air. We, as auditors, have to know better and employ good building science decision making to steer a project to success.

These codes require that combustion air be provided for fuel-burning appliances and permits (though we do **not** endorse/accept) using room air for combustion. If the space containing the combustion appliance is *unconfined* (this definition requires a certain air volume based on the Btu input of the combustion appliance), the room is usually fairly large and the appliance is small (alternately, the appliance space could be connected to another unconfined space).

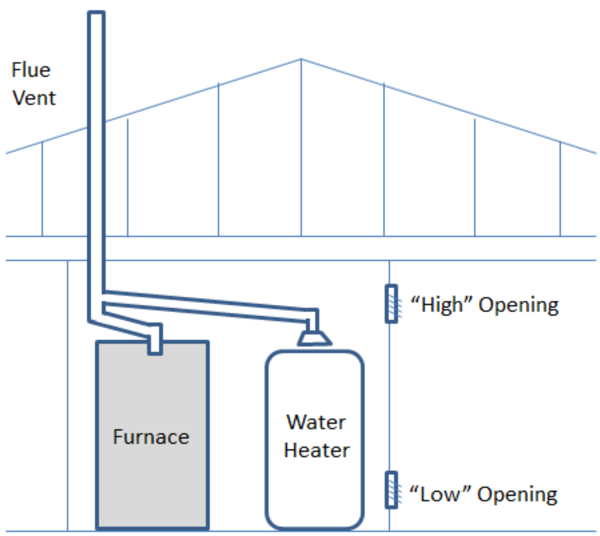


Figure 16: Undesirable – Avoid sourcing combustion air from occupied spaces (Barcik)

However, this approach does not address issues like the air leakage or exhaust appliances in the space and leaves to chance the relative ease with which the appliance could be backdrafted, especially if the building use or wall configuration changes over time. When encountered, these risky scenarios should be remedied by our audit recommendations.

The best approach is to either locate combustion appliances safely outside the building thermal envelope or convert them to sealed combustion, direct vent appliances. One method of disconnecting the combustion appliance from the interior space is to create a ***combustion closet*** around the appliance. The simplest way to illustrate this is with a standard atmospheric water heater inside a closet:

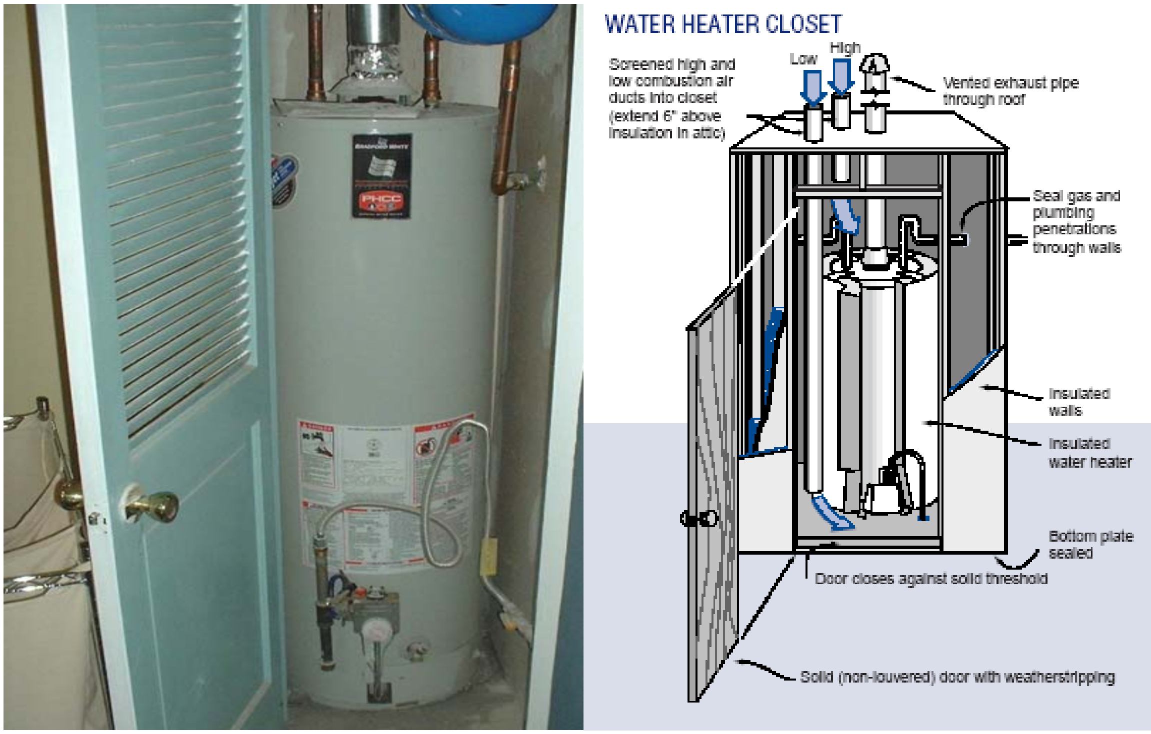


Figure 17: Atmospheric water heater gets combustion air from main space through louvered door (left). A safer alternative – combustion closet with High-Low vents (right). [Barcik photo, Southface image]

- If the closet door is louvered, then the water heater is effectively located inside the envelope, takes its combustion air from the same air that the occupants breathe, and is susceptible to backdrafting and spilling CO into the living space.

- If the closet door is solid (non-louvered), contains weatherstripping and a threshold, has all wall penetrations in the closet sealed and has combustion air delivered from the outside that is provided by two "High-Low" pipes, then the combustion air is disconnected from the living space air and the risks of backdrafting and introducing CO are greatly minimized.

As a commercial auditor, if the first case is encountered, strong consideration should be given for the scope of work to include requirements and instructions on how to convert the system to the second case or replace the heater with a safer, likely more efficient alternative. In all cases of envelope improvements (particularly spray foam retrofits), the combustion equipment must either be upgraded to sealed combustion direct vent, or a combustion closet must be constructed to isolate the standard combustion appliance and have outside combustion air provided as per code for that location.

Generally, the ***recommendation should be to upgrade the equipment*** due to increased energy savings and inherently improved safety; all envelope improvements can now safely proceed. It is a code violation for an unvented attic assembly to have standard combustion equipment with combustion air brought in from outside – this causes the unvented attic to now be vented!

Commonly, a combustion appliance is encountered in a confined space or closet with louvers that simply connect it to a larger, unconfined space. This strategy should be avoided, and remedied as part of the scope of work, as negative pressures in the connected space could backdraft the appliance in the connected closet.

