ASHRAE Position Document on Unvented Combustion Devices and Indoor Air Quality

Approved by ASHRAE Board of Directors
January 25, 2012

Reaffirmed by ASHRAE Technology Council
January 23, 2018

Expires
January 23, 2021

ASHRAE
1791 Tullie Circle, NE • Atlanta, Georgia 30329-2305
404-636-8400 • fax: 404-321-5478 • www.ashrae.org

COMMITTEE ROSTER

The ASHRAE Position Document on Unvented Combustion Devices and Indoor Air Quality was developed by the Society's Unvented Combustion Devices Position Document Committee formed on April 13, 2007.

Paul W. Francisco
University of Illinois at Urbana—Champaign
Champaign, IL

David Delaquila
Air Conditioning, Heating and Refrigeration Institute (AHRI)
Arlington, VA

Steven J. Emmerich
National Institute of Standards and Technology (NIST)
Gaithersburg, MD

Roger Hedrick
Architectural Energy Corporation
Boulder, CO

Michael Hodgson, MD, MPH
Veterans Health Administration
Washington, DC

FORMER MEMBERS AND CONTRIBUTORS

Richard A. Charles, PE (Former Chair)
Oakland, CA

Shelly L. Miller, PhD (Former Chair)
University of Colorado—Boulder
Boulder, CO

Ted Lemoff
National Fire Protection Association (NFPA)
Quincy, MA

The chairperson) of the ASHRAE Environmental Health Committee, Larry Schoen and Jianshun Zhang, also served as ex-officio members.

HISTORY OF REVISION/REAFFIRMATION/WITHDRAWAL DATES

The following summarizes this document's revision, reaffirmation, or withdrawal dates:

1/25/2012—BOD approves Position Document titled *Unvented Combustion Devices and Indoor Air Quality*

6/16/2014—Technology Council approves reaffirmation of Position Document titled *Unvented Combustion Devices and Indoor Air Quality*

1/23/2018—Technology Council approves reaffirmation of Position Document titled *Unvented Combustion Devices and Indoor Air Quality*

Note: ASHRAE's Technology Council and the cognizant committee recommend revision, reaffirmation, or withdrawal every 30 months.

Note: ASHRAE position documents are approved by the Board of Directors and express the views of the Society on a specific issue. The purpose of these documents is to provide objective, authoritative background information to persons interested in issues within ASHRAE's expertise, particularly in areas where such information will be helpful in drafting sound public policy. A related purpose is also to serve as an educational tool clarifying ASHRAE's position for its members and professionals, in general, advancing the arts and sciences of HVAC&R.

ABSTRACT

This document provides information and ASHRAE's positions based on the current state of knowledge of unvented combustion appliances. These appliances may be found in almost any occupancy. ASHRAE's position is that appliance standards and technology should be reviewed in light of increased knowledge of usage patterns and evolving air quality standards related to combustion by-products; a public information program should be developed that improves the knowledge of owners of these appliances with regard to usage and the importance of professional installation and maintenance; and research should be performed on these appliances to answer remaining questions about their impact on indoor air quality. Specific research questions relate to particle emissions, nitrogen dioxide emissions, the relative impact of cooking versus heating, and denatured alcohol kerosene appliances.

Note: ASHRAE position documents are approved by the Board of Directors and express the views of the Society on a specific issue. The purpose of these documents is to provide objective, authoritative background information to persons interested in issues within ASHRAE's expertise, particularly in areas where such information will be helpful in drafting sound public policy. A related purpose is also to serve as an educational tool clarifying ASHRAE's position for its members and professionals, in general, advancing the arts and sciences of HVAC&R.

CONTENTS

ASHRAE Position Document on Unvented Combustion Devices and Indoor Air Quality

SECTION **PAGE**

EXECUTIVE SUMMARY

This position document has been written to provide ASHRAE's membership and other interested persons with information about the effect of unvented combustion devices on indoor air quality and to provide recommendations for the proper use of these devices.

