# Flue Gas Venting for Residential Heating Appliances

Centrotherm
solutions beyond

BY:
Douglas A. Page
PE, LEED AP BD+C, CEM
CPD, CFM, CGI, MPA
*Sr. Associate*
**EME Group - Consulting Engineers**

# Flue Gas Venting for Residential Heating Appliances

*Purpose: Gas fired furnaces and boilers are appliances commonly installed in residential occupancies in the United States. They burn hydrocarbons that transfer heat to the distribution air or water for occupant comfort. When the venting system that carries the products of combustion to the outdoors fails, Carbon Monoxide poisoning of building occupants can lead to death or irreversible nervous system damage. This paper explores venting requirements and failures in the United States and provides solutions to mitigate the issues.*

## CO Poisoning

Carbon Monoxide (CO) is a colorless, tasteless, odorless gas that is produced by burning fossil fuels. CO poisoning occurs when elevated concentrations of CO is breathed. The CO replaces the oxygen in the bloodstream. The symptoms tend to mimic the flu and more severe cases can lead to death.

There is an abundance of data from recognized sources on CO deaths and injuries from gas fired appliances. The Consumer Products Safety Commission (CPSC) is one entity that regulates residential appliances. They have analyzed data from the National Center for Health Statistics (NCHS) that retains records of every death certificate in the United States, and other sources including their own Injury or Potential Injury Incident database. Although they have data for many years, their most recent appears to be from 2013-2015. For gas-fired furnaces and boilers, the CPSC found that an average of 19 non-fire CO deaths per year and they estimate 7,590 CO non-fire injuries (poisonings) per year. These deaths and injuries are preventable.

The CPSC has performed In-Depth Investigations on many of these cases. Two of the failure modes the CPSC found were disconnected or breached (hole) vents, and improper venting. This is not because the appliances were old and worn out. The average age of appliances was 9.6 years old. These failures were directly caused by the vent system not carrying the products of combustion to the exterior of residential occupancies.

## CODES

For industry professionals designing, installing, inspecting or furnishing residential appliances; the residential, fuel gas, and energy codes adopted by the authority having jurisdiction governs the appliance selection and installation. According to the International Code Council (ICC), the

International Residential Code (IRC) is in use or has been adopted in forty-nine states, the International Fuel Gas Code (IFGC) is in forty-one states, and the International Energy Conservation Code (IECC) is in forty-eight states. The IRC applies to One and Two family Dwellings and Townhouses, the IFGC applies to buildings not covered by the IRC, and the IECC applies to all buildings. The IRC and IFGC have many identical requirements regarding venting. The below explores the 2018 version of these codes and what they require regarding appliance venting.

As a matter of simple definition, vented appliances are categorized by the ICC as follows:

**Category I.** An appliance that operates with a nonpositive vent static pressure and with a vent gas temperature that avoids excessive condensation production in the vent.

**Category II**. An appliance that operates with a nonpositive vent static pressure and with a vent gas temperature that is capable of causing excessive condensate production in the vent.

**Category III.** An appliance that operates with a positive vent static pressure and with a vent gas temperature that avoids excessive condensate production in the vent.

**Category IV**. An appliance that operates with a positive vent static pressure and with a gas temperature that is capable of causing excessive condensate production in the vent.

## Energy Code

It is common for designers/installers involved in residential construction to use the performance-based compliance method to conform to the IECC. This essentially permits trade-offs between the efficiency of the building envelope and the efficiency of appliances. As energy codes become more stringent, so must the efficiencies of appliances in buildings. IECC also permits compliance with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1 *Energy Standard for Buildings except Low-Rise Residential Buildings*. The 2016 edition of ASHRAE 90.1 generally requires a minimum gas-fired hydronic boiler Annual Fuel Utilization Efficiency (AFUE) efficiency of 90%. ASHRAE 90.2-2018 *Energy-Efficient Design of Low-Rise Residential Buildings* requires a minimum efficiency of 90% for boilers and 95% for furnaces. In short, energy codes are driving the installation of Category IV appliances in new residential construction.