The preferred method of providing outdoor combustion air is described in the IMC 304.6 (IRC G2407.6). "High-Low" vents are described in IMC 304.6.1 (IRC G2407.6.1) as the Two Permanent Openings method. The basic premise is that two openings (one within 12" of the top, the other within 12" of the bottom) shall be provided and they must communicate directly or with ductwork to the outdoors or spaces freely communicating to the outdoors (e.g., a vented attic). Precautionary freeze-protection steps, such as insulating water pipes inside the combustion closet, may be warranted.

When the communication is through vertical ducts, the cross sectional area required for each duct is 1 square inch per 4,000 Btu/h and is based on the total input of all combustion appliances in that zone. If the communication is through horizontal ducts, the opening shall be twice as big, 1 square inch per 2,000 Btu/h. For reference, the cross sectional area of several diameters is listed below:

- 3" round – 7 square inches
- 4" round – 12.5 square inches
- 5" round – 19.6 square inches
- 6" round – 28.3 square inches
- 7" round – 38.5 square inches
- 8" round – 50.3 square inches
- 10" round – 78.5 square inches
- 12" round – 113 square inches

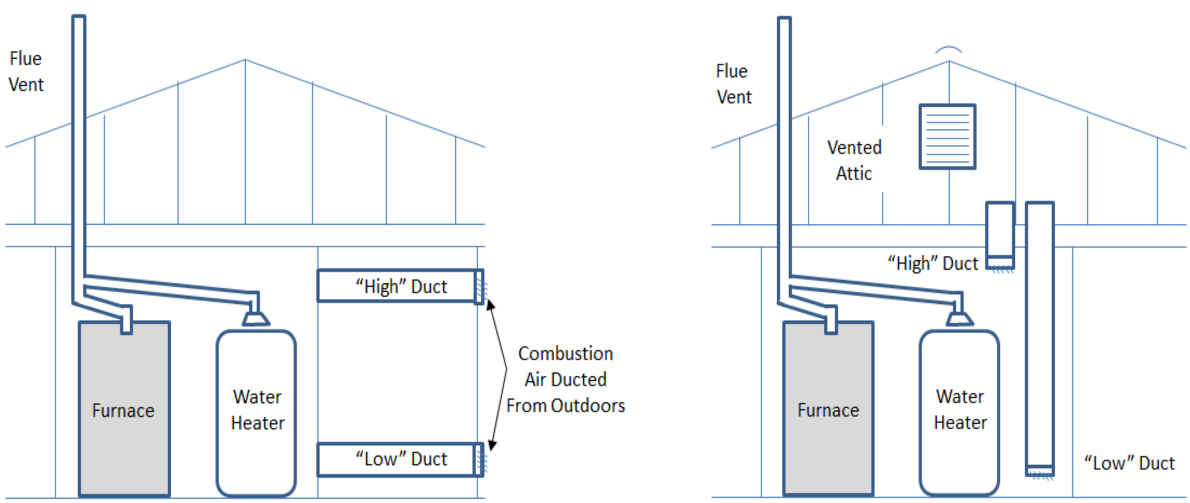


Figure 18: Safe! – Source combustion air via "High-Low" vents directly from the exterior (left) or from spaces connected to outdoors (e.g., a ventilated attic, right). (Barcik)

As an example, if a small closet contains a typical 40,000 Btu/h water heater, two 4" diameter pipes that communicate vertically with the vented attic above would be sufficient to satisfy the (40k/4k =) 10 square inches required. If the pipes ran horizontally, two 5 inch pipes would be very close to the necessary 40k/2k=) 20 square inches. If concerned about rounding errors, increase to two 6" pipes.

If there are multiple combustion appliances in the closet, add the input Btu/h for each and follow the same rules. For example, consider a room that contains a 40k water heater, 60k furnace and 100k gas dryer; the total Btu/h is 200k which when divided by 4k = 50 square inches; two 8" vertical pipes would suffice.

For new construction, the walls of the combustion closet should be insulated and carefully air sealed. In general, recommend against pulling combustion closet air directly from a vented crawlspace due to moisture and other concerns such as pest entry. When pulling combustion air from a vented attic, the two pipes should extend at least 6" above the flat ceiling insulation. All combustion air ducts should be covered by ¼ to ½" mesh ("hardware cloth") to minimize pest entry. Please note that this could impact net free area but is an important detail.

Of note, there is an additional "One-permanent-opening method", IMC 304.6.2 (IRC G2407.6.2) in the code, which still pulls all combustion air from the exterior at a 1 square inch to 3,000 Btu/h input ratio. The single opening may prove easier but lacks the redundancy of the two-opening approach in case an opening gets blocked or closed.

<u>A combustion closet retrofit can be a challenge</u>, particularly for furnaces. In some installations, the furnace is not located in a convenient place to run ducting for High-Low vents. Also, it can be *very difficult* to properly air seal the walls of the combustion closet due to the numerous duct, refrigerant and gas lines penetrating the closet walls. In many instances, it would be better to invest in upgrading the equipment to a two-pipe sealed combustion direct vent furnace.

Consider the age of the existing equipment when making decisions. If a standard 80% furnace is over 20 years old or a 60-70% furnace has finally reached the end of its life, the opportunity is ripe to upgrade to a 95+% condensing furnace. When the existing equipment is so old that it must be replaced, the incremental cost to upgrade from an 80% to a 95+% is relatively low. By upgrading to a two-pipe high efficiency furnace, at least 15% fuel savings is garnered while at the same time combustion safety is squarely addressed.

5 Scenarios and Case Studies about Combustion Air

Several combustion scenarios were encountered for the ACBI study. A neighborhood pre-school is in need of an upgrade and a local fire station (Fire1) has the upgrade but needs a building fix. Another fire station (Fire2) has a hybrid approach problem.

Fire1 was originally designed to have a standard atmospheric water heater in an interior closet and High-Low pipes combustion air through the roof were provided (GOOD!). However, at some point, a two-pipe condensing tank-type water heater was installed – either as a retrofit or as an upgrade during the original construction process (ALSO GOOD!). Unfortunately, the design and construction team did not realize that the combustion air vents are not necessary with this water heater, and these are simply acting as chimneys to the outside.

However, Fire1's combustion was also not designed and constructed to be separated from the occupied space by an air barrier; there is no door threshold and no air sealing of pipe penetrations through the walls and ceiling. Because of this, raw outside air (hot-humid or cold depending on the season) is wrapping around the water heater and infiltrating into the space. Building science-minded assessors identify this as a problem – in this case, the High-Low vents should be sealed off and could actually be removed (eliminating roof penetrations!).