ASHRAE's sole objective is to advance the arts and sciences of heating, refrigeration, air conditioning and ventilation, and their allied arts and sciences and related human factors, for the benefit of the public. Therefore, the impact and proper use of unvented combustion devices are relevant to ASHRAE.

ASHRAE's positions at present are:

- Users should properly operate unvented appliances installed in the home and get an annual inspection by a qualified service technician.
- A public education program should be developed that reinforces the health and safety information contained in industry literature.
- Unvented combustion appliances should never be used as the primary/sole source of heating.
- Consumers who want to reduce the risk of adverse health effects due to exposure to combustion products should not use unvented appliances.
- Carbon monoxide (CO) alarms should be installed in all homes regardless of heating fuel type.
- Gas cooking appliances with electronic ignitions should be selected when possible.
- Permanently mounted unvented combustion appliances should be installed according to the manufacturers' installation instructions and local codes and installation should be performed by a qualified installer.
- A reassessment of ventilation should be made when air-sealing measures have been implemented to a building containing an unvented appliance, with ventilation added when appropriate.
- Unvented gas-fired room heaters listed to a pre-1983 edition of ANSI Z21.11.2 and not equipped with an Oxygen Depletion Safety (ODS) device should be replaced immediately.
- Unvented kerosene room heaters should be removed unless listed to UL 647 and new installations should be avoided unless future research demonstrates adequate indoor air quality when they are used.
- Unvented denatured alcohol appliances should be removed unless listed to UL 1370 and new installations should be avoided unless future research demonstrates adequate indoor air quality when they are used.
- Research should be performed that investigates the effects of unvented space heater combustion on indoor air quality in residential buildings. Particular questions of interest include:

    1. the suitability of the ANSI Z21.11.2 emission standards for nitrogen dioxide (NO_2)
    2. the performance of units subject to ANSI Z21.11.2-2005 or later in the field with regard to NO_2
    3. particle emissions and their effect

- Research should be performed on kerosene and denatured alcohol appliance emissions and resulting indoor air quality.

- Research should be performed that investigates the effects of gas cooking combustion on indoor air quality in residential and commercial buildings. Particular questions of interest include:

    1. disaggregating the gas combustion from the cooking process
    2. emissions of NO_2, CO, and particles from modern units
    3. differences between range top cooking compared to oven cooking

- Industry sizing and installation guidance should be revisited in light of changes in housing stock.
- Code- and standard-making entities should require that installers be certified.
- Appliance standards should be reviewed and updated as needed in light of more recent understanding and standards/guidelines on acceptable levels of NO_2.
- Appliance standards should be reviewed and updated as needed in light of evidence that extended use is not uncommon and can result in unacceptable levels of CO, with considerations made to incorporating controls that prevent excessive durations of uninterrupted operation. These standards should also require that product information include language on the risks from extended use.

1. ISSUES

This position document discusses the effect of using unvented liquid and gas fuel combustion devices on indoor air quality. It addresses the various constituents within the products of combustion that are emitted from unvented combustion appliances into the indoor space and the appropriate measures that should be considered in order to maintain acceptable indoor air quality. Historically, indoor air quality problems from combustion devices have been related to their not being properly installed and maintained by a qualified service person and not being used in accordance with manufacturers' instructions.

Various appliances are designed to operate on different fuel types or are intended to be used for different space heating or cooking applications. Safety standards covering these products differ in the maximum allowable emissions of certain combustion by-products. Because of these differences, each type of device is addressed separately throughout this document.

Unvented combustion emissions from candles, incense, and devices that burn solid fuels are excluded from this position document.

2. BACKGROUND

Unvented combustion equipment may be found in almost any occupancy classification, although some are more common than others. Unvented heaters are permitted to be installed in most jurisdictions, but prohibitions or restrictions exist in some locations. All state codes permit the installation of unvented cooking appliances.