## ANSI Standards Cited by Code

Chapter 24 of the IRC is the Fuel Gas portion of the code. Section G2442 (Section 618 of the IFGC) requires "Forced-air furnaces to be tested in accordance with ANSI Z21.47 (*Gas-fired central furnaces*) or UL 795 (*Standard for Commercial-Industrial Gas Heating Equipment*) and shall be installed in accordance with the manufacturer's instructions.". If we review the more applicable ANSI Z21.47 standard, we find:

- Category II, III, and IV appliances are to be gas tight
- For Category II, III, and IV furnaces, the manufacturer's installation instructions shall specify the type of venting material to be used, vent size, and the minimum/maximum vent lengths.
- Labeling is required and the Standard states, "This furnace requires a special venting system. Refer to the installation instructions for parts list and method of installation."
- The temperature of the venting system shall not exceed the temperature for which the venting system material has been determined to be acceptable.
- The maximum Heat Deflection Temperature (HDT) for PVC vents is 158 °F.
- Furnace to operate within the furnace's intended temperature-rise range with a duct system which has an external static pressure within the allowable range, as specified in the manufacturer's instructions

Similarly, G2452 (631 of IFGC) requires boilers to be listed per ANSI Z21.13 (*Gas-fired low pressure steam and hot water boilers*) or UL 795 (*Standard for Commercial-Industrial Gas Heating Equipment*), and installed per the manufacturer's instructions. Like the ANSI standard for furnaces, ANSI Z21.13 includes requirements for the manufacturer to dictate the venting system and to provide installation instructions for the vent. It also includes:

- The water temperature limiting device maximum temperature setting is the ASME nameplate rating for the boiler.
- Maximum allowable temperature for PVC venting is 158°F
- Cellular core PVC pipe is not permitted for venting

In summary, the appliance manufacturer determines the material and installation for the venting. The vent system should be gas tight. The vent material should not exceed its temperature rating – according to ANSI this is 158°F for PVC. Cellular core PVC is not permitted for venting boilers.

The purpose of the temperature limiting device on boilers is to prevent appliance overheating. This device does not stop the vent from overheating. Manufacturers' instructions were found that indicate the water side temperature limiting device is field adjustable with an upper value of 190°F. Unless a temperature limiting device is provided that the owner/occupant cannot readily override by increasing the supply temperature setpoint, a Category IV appliance can easily become a Category III appliance and exceed the temperature rating of the vent under normal operation. In the case of PVC, this is 158°F according to the ANSI standard. *However*, review of several PVC pipe manufacturers' requirements yields a maximum service temperature for their PVC piping is 140°F.

ANSI Z21.47 explicitly states a furnace should operate within the temperature rise range of the external static pressure published for the furnace. If this does not occur, by causes such as poorly designed ductwork or overloaded air intake filters, there will be insufficient airflow for the distribution system. With reduced airflow, the heat transfer between the combustion side of the heat exchanger and the air supplying the building spaces will exceed the levels designed by the manufacturer. The supply air temperature leaving the furnace will be excessive (as defined by ASHRAE Standard 55 *Thermal Environmental Conditions for Human Occupancy*) and the temperature of the products of combustion leaving the furnace will rise. Even for a listed Category IV appliance, the discharge temperature in the vent can easily exceed 158°F.

Temperature rise on the combustion side of boilers can be caused by scale on the water side of the heat exchanger. Scale is produced from minerals in the water that tend to precipitate out of the water onto heating surfaces. Minerals may enter the hydronic system during the initial installation and may be exacerbated by cold water make-up required by system leaks or periodic drain of the system. Scale on boilers acts as an insulator of the tubes between the products of combustion and the water being heated. This can cause overfiring of the appliance and overheating of the discharge to the venting system.

Antifreeze is occasionally used in hydronic systems for freeze protection. The specific characteristics of the antifreeze solution depends on several variables such as type, concentration, and temperature. Antifreeze solutions will decrease the heat transfer from the combustion side to the hydronic side of the boiler. To maintain adequate heat transfer, hydronic flow rates are usually increased with a significant increase in pump horsepower. When this is not done, the temperature of the flue gas will increase.

Where Category IV are operated close to the vent temperature service limit, adding glycol could drive the flue gas temperature above the temperature rating of the vent.

## The Code and Venting

Chapter 24 of the IRC provides requirements for vents.

G2426.1 (502.1 of the IFGC) states, "Vents, except as provided in Section G2427.7, shall be *listed* and *labeled*. Type B and BW vents shall be tested in accordance with UL 441. Type L vents shall be tested in accordance with UL 641. Vents for Category II and III *appliances* shall be tested in accordance with UL 1738. Plastic vents for Category IV *appliances* shall not be required to be *listed* and *labeled* where such vents are as specified by the *appliance* manufacturer and are installed in accordance with the *appliance* manufacturer's instructions."