Figure 19: Paint can sits atop rooftop inlet for High-Low vents. PVC air intake and exhaust for installed condensing gas tank. (Fire1) [Barcik photo]

Figure 20: Interior closet view of High-Low vents that should be sealed over or removed (Fire1). Condensing gas tank water heater with PVC air intake and exhaust (Fire1) [Barcik photos]

Pre-school1's building was built in the 1980's and has an 80-gallon standard atmospheric tank water heater located in a large utility closet. This tank also has two somewhat common features found in commercial applications – a standby-loss-reducing motorized damper at the top (before the draft diverter) that is normally closed but opens when firing and an electronic igniter to eliminate the pilot. Combustion air is provided by fixed louvers in place of one of the windows in the closet (GOOD). Unfortunately, this closet also contains the washer, dryer and storage and is being supplied with conditioned air through a ducted forced-air system. This is equivalent to supplying conditioned air into a room with the window open all year!

Figure 21: Atmospheric gas water heater (left) & combustion air louvers (right, Pre-school1).[Barcik photos]

Figure 22: Floor plan shows design included combustion air louvers in small laundry room with supply air and water heater (Pre-school1). Atmospheric water heater and combustion air louvers (Pre-school1). [Barcik photos]

The appropriate upgrade for the school would be to retrofit the unit to a high efficiency water heater (e.g., a condensing, tank, two-pipe system). The old flue should be closed off and can be removed during a future reroof. The metal louvers in the window opening should be sealed off. All of these tasks would likely <u>not</u> normally be performed by a plumber during a water heater replacement; unless specifically listed in a scope of work provided by the client or a building science professional, these important details can easily be overlooked.

Aspects of the mechanical code assume leakier buildings (0.4 to 0.6 ACH is referenced in IMC 304.5) and tend to view the situation from the vantage point of the equipment, not necessarily from a building science or building as a system standpoint. As mentioned earlier, avoid pulling combustion air from inside. This includes hybrid approaches where some combustion air comes from outside and some from inside. Hybrid strategies can be a disaster from an energy standpoint and can lead to occupants “fixing” a drafty space by sealing over the exterior combustion air vent.

Trouble with a hybrid approach: An assessment of Fire2 found a CAZ with three common-vented combustion appliances in a room adjacent to the kitchen. This closet included a duct to the outside, louvers through a window, and louvers into the kitchen. The occupants were cold and had sealed over the louvers to the outside due to comfort issues from cold outdoor air leaking into the equipment closet and then into the main building. Drafty air is a common outcome of trying to provide combustion air from both inside and outside at the same time.

Figure 23: Occupants added plexi-glass to seal off outdoor combustion air louvers because of cold air drafts since there were also louvers connecting to the conditioned space (left, Fire2). Common-vented appliances are often easier to backdraft due to their large-sized flue pipes (right, Fire2) [Barcik photo]

6 What to Look For During an Assessment

While traditional combustion safety testing (such as worst case depressurization, spillage, draft, ambient CO and flue CO levels) can certainly be performed using a number of available protocols (RESNET, BPI, ACCA, etc.), the tests take time, involve expensive equipment and require a trained operator. And while the tests are usually performed under worst case conditions, the main problem with these tests is that they are ultimately just a snapshot of the performance of the combustion appliance on that day. Weather conditions, future changes to the building use, layout or occupancy as well as equipment or flue degradation could render the test results invalid and misleading down the road. Design the solution to be more robust.

Visual inspection can be a relatively fast and inexpensive way to identify possible combustion safety problems – being able to recognize red flag issues is also a low liability endeavor. Examples of items that can easily be visually checked include:

- Fuel lines – confirm connections are NOT soldered, sediment traps (drip legs) are present, and hard connectors are used when entering the metal furnace cabinet (flex lines could be worn by abrasive vibrations of the thin metal of the cabinet. Use your nose to smell or an electronic leak detector to locate obvious gas leaks, or apply a soapy water or approved leak detection solution to identify leaky fittings. If flex lines are soldered or date from before 1974, recommend replacement.

Figure 24: Proper gas line installation shows hard connector entering cabinet and gas drip leg (left). Flexible gas line with date tag (right). [Barcik photos]

- Draft diverter – visually inspect for evidence of corrosion caused by spillage, (remember that often "dust occurs before rust occurs"), and confirm proper placement and mechanical attachment to flue.

Figure 25: Corrosion on water heater draft diverter caused by condensation due to poorly drafted flue (Fire2). [Barcik photo]

Figure 26: Extreme corrosion on draft diverter and on water line caused by condensation due to faulty drafting (WX1). [Barcik photo]

- Burners - examine for corrosion, dirt, and/or debris.
- Metal flue pipes – are they sloped upwards a minimum **¼" in 12" upward slope** and how are they being terminated outside? Is there evidence of corrosion or leakage?

Figure 27: Oops! Water heater flue pipe drops 2" in connecting to the shared flue (Virginia1). Corrosion caused by condensation due to poorly drafted flue (Fire2). [Barcik photos]

- Watch the burner(s) when firing, observe the flame color (blue = good; lots of yellow-orange could warrant a tune-up); observe the cabinet or burner area for prior evidence of flame rollout.
- furnaces - watch the flame when AHU blower first operates, if it dances upon blower startup, it could mean a cracked heat exchanger.

Figure 28: (Left), Watch for flame dance as furnace burners fire and when AHU first operates; observe flame color (Fire2). (Right), Belt CO detector to be worn during audits. [Barcik photo, internet image]

- Belt CO detector – consider wearing for personal safety of auditor (should alert at 35 ppm ambient CO)
- Take pictures – of the appliances and the room (CAZ) in which they are located. When appropriate, consult with a combustion / building-as-a-system expert to examine them and discuss the installation scenario. A second set of eyes and a discussion will often find additional important nuances of the situation.

7 Economics of Fuel Choices

Because some states and locales have deregulated utility rates, the monthly “meter” or service fees for the fuel connection can be fairly high while the per-therm prices may be fairly low. In these cases, the overall strategy should be to consider going all-electric or using gas for every appropriate appliance (space heating, water heating, clothes drying, cooking, etc.).

As an example, in 2015, an Atlanta base fee for natural gas was $25 (base meter fee + provider service charge + taxes) but the per-therm rate was $0.50. In contrast, Birmingham’s rate was $8 per month “meter fee” and $1.25 per them. These rate differences have dramatic effects on energy decision making as reducing gas consumption in the Atlanta scenario yields much lower $ savings than in Birmingham. However, assuming the Atlanta building is going to continue to pay to have connected gas service each month, switching to a gas clothes dryer (assuming ~$100 premium over a new electric dryer at time of replacement) is a much faster payback than in Birmingham.