The National Fuel Gas Code, ANSI Z223.1/NFPA 54 published jointly by the National Fire Protection Association (NFPA) and the American Gas Association (AGA), governs the installation of unvented gas-fired room heaters, but prohibits installation in certain occupancies, which include residential board and care or health care (ANSI Z223.1/NFPA 54-2009). The International Fuel Gas Code, published by the International Code Council (ICC), also governs the installation of unvented gas-fired room heaters but prohibits installation in assembly, educational, and institutional occupancies (ICC 2012). NFPA 501, Standard on Manufactured Housing prohibits the installation of unvented room heaters in manufactured housing as part of the construction code (NFPA 501-2010). Once the manufactured home is sited, unvented gas-fired room heaters can be installed where allowed by state and local code.

The Life Safety Code (NFPA 101-2012), allows gas-fired room heaters that are in compliance with ANSI Z223.1/NFPA 54 but prohibits the use of unvented fuel-fired heating equipment, including kerosene and denatured alcohol, from being used in educational, day care, rooming/lodging, hotel/dormitory, apartment, and health care occupancies. Portable space heating devices are prohibited in detention/correctional facilities.

Unvented combustion heaters, including propane and natural gas-fired heaters listed to the *Standard for Gas-Fired Room Heaters, Vol. II, Unvented Room Heaters* (ANSI Z21.11.2-2007), and kerosene heaters listed to the *Standard for Unvented Kerosene-Fired Room Heaters and Portable Heaters* (UL 647-1993), are most commonly found in residential occupancies.

Gas-fired room heaters, especially gas log types, are sometimes used in hotel/lodging common areas and assembly occupancies, such as restaurants, for their aesthetic effect.

In commercial building and storage occupancies the use of unvented combustion room heaters is very rare, although not prohibited by NFPA 101 or the International Fuel Gas Code (IFGC). Unvented infrared radiant heaters can be found in industrial occupancies, such as aircraft hangers, repair garages, or similar large open spaces requiring localized heating for the workers.

The Third National Health and Nutrition Examination Survey (NHANES III) estimated that 13.7 million adults have at some time used an unvented combustion space heater. Since 1992, use of unvented combustion heaters has increased because in many states, regulations prohibiting the use of these devices have been rescinded (MMWR 1997).

About 170 people in the United States die every year from carbon monoxide (CO) produced by non-automotive consumer products. These products include malfunctioning fuel-burning appliances such as furnaces, gas ranges, water heaters, room heaters, engine-powered equipment such as portable generators, solid-fuel burning fireplaces, and charcoal that is burned in homes and other enclosed areas (CPSC 2011b). Since 1984 the U.S. Consumer Product Safety Commission (CPSC) staff has collected data on fatal CO poisonings and is not aware of any documented incident associated with a gas-fired space heater complying with ANSI Z21.11.2-1982, though such an incident was not precluded (Switzer 2005).

The installation and usage of these appliances have an impact on indoor air quality. When improperly installed or maintained or misused the potential for harmful emissions being released into the living space increases.

3. PRODUCTS OF COMBUSTION

The primary products of combustion that are of concern for natural gas are CO, oxides of nitrogen including nitrogen dioxide (NO_2), and water. Carbon dioxide (CO_2) is also a primary product of combustion but is of less concern. Other fuels may produce greater quantities of other pollutants such as respirable particulate matter (PM10 and PM2.5), several carcinogenic compounds (e.g., polycyclic aromatic hydrocarbons, benzene), and aldehydes (Girman et al. 1982; Traynor et al. 1990; Rogge et al. 1993; Moschandreas et al. 1986). This section describes the primary products of combustion, their potential health impacts, and the thresholds established by cognizant authorities.

3.1 Health Effects and Thresholds

Various organizations around the world have established standards and guidelines for combustion by-products. Some of these have been established in the context of outdoor thresholds but are often applied to indoor environments. The health effects of these pollutants depend on the concentration and exposure time in addition to other factors such as personal susceptibility.

3.1.1 Carbon Monoxide

Carbon monoxide is an odorless, colorless gas that can cause illness, loss of consciousness, and even death. The most common symptoms of CO poisoning are headache, dizziness, weakness, nausea, vomiting, chest pain, and confusion. Unless suspected, CO poisoning can be difficult to diagnose because the symptoms mimic other illnesses. People who are sleeping or intoxicated can die from CO poisoning before ever experiencing symptoms.