Section G2427.4.1 (503.4.1) reads, "Where plastic pipe is used to vent an *appliance*, the *appliance* shall be *listed* for use with such venting materials and the *appliance* manufacturer's installation instructions shall identify the specific plastic piping material. The plastic pipe venting materials shall be *labeled* in accordance with the product standards specified by the *appliance* manufacturer or shall be *listed* in accordance with UL 1738."

Category I appliances are generally less efficient appliances and are commonly replaced with more efficient units upon failure. The vents for Category II and III appliances are already required by the IRC and IFGC to be listed to UL 1738 *Standard for Safety for Venting Systems for Gas-Burning Appliances. Categories II, III, and IV*. UL 1738 is discussed below. This leaves us with discussion on Category IV appliances.

Per the IRC/IFGC, Category IV appliance vents need to conform to the appliance manufacturer's requirements or UL 1738. Appliance manufacturers generally permit multiple materials for venting systems with their appliances. For category IV appliances, these generally are corrosion-resistant steel, PVC, CPVC or PP. Due to relative costs of materials and installation, venting material for these residential appliances tend to be plastic.

Many vent installations for these residential appliances are not listed or labeled, instead relying on the appliance manufacturers' installation instructions. Several manufacturers' instructions have been studied for cited standards of venting. Cited standards of venting permitted by appliance manufacturers include ASTM D1785 *Standard Specification for Poly(Vinyl Chloride) (PVC) Plastic Pipe, Schedules 40, 80, and 120*; ASTM 2665 *Standard Specification for Poly Vinyl Chloride (PVC) Plastic Drain,*

*Waste and Vent Pipe and Fittings*; and ASTM D2241 *Standard Specification for Poly(Vinyl Chloride) (PVC) Pressure-Rated Pipe (SDR Series)*. Reviewing the scope of these standards we find:

- The scope of ASTM D1785 states, "The products covered by this specification are intended for use with the distribution of pressurized liquids only…" Note 2 of the Scope states that the Standard, "…does not include provisions for the use of these products for venting of combustion gases. UL 1738 is a standard that does include specific testing and marking requirements for flue gas venting products, including PVC."
- The scope of ASTM D2665 states, "This specification covers requirements and test methods for … poly(vinyl chloride) plastic drain, waste, and vent pipe and fittings…" The vent stated in the Standard is plumbing venting, not appliance venting.
- The scope of ASTM D2241, Note 2 states, "This standard specifies dimensional, performance, and test requirements for plumbing and fluid handling applications, but does not address venting of combustion gases."
- Standards ASTM D1785 and D2241 do not include fittings. These Standards only apply to the piping. Manufacturers have omitted the ASTM Standards that do apply to fittings.

The standards referenced by appliance manufacturers have no applicability to venting the products of combustion. They are standards for drainage, waste, and vent pipe of drainage systems. Further, these are *material* standards and not *installation* standards. Several manufacturers lack adequate assembly instructions for their materials including vent fittings, expansion compensation, support spacing of the vent, types of supports, and glue types to be provided. Some installations require CPVC at the appliance and PVC at the terminal. This would require different glues for the different materials, or a glue listed for both PVC & CPVC.

PVC drainage piping has a maximum fluid carrying temperature of 140 °F, according to its manufacturers. Category IV appliances, by definition, utilize condensing technology. Condensing in these appliances allows extraction of the latent energy in the flue gases. For boilers, this generally means return water temperatures below 130°F and flue gases generally below 135°F. However, occupants/owners can increase the temperature of the flue gases by simply increasing the output/supply temperatures of the boiler. Also, both furnaces and boilers lack a mandatory thermal limit safety in the flue that prevents increasing the flue gases from exceeding 140°F (the PVC drainage pipe thermal limit) and is a potential source of vent failure.

# Other Concerns

## - New Boilers in Existing Residences

Historically, hydronic heating systems were designed for 180°F water leaving the boiler and 160°F water temperature at the return. This is the typical heuristic approach that older systems were designed to. When heating load (loss) calculations were performed, terminal devices such as finned tube radiators were sized in rooms to address the heat loss of the room based on an average water temperature

(Approximately 170°F). We also find many homes that once had steam boilers may have high mass cast iron steam radiators and low mass finned tubes. This often happens in the same hydronic circuit.