Table 1: Gas Rate Example

Location	Atlanta	Birmingham
Monthly Gas Base Fee (annual)	$25 ($300 per year)	$8 ($96 per year)
Price per therm	$0.50	$1.25
$ Impact of saving 100 therms/year	$50	$125
Monthly $ Cost to operate clothes dryer @ 2 therms / month	$1.00 ($12 per year)	$2.50 ($30 per year)
Cost of equivalent electric clothes dryer operation @ $0.12/kwh	$7.03 ($84 per year)	$7.03 ($84 per year)
Monthly (annual) savings	$6.03 ($72 per year)	$4.53 ($54 per year)
Simple Payback of $100 Gas Dryer Upgrade (at time of replacement)	17 months (<1.5 years)	22 months (<2 years)

Consider that a $1,000 envelope or furnace improvement that saved 100 therms annually would take much longer to pay back in Atlanta than in Birmingham (20 years versus 8 years) while switching to a gas clothes dryer would pay back ~25% faster in Atlanta.

Generally, although not always, heating something with gas is more efficient, cost effective and environmentally better than using fossil-fuel produced electricity for resistance heat. However, in some areas, there is no gas available or there is a fairly significant fee to have an active gas meter each month so, consider an "all or none" approach with gas in those places. Essentially, use gas for everything or consider all electric to avoid the high monthly gas "meter fee".

In some commercial building applications, it may be economically attractive to disconnect the gas during the warmer months and pay the reconnect fee when the winter approaches. For the recent retrofit of Historic1 building (now a museum with little need for hot water), two small point-of-use electric water heaters replaced the old gas water heater that had been located in the kitchen (more on this retrofit is discussed later). The only remaining gas appliance (besides the furnace) is an old gas oven/range with standing pilots that is ripe for replacement…

"S, if your team could live without the gas stove (using the microwave, hot plate or electric kettle to make hot water?), you could convert to a "seasonal gas rate" whereby you suspend gas service until you need it next winter. This would save you about $140 per month. With an $85 reconnection fee, the net annual cost savings would be about $600 to $700 per year."

As an exception, consider the Office1 building**.** This building already has an electric tank water heater even though the building has two gas furnaces. *HOWEVER,* it is doubtful that much hot water is used in the building (maybe just one dishwasher use per day) so converting back to gas hot water is probably not worth it. A good audit recommendation would be to wrap the electric water heater tank with an insulating blanket and insulate the hot water lines.

If the current electric tank is near the end of its expected life, a gas water heater could be considered since the service is available or if usage is expected to increase. A point-of-use electric tank located near the fixture to minimize distribution losses would be another option.

Propane has historical price volatility and could cost more than electric resistance so be cautious with this fuel recommendation and application. It is also viable to consider heat pump water heaters in certain applications as their efficiency is double that of electric resistance; give due consideration to the complexity of some small commercial electricity rate structures.

Table 2: Water Heating Economics Example

Water Heating Annual Cost (For a given daily hot water consumption - REMRate)	Nat Gas @ $0.75/therm (flat rate)	Propane @ $2.00/gallon (flat rate)	Electric Resistance @ $0.12/kWh (flat rate)	Electric Heat Pump Water Heater @ $0.12/kWh (flat rate)
Older unit	0.56 EF, $146	0.56 EF, $427	0.87 EF, $444	2.0 EF, $194
More efficient	0.65 EF, $127	0.65 EF, $370	0.95 EF, $409	2.5 EF, $155

Another issue when considering an all-electric retrofit - be cautious of converting gas furnaces to heat pumps on old, inefficient shell buildings with leaky duct systems. Gas furnaces provide a warmer supply air temperature that occupants are accustomed to. If the furnaces are converted to heat pumps without fixing the ducts and envelope, comfort problems and higher bills could easily ensue. And while condensing furnaces do not supply air quite as hot as 80% furnaces, they typically have supply air temperatures warmer than those from a heat pump. As an added bonus, 95% AFUE furnaces typically feature a more efficient, variable-speed blower.

In practice, it is advantageous to upgrade the envelope first and then the equipment. The improved envelope and lighting system should be accounted for in the load calculation for any new equipment. Be cautious of like-for-like equipment change-out. Often the original equipment was oversized even before envelope upgrades were made.

An older, former-residential Office2 building featured a single 90% furnace that served three floors and was probably undersized even before certain passive solar features were removed. At some point after the building was sold in the late 1990’s and new occupants moved in, the furnace was switched to a heat pump (probably due to a large utility incentive).

The old building had prior zoning comfort issues that were exacerbated by this – the upstairs got too hot in the winter, the downstairs was cold and much individual resistance space heater usage led to exorbitantly high power bills for the occupants (it didn’t help that they opened the upstairs windows in the winter while using electric space heaters on the lower floor).

Figure 29: Maybe not the best candidate for a single zone heat pump! (Office 2) [Southface photo]

An older, two-story former manufacturing building has a 2,500 s.f. second floor loft tenant space. The space is conditioned with one mechanical system that is AC + electric furnace and another mechanical system that is AC + 80% gas furnace (this was located in a confined space that is overhead above the conference room). Their electric bills were:

- $250 Oct-Nov,
- $550 Nov-Dec,
- **$1750** Dec-Jan

For reference: The tenant in a slightly smaller space below was all electric heat pump and claimed his monthly bills were usually a few hundred dollars.

It is apparent that the extremely high spike in the client's electric bill comes from overly running the resistance heat (electric furnace). This appeared to be a result of a poorly functioning gas furnace that is not consistently operating, and thus, the electric furnace is being asked to carry too much of the space heating load. Either way, the electric furnace should be operated minimally in the heating season – upgrading to a heat pump or using gas heat are options.

Note: One likely explanation for the gas furnace's poor operation is that it is located in a **confined** overhead space that is no larger than 20'x20'x3' for a total volume of only ~1,200 c.f. This is extremely undersized for the 75,000 Btu/hr furnace. At the very least, this confined space should be converted into a combustion closet to allow the unit adequate combustion air.

8 Liability

A disclaimer – Buildings are systems and as the observing auditor we are not liable for problems that are encountered; we are only inspecting and it should be clearly understood that following the order of our listed improvements listed can be critical. Owner "cherry picking" from a list of upgrades should never be done without proper guidance and occupant health and safety must come first in terms of priority.

We are there to inspect and assess, not make adjustments – so use good judgment. It's one thing to help the building owner readjust the time clock for when the exterior lights dim to a curfew setting, it's another to adjust the control settings on a boiler without having the proper experience. We are knowledgeable (likely more than most people involved in the building) but we are not necessarily licensed contractors or designers. Use the best strategies of the code for recommendations and be sure to reference appropriate code sections in scopes of work.

> **809.1.8** The scopes shall reflect the "house as a system" approach, recognizing measure interaction. The following statement shall be included whenever a fireplace or combustion appliance is located within the building enclosure:
>
> > "This work scope is not a list of recommendations that may be implemented independently; any exclusions or variations to this scope may increase the risk of flue gas spillage, back-drafting, carbon monoxide production and/or moisture problems within the home."