The toxic effects of carbon monoxide are usually associated with acute exposure. However, low-level exposure to carbon monoxide may produce long-term effects without producing the typical symptoms associated with acute exposure (HUD 2005).

The U.S. Environmental Protection Agency (EPA) has published National Ambient Air Quality Standards (NAAQS) on time-weighted CO concentrations (US EPA 2000). The current EPA primary standards set limits to protect public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly. EPA has primary standards for an 8-hour average (9 parts per million [ppm]) and for a 1-hour average (35 ppm). These standards apply to concentrations in outdoor air; U.S. standards for indoor air have not been set. Health Canada has residential indoor air quality guidelines for an 8-hour average (10 ppm) and for a 1-hour average (25 ppm) (Health Canada 2011). The World Health Organization (WHO) uses the same 8-hour value in their guideline as the EPA and applies it to both indoor and outdoor air. The WHO also has a 1-hour value of 25 ppm (WHO 2000).

3.1.2 Nitrogen Dioxide

NO_2 is a potential cause of respiratory disease. The NAAQS set by the U.S. EPA enacted a primary outdoor standard for NO_2 of 100 parts per billion (ppb) for a 1-hour average (EPA 2010). It should be noted that the NAAQS standard is not intended for application to indoor air but is used as a comparative reference level. The WHO guideline is 110 ppb for a 1-hour average, which applies to both indoor and outdoor air (WHO 2000). Health Canada has residential indoor air quality guidelines for a 24-hour average (50 ppb) and for a 1-hour average (250 ppb) (Health Canada 2011).

3.1.3 Moisture

Dampness in buildings, even in the absence of mold, has been found to have a correlation with illness, especially respiratory problems (e.g., IOM 2004, Mudarri and Fisk 2007, Fisk et al. 2007). However, moisture is not considered a pollutant in the way that other combustion byproducts are. Whereas less CO and NO_2 are always preferable to more, it is not always preferable to have less moisture in the air because of the potential for mucosal irritation.

Fungi grow in water condensed on surfaces and may generate three primary environmental concerns in buildings: 1) adverse health of occupants, 2) decreased durability of building materials, and 3) discomfort among occupants. Assessing the indoor environment with regard to moisture and its impact on these three topics is not straightforward, even regarding what metric to use. Relative humidity has traditionally been used as a surrogate for water load. ASHRAE Standard 62-1989 and earlier versions of ASHRAE Standard 55 set an upper limit of 60% (ASHRAE 1989; ASHRAE 1992), but Standard 55 now has a variable threshold, dependent on other factors such as temperature, and can be as high as approximately 85% (ASHRAE 2004). ASHRAE Standard 62.1-2010 recommends 65% relative humidity as a design upper limit (ASHRAE 2010). ASHRAE Standard 160 provides details on determining the potential for moisture concerns (ASHRAE 2008). With cold surfaces and local higher relative humidities, mold growth may occur in a room even if the center-of-room relative humidity is well below 70%. Comparing the dew point of the air to surface temperatures is widely considered a reasonable approach though this remains unconfirmed by systematic, empiric studies. Unvented combustion can potentially produce a substantial quantity of moisture and affect both comfort and building durability. Still, in general, if there are moisture problems on building surfaces in localized areas within the building, the most likely cause is a thermal bridge such as missing insulation, which should be the target of any remedy. If condensation or other moisture problems are widespread, then the focus of remediation should be on the various sources of moisture found in the home. Such sources are primarily bulk moisture intrusion through the envelope or water system leaks, but also include an unvented combustion appliance.

3.1.4 Particles

Many of the particles produced by unvented combustion appliances are ultrafine particles (i.e., particle diameters of less than 100 nm). Ruiz et al. (2010) measured higher ultrafine particle concentrations in homes with unvented combustion compared to those with electric heaters. Ultrafine particles have recently been linked to health effects such as oxidative damage to DNA and mortality (Stölzel 2008; Knol et al. 2009; Vinzents et al. 2005). There are currently no standards or guidelines on ultrafine particles.