These existing installations have a common problem of thermal comfort in the rooms. If a Category IV appliance is provided, with say a 160°F supply and 130°F return water temperature, the terminal devices will not provide adequate heat to the space. Aggravating this inadequate heat transfer in the rooms could be high mass radiators that take longer than finned tube to absorb heat from the boiler water and release heat to the space. When occupants are cold, they may start with increasing the setpoint at the wall thermostat. If this does not improve the thermal comfort in the spaces, they most likely will turn up the supply water temperature of the boiler. The supply water temperature may increase, and so will the temperature of products of combustion going to the appliance's vent system. The occupants essentially have changed the Category IV appliance into a Category III appliance. Even operating under normal conditions, the flue temperatures can exceed 160°F.

The IRC requires chimney passageway be inspected prior to connecting an appliance to the chimney. If deficiencies are found, the chimney needs to be repaired, relined, or replaced. Also, the existing flue may be too large, or may not be corrosion resistant, for a new high efficiency condensing appliance. In this case, the chimney flue needs to be replaced with suitable venting.

## - Multiple Appliances/Different Manufacturers

The Code prohibits connecting Category II or IV appliances with a Category I appliance in the same venting system. With rare exceptions, the Code also prohibits from connecting solid fuel 'appliances' with non-solid fuel appliances.

The Code explicitly requires the appliance manufacturer to size, determine materials, and provide instructions on the vent system. What happens when multiple appliances are installed into the same vent? Some manufacturers have instruction supplements in cases where the vents of multiple appliances of their manufacturer are headered together. Others require independent venting to the exterior.

What happens when multiple appliances are being installed by different manufacturers? This is common, for example, when a boiler and a domestic water heater for a residence. It appears there are two possible solutions. First, install the venting independently for each appliance. The second option may be to have a qualified party, such as a manufacturer of listed venting, engineer a design that would be permitted by R104.11 of the IRC and 105.2 of the IFGC, *Alternative materials, design and methods of construction and equipment*. These would need to be approved by the Code Enforcement Official. This issue has yet to be fully vetted by the industry.

## UL 1738

UL 1738 – *Standard for Venting Systems for Gas-Burning Appliances, Categories II, III, and IV* treats the vent parts and system as an assembly. Some of the topics covered in UL 1738 include

a. Materials
b. Joints
c. Support assemblies
d. Pressure, temperature, and leakage tests
e. Draft loss, wind effect and induced updraft test
f. Vent sag and deflection tests
g. Strength tests
h. Installation and Maintenance Instructions

Of particular interest is the Temperature Test. UL 1738 requires the vent assembly to be heated to 70°F above its temperature rating for 3 hours. The Standard defines Temperature Rating as "The maximum use temperature specified by the vent manufacturer for which the venting system is intended. The marked temperature rating is equal to the minimum vent input temperature selected from Table 19.1 less 70°F (38.8°C)." A vent assembly is (internally) subjected to a heat generator of 70°F above the vent rating for a minimum of 45 minutes. For plastic venting, the non-metallic parts shall not have softened, melted, distorted, creeped, or moved in relation to other components.

PVC listed to plumbing drainage standards would readily melt at 210°F (140°F + 70°F), the minimum listed temperature of Table 19.1. By contrast, there are listed polypropylene assemblies with an operating temperature of 230°F that are tested at 300°F and conforms to the UL 1738.

Other tests of UL 1738 are rigorous and are focused on the application of appliance venting. The vertical support test includes a weight applied for 60 minutes equal to four times the load imposed by the heaviest assembly that the support will be required to sustain in service. Similarly, joints and elbows are subjected to a load equal to four times the weight of the longest venting system section but not less than 10 pounds. The sag test essentially involves heating a vent section to 70°F above its temperature rating for three hours and determining if it sags more than 6.25 percent. A joint tightness test involves applying a 25 foot-pound torque to a joint to verify it will not separate.

The Strength Test for Joining Non-Metallic Vent Systems involves heating a sample vent assembly via a heater for 10 minutes on and 15 minutes off – for 12,000 cycles. Some polymer systems meet this requirement, such as listed polypropylene assemblies. PVC with solvent-weld joints and temperature ratings of 140°F or less are exempt from this heat cycling test.

UL 1738 also requires the manufacturer to provide Installation and Maintenance Instructions (I&M). Per the Standard, "Installation instructions shall be illustrated and include directions and information necessary to complete the intended installation of the venting system." The Standard requires details of all parts required and step-by-step process for installing the venting system. This includes vent fittings, expansion compensation, support spacing of the vent, types of supports, and glue types to be provided.

Succinctly, venting assemblies that conforms to UL 1738 have proven their safety and applicability to venting of appliances.