Sample residential disclaimer language (RESNET Standards)

Figure 30: (Left), Should the missing flue pipe be corrected before air-sealing is conducted?! (Right), Does the squirrel in the flue pipe read disclaimers?! [D. Coffey photo (left), J. Apicella photo (right)]

9 More Scenarios – Real World Examples to Learn From

An Early Childhood Care center, a 17,000 s.f. ACBI / Grants to Green project, incorporated a combustion closet with separate High-Low vents to provide combustion for about half of the (80%) furnaces; the remaining furnaces and a standard gas tank water heater were in a vented attic mechanical space with similar combustion air provided. However, one large water heater was located inside an interior closet and room air was provided as combustion air by grills connecting the closet to the main hallway outside.

Because the majority of the mechanical equipment was in good condition and safely located outside the envelope, upgrading the furnaces would likely not be a high recommendation. However, sealing ducts and improving the envelope (air sealing and insulation of the flat ceiling) would be helpful and a high priority. Alternately, if the attic roofline were foamed (desired by the clients to prevent sprinkler pipes from freezing), this attic mechanical room could easily be converted to a combustion closet.

The large water heater located in the interior closet should be converted to a two-pipe high efficiency condensing unit. Another option would be to have a smaller combustion closet retrofitted around it (with High-Low ducts from the vented attic above or outside) or the water heater could be relocated into the other combustion closet. Once the large water heater combustion air is safely addressed, envelope improvements can proceed.

Whenever recommendations include upgrading standard efficiency combustion equipment (with a vertical metal flue pipe) to high efficiency condensing equipment, the new PVC pipes will often be run horizontally. We must make certain old metal flue pipes are removed and these envelope penetrations are sealed; also, holes in the roof can be patched immediately or we should clearly communicate that old, unused flue pipe roof penetrations can be covered at a future reroof.

Figure 31: Small standard gas water heater in vented attic mechanical room (Early Childhood Care center, left). Large standard gas water heater in internal closet (Early Childhood Care center, right). [Barcik photos]

Youth Activity Center3 (YAC3) includes an original 10,000 s.f. building with an adjacent 2,800 s.f. insulated metal roof assembly that contains mostly offices and connects to a gymnasium. Presently, both roofs are vented with ridge and soffit vents and both contain a major envelope flaw – batts on top of a drop ceiling.

Figure 32: (Left), Ridge and soffit vents with insulation installed at roofline? Never vent under the insulation! (YAC3). (Right), a horrible detail – never put insulation batts on drop ceiling tiles! (YAC3). [Barcik photos]

The water heater and furnace for the office area of YAC3 are in a separate, outside vented mechanical room (GOOD). However the three furnaces that serve the original (10,000 s.f.) building are in a mechanical / storage closet. This location gets some combustion air through leaks up to the vented attic, some from leaks to the conditioned space, and some from leaks through an exterior window.

Figure 33: Currently, this closet's combustion air comes from leaks to the vented attic – this should be sealed off if the roofline is foamed and then have combustion air provided from the exterior (YAC3). [Barcik photo]

Figure 34: Three standard 80% furnaces that will require separate combustion air be provided to them if the roofline is foamed (YAC3). [Barcik photo]

If the batts are removed and spray foam is applied along the roof line, the YAC3 mechanical closet should be more carefully sealed and insulated from both the (now unvented) attic and the conditioned space. Horizontal High-Low ducts should be added from the exterior wall / window with enough cross-sectional area to satisfy the total Btu input for all three furnaces.

The Historic1 building features two 60-70% 100k Btu/hr furnaces in a crawl/basement. These are good candidates for replacement to two-pipe condensing furnaces and this upgrade will allow for enclosing the crawlspace/basement.

Figure 35: Four burner atmospheric furnace (historic building). [Barcik photo]

The main remaining risk comes from an atmospheric vented water heater located in a small kitchen area that is jointly used as an office. Since the hot water usage in the building is low, small point-of-use electric water heaters are likely the best option. However, since it may take some time for this change to occur, the need for a CO detector (or better yet, a CO monitor) is critical. This is arguably an example of a good candidate for combustion safety testing – if the tank removal was imminent, this could be skipped.