4. UNVENTED COMBUSTION EQUIPMENT

This section describes types of unvented combustion equipment and the standards to which they are held.

4.1 Natural and Propane Gas-Fired Unvented Room and Hearth Heaters

Unvented gas-fired room heaters are designed for permanent installation to a gas piping system and securely mounted in a fixed position. Various designs include room heaters (e.g., infrared and blue-flame) and hearth heaters (e.g., gas logs and fireplaces). These appliances can have single or multiple heating capacities. They can be either thermostatically or manually controlled.

In the United States, the industry consensus product safety standard covering unvented gas-fired unvented room heaters and hearth (fireplace) products is the American National Standard for *Gas-Fired Room Heaters, Volume II, Unvented Room Heaters*, ANSI Z21.11.2. Installation codes, such as the National Fuel Gas Code, require gas-fired unvented space heaters to be listed to the Z21.11.2 standard. The Z21.11.2 standard applies to newly produced room heaters for permanent connection to the building fuel supply system. The scope of the standard limits the size and gas input rate to 40,000 Btu/h (11723 W), except for bedroom and bathroom installations, where the input rate limitation is reduced to 10,000 and 6,000 Btu/h (2931 W and 1758 W), respectively.

The Z21.11.2 standard requires these appliances to be equipped with a number of safety devices including an oxygen depletion safety shutoff device (ODS) that is designed to shut off the gas supply to the main burner when the oxygen level in the surrounding atmosphere is reduced to not less than 18%. In addition, each certified heater design is tested and evaluated for combustion and burner operating characteristics. Laboratory combustion testing limits the emissions of CO to 0.02% air-free, and NO_2 to 0.002% air-free. In addition, a heater cannot produce CO in excess of 0.025% in a room with no air changes occurring during combustion of the amount of gas necessary to reduce the oxygen content of the room to 15.1% by volume.

4.2 Natural and Propane Gas-Fired Cooking Appliances

Gas-fired residential cooking equipment is inherently unvented. In some cases, range hoods which are vented to the outside will partially serve the venting function, but range hoods are installed primarily to vent emissions from the cooking process, e.g., smoke, grease, steam, and odors. For this reason, where they are required by code, they are required for both electric and fuel-fired appliances. It should also be noted that many range hoods do not vent to the outdoors, but are recirculating hoods which are primarily intended to remove grease and other large particles from the airstream.

In the United States, the industry consensus product safety standard covering gas-fired cooking appliances is the American National Standard for *Household Cooking Gas Appliances*, ANSI Z21.1-2010. National, state, and local codes, such as the National Fuel Gas Code and the U.S. Manufactured Home Construction and Safety Standard, govern the proper installation of these appliances.

ANSI Z21.1 standard requires that an appliance shall not produce a concentration of CO in excess of 0.08 percent in an air-free sample of the flue gases when the appliance is tested in a room having approximately a normal oxygen supply. ASHRAE Standard 62.2 (ASHRAE 2010) includes a requirement for local exhaust in the kitchen, which should be operated whenever cooking appliances are used to assist in the removal of smoke and effluents produced by the cooking process.

4.3 Portable Kerosene Unvented Room Heaters

In the United States, kerosene-fired unvented room heaters are primarily designed to provide localized space heating that can be either permanently mounted in a fixed location or portable and capable of being relocated to different areas of a home as needed. Local codes typically require that these heaters meet the requirements of the *Standard for Unvented Kerosene-Fired Room Heaters and Portable Heaters* (UL 647-1993). This standard limits the maximum fuel input rate for fixed-mounted space heaters to 30,000 Btu (31.65 MJ) per hour and 25,000 Btu (26.38 MJ) per hour for portable heaters. The UL 647 standard specifies maximum levels of certain emissions for the following constituents: CO (air-free) is 0.04% at maximum burner setting and 0.08% at minimum burner setting; NO_2 is 0.0003 in^3/Btu (0.005 cm^3/kJ) at all settings. The standard also limits the smoke in the combustion products not to exceed a No. 1 Smoke Spot. This test is similar to the smoke spot test specified in oil-fired heating equipment for heating fuel oil. Lastly, UL 647 requires portable kerosene heaters to meet a tip test at an angle of 20 degrees. There are currently five manufacturers that have product listed to UL 647.