## Recommended Code Language Change

There is a simple solution to improve the safety of Category IV appliance venting. The solution is to have vents tested to a standard that is written for appliance venting. The IRC and IFGC already require this for venting of Category II and III appliances. This can be done by changing section G2426 (502 of IFGC) to read:

"Vents, except as provided in Section G2427.7, shall be *listed* and *labeled*. Type B and BW vents shall be tested in accordance with UL 411. Type L vents shall be tested in accordance with UL-641. Vents for

Category II, III and IV *appliances* shall be tested in accordance with UL 1738 and installed per the appliance manufacturer's and listed vent manufacturer's instructions."

And change section G2427.4.1 (503.4.1) to read:

"Where plastic pipe is used to vent an *appliance*, the *appliance* shall be *listed* for use with such venting materials and the *appliance* manufacturer's installation instructions shall identify the specific plastic piping material. The plastic pipe venting materials shall be *labeled* in accordance with the product standards specified by the *appliance* manufacturer and shall be *listed* in accordance with UL 1738."

*Summary: If injuries and deaths due to carbon monoxide poising from gas-fired appliances is to be reduced, then the industry should be providing venting assemblies listed for the venting application. Installation instructions for the vent assembly should be explicit and include vent fittings, support spacing, and expansion compensation. Products designed and listed for plumbing drainage should not be permitted for appliance venting. Appliance Category IV vent systems in compliance with UL 1738 would mitigate many core issues with appliance venting.*

## About the author:

Doug Page PE, CPD, LEED AP BD+C, CEM, CGI, CFM has been involved in building construction for more than 36 years and is a Senior Associate with the EME Group, a New York based Engineering and Architectural firm. Doug received his BS from Clarkson University and his MPA from the University at Albany/Rockefeller College.

He holds several industry certifications and is a NYS certified code enforcement official. He currently serves on the ASHRAE Northeast Chapter Board of Governors and is a past president of the ASPE Capital Region New York Chapter. Doug can be reached at dpage@emegroup.com

# Bibliography


ASHRAE. 2017. *Handbook* – Fundamentals. Atlanta. ASHRAE

ASHRAE. 2016. *Handbook* – HVAC Systems and Equipment. Atlanta. ASHRAE

ASHRAE. 2013. *Thermal Environmental Conditions for Human Occupancy*. ANSI/ASHRAE Standard 55-2013. Atlanta. ASHRAE

ASHRAE. 2016. *Energy Standard for Buildings Except Low-Rise Residential Buildings*. ANSI/ASHRAE/IES Standard 90.1-2016. Atlanta. ASHRAE.

ASHRAE. 2018. *Energy-Efficient Design of Low-Rise Residential Buildings*. ANSI/ASHRAE/IES Standard 90.2-2018. Atlanta. ASHRAE

CSA Group. 2017. *Gas-fired low pressure steam and hot water boilers*. ANSI Z21.13-2017. CSA 4.9-2017. Toronto. CSA Group.

CSA Group. 2016. *Gas-fired central furnaces*. ANSI Z21.47-20165. CSA 2.3-2016. Toronto. CSA Group.

Dow Chemical Company. 2008. *Engineering and Operating Guide for Dowfrost and Dowfrost HD Inhibited Propylene Glycol-based Heat Transfer Fluids*. Midland. Dow.

International Code Council, Inc. 2019. *2018 International Energy Conservation Code*. Country Club Hills. ICC.

International Code Council, Inc. 2019. *2018 International Fuel Gas Code*. Country Club Hills. ICC.

International Code Council, Inc. 2018. *2018 International Residential Code*. Country Club Hills. ICC.

UL. 2014. *Standard for Venting Systems for Gas-Burning Appliances, Categories II, III, and IV*. ANSI/UL 1738-2014. Northbrook. UL

United States Consumer Product Safety Commission. 2019. Briefing Packet for CPSC's *Advanced Notice of Proposed Rulemaking: Performance Requirements for Residential Gas Furnaces and Boilers*. Bethesda. CPSC

United States Consumer Product Safety Commission. 2012. Memorandum from Jordan to Ray regarding *Updated Review of In-Depth Investigations Associated with Carbon Monoxide Poisoning and "Modern" Gas Furnaces and Boilers*. Washington DC. CSPC

United States Consumer Product Safety Commission. 2018. *Non-Fire Carbon Monoxide Deaths Associated with the Use of Consumer Products 2015 Annual Estimates*. Bethesda. CSPC