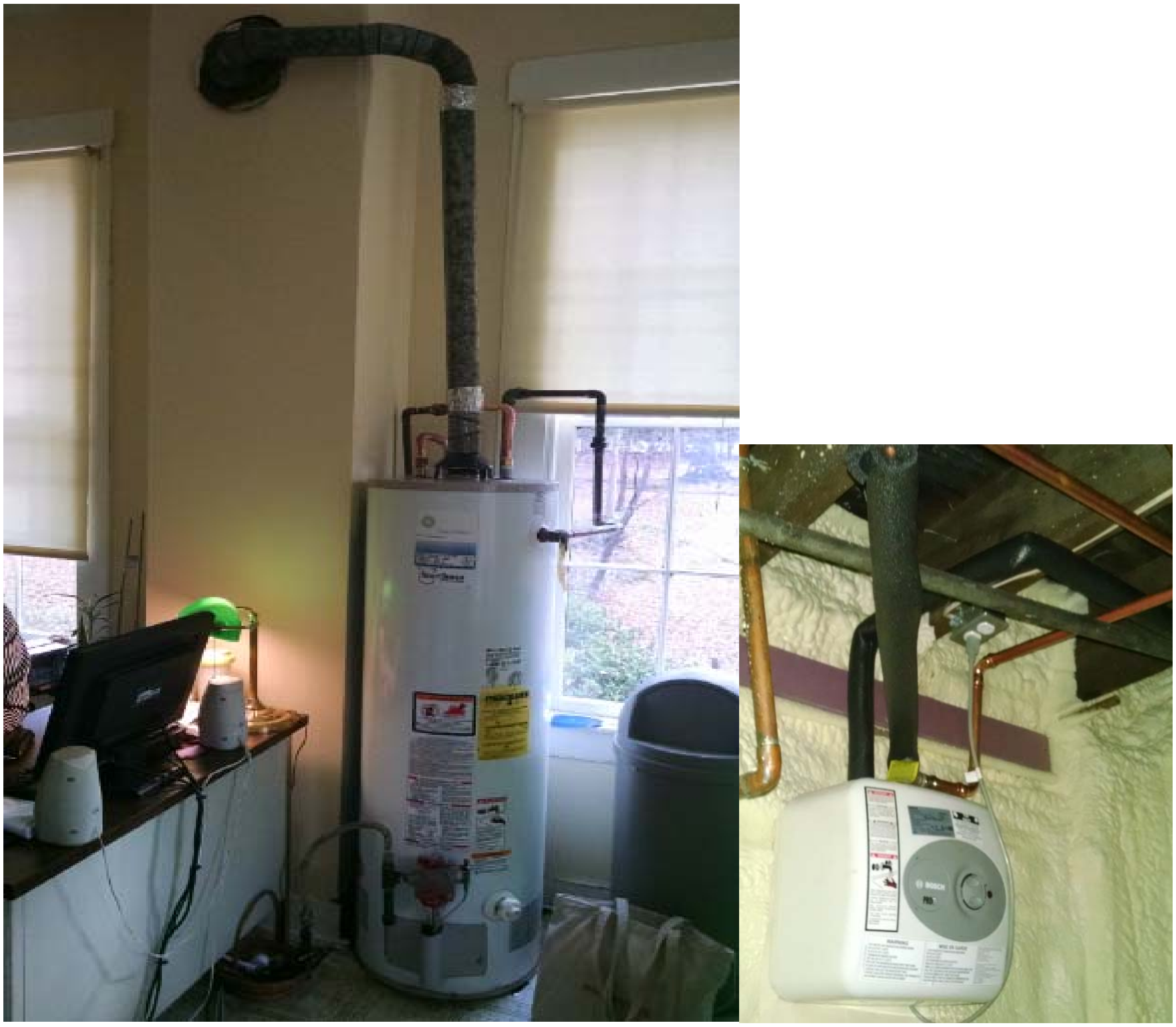


Figure 36: Standard gas water heater adjacent to desk (Historic1 building). Upgrade: 2.5 gallon electric point of use water heater inside insulated, conditioned crawlspace (Historic1 building). [Barcik photos]

Southface performed commercial blower door testing on five metro Atlanta restaurants in five straight days in December 2014. From these visits of five different restaurants, several were all-electric, some had efficient gas, and one (Restaurant1) had a malfunctioning atmospheric gas tank in a closet with louvered doors for combustion air.

We suspect that the hood operated and snuffed out the pilot light and possibly backdrafted the unit. The store was relying on their additional electric water heater but still paying for gas. An unused mechanical exhaust penetration (an intentional hole!) in the back wall would make for an excellent combustion air source if it was ducted to the closet and the louvered doors were sealed off. This simple retrofit would allow gas to safely be used once again.

Figure 37: (Left), Standard gas water heater in closet with louvered door (Restaurant1). (Right), Note unused wall penetration that could be ducted to provide air to the combustion closet (Restaurant1). [Barcik photos]

Youth Activity Center 4 (YAC4) had a massive double louvered door to the outside which fed directly into a mechanical space where a large split system AC and separate furnace were located. Unfortunately, this mechanical room space connected to the plenum space above the dropped ceiling. In fact, blower door testing confirmed that a whopping 25% of the infiltration for this fairly leaky building was from that one location. All other furnaces in the building were condensing type units so if this one furnace was upgraded to a two-pipe 90% unit, the mechanical doors could be sealed up and massive amounts of air leakage could easily be reduced.

Figure 38: (Left), Furnace in highly vented mechanical room fully connects to the rest of building due to connected overhead plenum space (YAC4). (Right), Mechanical room louvered doors (YAC4). [Barcik photos]

Figure 39: Moisture laden air caused numerous ceiling tile failures due to overhead plenum space connection with mechanical room louvered doors (YAC4). [Barcik photos]

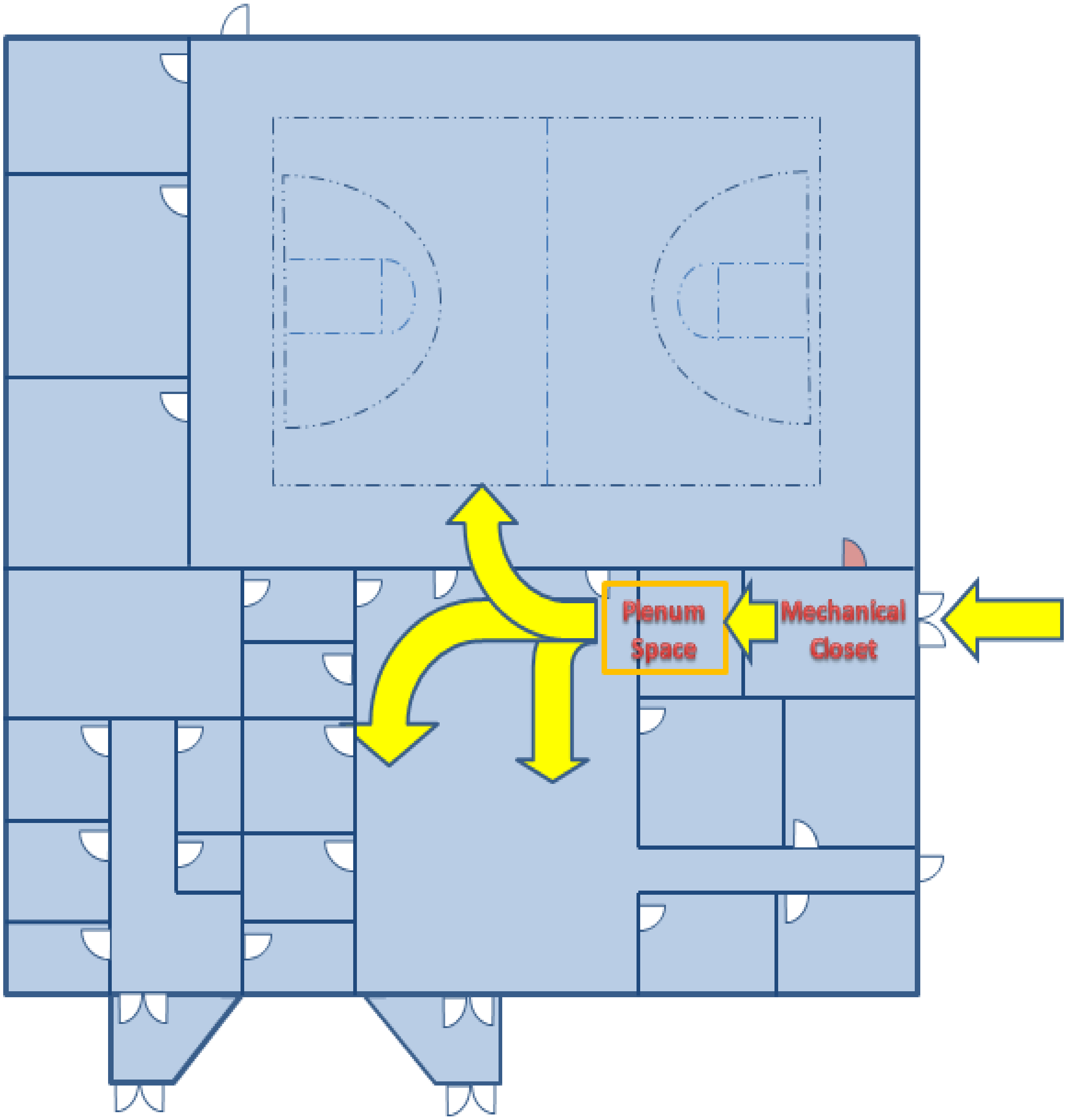


Figure 40: Floorplan shows how poor air sealing and combustion details allow infiltration throughout entire building causing poor humidity and serious condensation problems (YAC4). [Barcik photo]