The National Kerosene Heater Association, the American Petroleum Institute, and the Consumer Product Safety Commission recommend only 1-K kerosene be used in these heaters (CPSC 2001a). The Consumer Products Safety Commission provides additional operating recommendations for these products (CPSC 2001a).

4.4 Decorative Denatured Alcohol Appliances

In the United States, decorative denatured alcohol burning unvented appliances are designed primarily for decorative purposes and not intended to provide significant heat to the living space. These appliances are expected to meet the UL Standard 1370, *Outline for Unvented Alcohol Fuel Burning Decorative Heating Appliances* (UL 2011).

UL Standard 1370 requires all floor-mounted appliances to be a minimum width of 36 in. (91.4 cm) and a minimum weight of 100 lb (45.36 kg). In addition, floor or freestanding appliances are required to be mounted in place. These size, weight, and mounting requirements are intended to discourage consumers from readily relocating the appliance from its intended location. The standard limits the input rate to a maximum 0.25 gallons per hour (0.95 liters per hour) and the total volume of all fuel reservoirs and combustion chamber to a maximum of 1.3 gallons (5 liters). There are currently five manufacturers that have product listed to UL 1370. Fuel oils, kerosene, gasoline, and other non-alcohols are not covered by these requirements.

With respect to combustion emissions testing, the UL Subject 1370 requires a "closed room" test, whereby the concentration of CO within the room shall not exceed 0.025% and the oxygen concentration shall not be reduced to 15.1% or less by volume. The standard also requires combustion testing in an open room whereby the concentration in the combustion gases, measured air-free, shall not exceed 0.02% of CO or 0.002% of NO_2.

5. EMISSIONS AND INDOOR AIR CONCENTRATIONS

This section details measured emission rates and indoor concentrations from published studies.

5.1 Natural and Propane Gas-Fired Unvented Heaters

A study by Francisco et al. (2010) measured indoor air concentrations in 30 homes that used unvented gas heaters manufactured since 1980. This study found that 20% of homes exceeded the EPA and WHO threshold for an 8-hour average CO level of 9 ppm, primarily when they were used for continuous, extended periods of time. This usage pattern is contrary to industry recommendations, which state that unvented heaters should be used as supplemental heaters, not primary heaters or for excessive periods of time. The study also showed that 80% of units produced NO_2 levels greater than the WHO 1-hour levels. The same number of units also exceeded the EPA outdoor standard 1-hour reference level, though the sampling time of 3–4 days is less than the method of test duration of 3 years required by the EPA standard. The EPA standard was not intended for indoor spaces. ANSI Z21.11.2, which requires that appliances comply with a maximum NO_2 level, was based on a 300 ppb level that had been recommended by the Consumer Products Safety Commission at the time. Francisco et al. found that 60% of homes met the 300 ppb for a 1-hour average. (It should be noted that the 300 ppb standard went into effect after most units in the study had been manufactured.)

Francisco et al. also found that regardless of unvented fireplace usage pattern, the relative humidity rarely exceeded 50% in 30 homes tested in Central Illinois. Francisco et al. commented that winter humidity levels in Central Illinois are low. Whitmyre and Pandian (2004) used modeling to show that, given assumptions about usage and house characteristics, unvented heating appliances did not produce enough moisture to result in indoor relative humidity levels that promote mold growth in United States DOE Climate Zones 2–5, and only in about 5% of cases in Climate Zone 1.

The potential for moisture concerns in a home is complex. It depends on sources, local ventilation, temperature conditions at surfaces, etc. It also depends on the time of year and the moisture-generating processes undertaken at those times of year. Gas-fired cooking appliances may be used throughout the year, regardless of background humidity levels. Gas-fired heating equipment will be used primarily in the winter, when conditions are dry in many but not all locations. All of these factors must be taken into account when assessing the potential for any source, including unvented combustion, to promote moisture conditions of concern.

Hedrick and Krug (1995) measured emissions from unvented gas-fired space heaters that used different heat transfer technologies. The different device types are intended to reduce emission rates of one pollutant or another. A blue-flame heater allows the combustion process to continue to its natural completion. This results in low CO emissions but the combustion process's extended time at high temperature increases NO and NO_2 emissions. A radiant tile heater and a perforated tube heater both impinge the flame onto surfaces, quenching the combustion. The quenching terminates the production of NO_2, but it also terminates the formation of CO_2, resulting in increased CO emissions relative to the blue-flame heater. A fan-forced heater requires an electrical connection, which the others do not, but the fan allows the designers to better control the combustion and reduce emissions. This unit had low emissions of all contaminants, but the unit tested was only available in Japan, where use of unvented heaters is common.

5.2 Cooking Appliances

Past studies have identified cooking as being an important source of indoor pollutants (Wallace 1996) and have established links to respiratory health impacts (e.g., Jarvis et al 1998; Wong et al. 2004). However, these studies have not differentiated between pollutants generated by the fuel combustion process and those produced from the cooking itself.

Traynor et al. (1996) reported on an extensive literature review of residential natural gas appliance pollutant emission factors including cooking appliances. Most of the data were from laboratory tests conducted under a variety of conditions. Relative to ovens and broilers, they found that range burners had similar emission factors for NOx, higher emission factors for CO and fine particles, and lower emission factors for formaldehyde.

More recently, Singer et al. (2010) analyzed cooking appliances along with other devices as part of a study aimed at evaluating the impact of natural gas on pollutant emissions. The study included both laboratory and field tests and found that baseline emissions (with line gas) varied widely across and within burner groups and with burner operational model. Based on the range of values for different pollutants, broilers had lower NOx emissions than cooktop burners and ovens; cooktop burners had higher NO_2 emissions than ovens and broilers; broilers had lower CO emissions, though there were some cooktop burners and ovens with low CO emissions; ovens had higher formaldehyde emissions than cooktop burners or broilers; and broilers had the highest particle emissions, with cooktop burners somewhat higher than ovens. Also, Wallace et al. (2008) reported ultrafine particle emissions from a gas stove cooktop and oven burners in a test house that ranged from 0.3×10^{12} per minute to 13×10^{12} per minute.

A primary indoor air quality impact of cooking comes from the food itself, which occurs with both electric and fuel-fired appliances. Fuel-fired appliances will have some additional emissions from the gas combustion.

A number of older studies showed health effects associated with the presence of gas cooking appliances. The cooking appliances all had standing gas pilots, and the health effects may have arisen primarily from emissions from the pilots which operated continuously.

6. VENTILATION CONSIDERATIONS

In addition to fuel, the operation of any combustion system requires the provision of oxygen and the removal of products of combustion. At a basic level, these processes are required simply to allow combustion to occur. For an unvented combustion appliance, the provision of oxygen occurs by drawing in room air to the combustion zone, and the products of combustion are dispersed into the room. Over time, without providing adequate make-up, combustion, and ventilation air, the oxygen in the room is consumed and the concentration drops, while products of combustion accumulate with concentrations increasing. The result is decreasing indoor air quality.

Ventilation of the room is one means by which this decrease in indoor air quality can be controlled. Ventilation of the room provides outdoor air, including oxygen, to replace the oxygen that is consumed. Additionally, ventilation removes air from the space, including the products of combustion.

The indoor air quality in a space containing an unvented combustion appliance is thus determined by two primary factors: pollutant emission rates and the ventilation rate. Emission rates are the time-averaged amount of fuel combustion (fuel input rate × fractional on-time) multiplied by the individual emission factors for the specific contaminants. Volume of the space is a secondary factor which affects the indoor air quality level for dynamic (non-steady state) processes, which includes most real world applications.