Retrofit spray foamed rooflines are a common consideration for an envelope upgrade, especially in buildings where the ductwork is currently located in the unconditioned attic. However, care must be taken to remember the building is a system so any standard atmospheric vented combustion equipment (such as an 80% furnace) must be upgraded to a 2-pipe high efficiency unit due to the difficulty of creating an effective combustion closet around the existing equipment. Do not use the attic air as a source of combustion air and do not add High-Low vents to the <u>unvented</u> attic assembly.

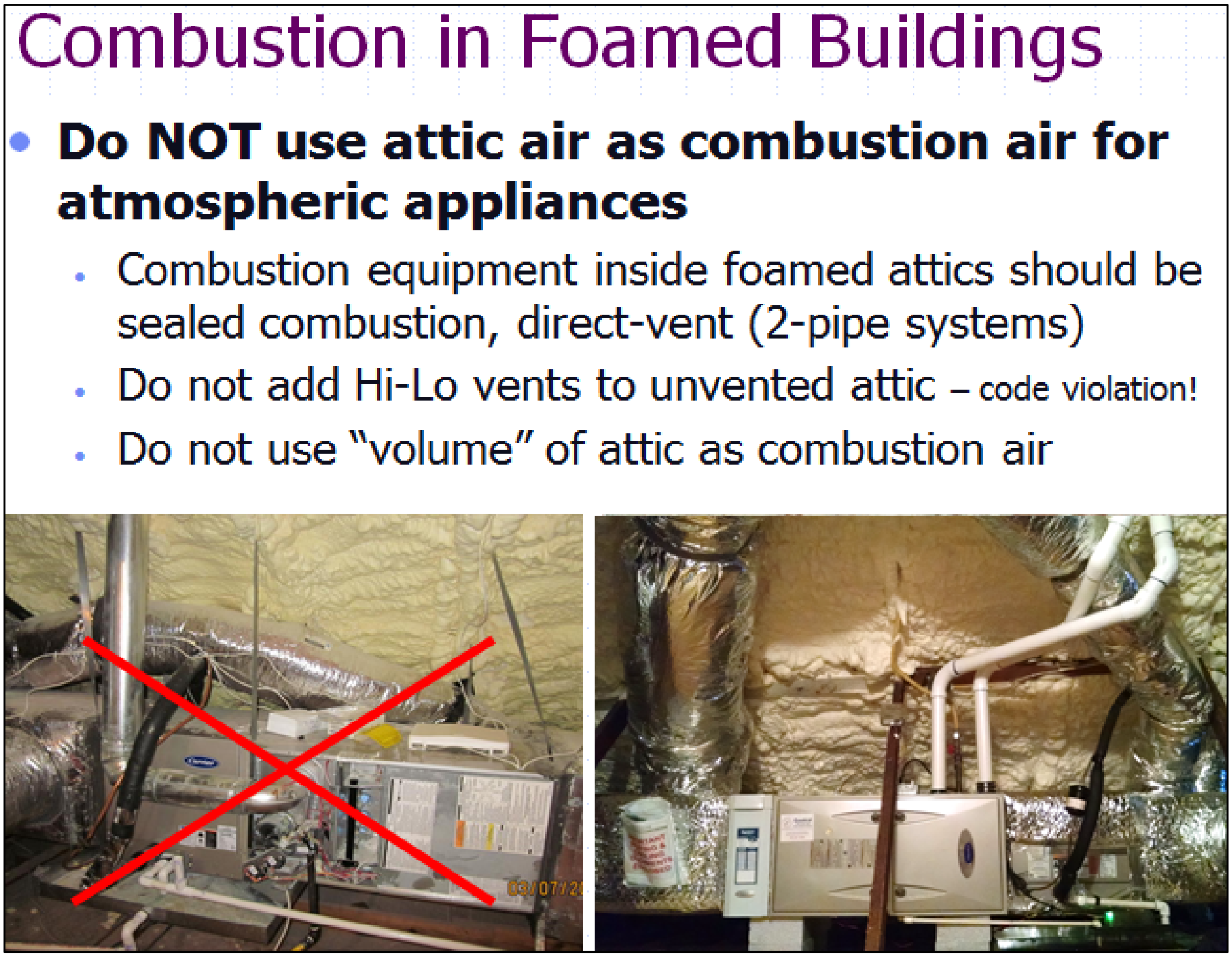


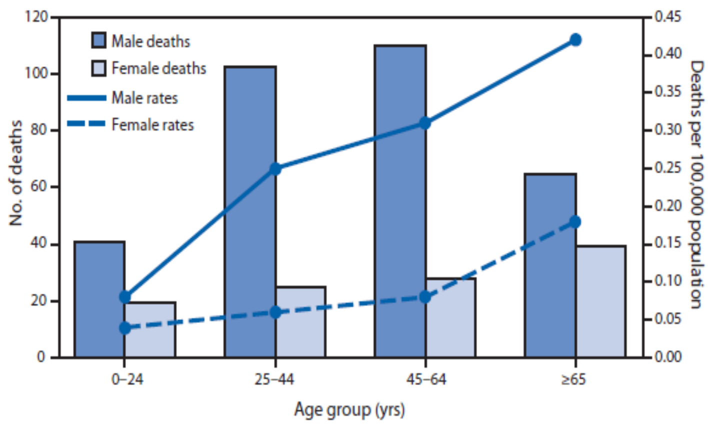
Figure 41: (Left) A poor decision - where will combustion air come from in this unvented attic assembly? (Right), a correct 2-pipe 95% AFUE furnace that is properly installed in this (retrofitted) unvented foamed attic (Lindsley attic). [Barcik photos]

References

1. http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6303a6.htm

Related Carbon Monoxide Poisoning,*† by Sex and Age Group — United States, 1999-2010

Weekly
January 24, 2014 / 63(03);65



* Unintentional, non–fire-related carbon monoxide poisoning is defined both as 1) accidental poisoning by and exposure to gases or vapors (code X47) listed as the underlying cause, and 2) toxic effect of carbon monoxide (code T58) listed as the contributing cause, according to the *International Classification of Diseases, 10th Revision*. All deaths caused by intentional exposure (X67), exposure of undetermined intent (Y17), or fire-related exposure to carbon monoxide (codes X00–X09, X76, X97, and Y26) were excluded.

† Deaths are 12-year annual averages, and death rates are per 100,000 12-year annual average population.

During 1999–2010, a total of 5,149 deaths from unintentional carbon monoxide poisoning occurred in the United States, an average of 430 deaths per year. The average annual death rate from carbon monoxide poisoning for males (0.22 per 100,000 population) was more than three times higher than that for females (0.07). The death rates were highest among those aged ≥65 years for males (0.42) and females (0.18). The rates were the lowest for males (0.08) and females (0.04) aged <25 years.

Source: National Vital Statistics System. Mortality public use data files, 1999–2010. Available at http://www.cdc.gov/nchs/data_access/vitalstatsonline.htm.

Reported by: Jiaquan Xu, MD, jiaquanxu@cdc.gov, 301-458-4086.

2. http://www.cpsc.gov/en/Safety-Education/Safety-Education-Centers/Carbon-Monoxide-Information-Center/Carbon-Monoxide-Questions-and-Answers-/

Consumer Product Safety Commission

How many people are unintentionally poisoned by CO?

On average, about 170 people in the United States die every year from CO produced by non-automotive consumer products. These products include malfunctioning fuel-burning appliances such as furnaces, ranges, water heaters and room heaters; engine-powered equipment such as portable generators; fireplaces; and charcoal that is burned in homes and other enclosed areas. In 2005 alone, CPSC staff is aware of at least 94 generator-related CO poisoning deaths. Forty-seven of these deaths were known to have occurred during power outages due to severe weather, including Hurricane Katrina. Still others die from CO produced by non-consumer products, such as cars left running in attached garages. The Centers for Disease Control and Prevention estimates that several thousand people go to hospital emergency rooms every year to be treated for CO poisoning.

3. http://www.fishnick.com/ventilation/designguides/CKV_Design_Guide_1_031504.pdf

Design Guide 1

Improving Commercial Kitchen Ventilation System Performance

Selecting & Sizing Exhaust Hoods

This design guide provides information that will help achieve optimum performance and energy efficiency in commercial kitchen ventilation systems by properly selecting and sizing exhaust hoods. The information presented is applicable to new construction and, in many instances, retrofit construction. The audience for this guideline is kitchen designers, mechanical engineers, code officials, food service operators, property managers, and maintenance people. This guide is intended to augment comprehensive design information published in the Kitchen Ventilation Chapter in the ASHRAE Handbook on HVAC Applications, as well as *Design Guide 2: Improving Commercial Kitchen Ventilation System Performance – Optimizing Makeup Air* (previously published in 2002 by the California Energy Commission under the title *Improving Commercial Kitchen Ventilation Performance*).

Fundamentals of Kitchen Exhaust

Hot air rises! An exhaust fan in the ceiling could remove much of the heat produced by cooking equipment. But mix in smoke, volatile organic compounds, grease particles and vapor from cooking, and a means to capture and contain the effluent becomes necessary to avoid health and fire hazards. While an exhaust hood serves that purpose, the key question becomes: what is the appropriate exhaust rate? The answer always depends on several factors: the menu of food products and the type (and use) of the cooking equipment under the hood, the style and geometry of the hood itself, and how the makeup air (conditioned or otherwise) is introduced into the kitchen.

The Cooking Factor

Cooking appliances are categorized as light-, medium-, heavy-, and extra heavy-duty, depending on the strength of the thermal plume and the quantity of

4. http://buildingscience.com/documents/insights/bsi-070-first-deal-with-the-manure

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BSI-070: First Deal with the Manure and Then Don't Suck

Joseph Lstiburek

JUNE 11, 2014

"If there is a pile of manure in a space, do not try to remove the odor by ventilation. Remove the pile of manure."

Max von Pettenkofer, 1858[1]

Gotta love those Germans. Especially the really old ones. Got it right big time. Dilution is not the solution to indoor pollution. Any powerful contaminant will overpower your ability to dilute it. Source control, source control and source control.

A ventilation system will not save you if you do stupid things. Like air sealing a building with a wet basement or one that is filled with "bad stuff" like insulation that is filled with rat droppings, bat droppings, mice droppings or other critter stuff and body parts either living or dead. Or worse—air seal a building where you store all manner of cleaning stuff, paint stuff, car stuff

5. http://www.energyvanguard.com/blog-building-science-HERS-BPI/bid/56595/Don-t-Compromise-Get-a-Low-Level-Carbon-Monoxide-Monitor

Don't Compromise — Get a Low-Level Carbon Monoxide Monitor

Posted by Allison Bailes on Mon, Dec 3, 2012

You know that saying, *Don't judge a book by its cover?* That certainly applies to what may be the best protection against carbon monoxide poisoning you can buy. The CO Experts carbon monoxide monitor doesn't have a flashy website or marketing program. It doesn't even have the approval from Underwriters Laboratories (UL) that so many products crave. And there's a good reason for that.

The CO Experts monitor is a low-level monitor that tells you what's going on with the carbon monoxide levels in your home in real time. It cannot get listed by UL because UL has decided that only high levels matter. Here's a quote from the UL standard, as given on the CO Experts website:

Carbon monoxide alarms covered by this standard are not intended to alarm when exposed to long term, low level carbon monoxide exposures or slightly higher short term transient carbon monoxide exposures, possibly caused by air pollution and/or properly installed/maintained fuel-fired appliances and fireplaces. See Table 38.1, Part B, False alarm resistance specifications

Appendix A
Relevant Resources

ACCA/RESNET Standard 12
http://www.acca.org/communities/community-home/librarydocuments/viewdocument?DocumentKey=df1e10b8-c437-473e-a125-b8152e78215e

ANSI/BPI 1200-S-2015
http://www.bpi.org/files/pdf/ANSI%20BPI-1200-S-2015%20Standard%20Practice%20for%20Basic%20Analysis%20of%20Buildings.pdf

National Fire Protection Agency 54/ANSI Z223.1
http://www.nfpa.org/codes-and-standards/document-information-pages?mode=code&code=54

International Building Code
http://publicecodes.cyberregs.com/icod/ibc/

International Fuel Gas Code
http://publicecodes.cyberregs.com/icod/ifgc/

International Mechanical Code
http://publicecodes.cyberregs.com/icod/imc/

International Residential Code
http://publicecodes.cyberregs.com/icod/irc/

LBNL compilation paper
http://eetd.lbl.gov/node/51254

Southface Basics of Building Science
http://www.southface.org/LMS-Modules/Basics-of-Building-Science/player.html