Of the factors that affect indoor air quality, in general, only two are under the control of the user. The on-time of the appliance is controlled by the user, either directly or through the setting of a thermostatic control. The ventilation rate is also controllable, in some circumstances and to some extent, by the user. This control might be through window opening, or through ensuring that a primary ventilation system is operating. Excessive appliance operation will increase the amount of contaminants in the space, degrading the air quality. Provision of adequate ventilation will provide air for proper combustion, remove contaminants, and improve air quality.

A key component of high quality installation is ensuring that a space has adequate ventilation and make-up air. If the provision of adequate ventilation is dependent on the operation of fans, windows, or doors, etc., then it is critical that the user has access to these and understands their proper use. Failure to provide adequate ventilation can result in elevated contaminant concentrations and increase the risk of poor indoor air quality, health impacts, water condensation, and other adverse consequences.

7. POSITIONS OF OTHER COGNIZANT AUTHORITIES

While treatment of these devices under U.S. building codes has been addressed above, it is helpful to consider the positions of other knowledgeable governmental and private bodies that have published documents addressing this issue. In some cases, a single agency has addressed the issue in more than one document. Typically, these documents do not include technical analysis detailing the reasons for the various positions and recommendations.

In Publication 466 *Carbon Monoxide Fact Sheet* (CPSC 2001b), the U.S. Consumer Product Safety Commission (CPSC) recommends making sure appliances are installed and operated according to the manufacturer's instructions and local building codes; installed by qualified professionals; having heating systems professionally inspected and serviced annually to ensure proper operation; never operating unvented fuel-burning appliances in any room where people are sleeping; installing CO alarms in all homes; never using gas appliances such as ranges, ovens, or clothes dryers to heat a home; and not covering the bottom of natural gas or propane ovens with aluminum foil. Additionally, in Publication 450 *The Inside Story A Guide to Indoor Air Quality* (CPSC 2001a), CPSC recommends taking special precautions when operating fuel-burning unvented space heaters, installing and using exhaust fans over gas cooking stoves and ranges, and keeping the burners properly adjusted.

The U.S. EPA Energy Star with Indoor Air Package does not permit decorative gas logs or unvented combustion appliances except for kitchen-type cooking devices which are required to have exhaust ventilation like all cooking appliances (EPA 2007). In the Inside Story: A Guide to Indoor Air Quality, the EPA recommends taking "special precautions" when operating unvented space heaters (including opening a window and a door to the rest of the house) and suggests consumers consider purchasing a vented space heater when replacing an unvented one (EPA 1993). The U.S. Department of Housing and Urban Development (HUD) also advises occupants to open a window when using unvented heaters or vent-free fireplaces and warns not to use them while sleeping (HUD 2003). Additionally, HUD recommends having CO alarms in all homes, whether or not there are unvented devices.

The U.S. Department of Energy's (DOE) Building America program has published best practice handbooks that recommend not using "non-vented" combustion appliances except for cooking appliances (US DOE 2012).

In addition, a few non-governmental entities have taken relevant positions on unvented combustion appliances. For example, the U.S. Green Building Council's LEED for Homes Rating System (USGBC 2008) allows no unvented combustion heating appliances as a prerequisite. In a March 2005 Consumer Reports article (CU 2005), the Consumers Union repeats many of the same recommendations as governmental bodies such as making a vented appliance a preferred choice, observing sizing guidelines, limiting usage, opening a window in the space, and using CO alarms with any combustion appliance.

The New York State Department of Health (NYSDH) does not make the same recommendations as the aforementioned agencies (NYSDH 2000). The NYSDH does warn that unvented gas heaters should be installed by a professional, should not be oversized, should be inspected and serviced regularly, and should never be used as a main heat source, even during power failures.

8. RECOMMENDATIONS

- Users should properly operate unvented appliances installed in the home and get an annual inspection by a qualified service technician.
- A public education program should be developed that reinforces the health and safety information contained in industry literature.
- Unvented appliances should not be used as the primary/sole source of heating.
- Consumers who want to reduce the risk of adverse health effects due to exposure to combustion products should not use unvented appliances.
- CO alarms should be installed in all homes regardless of heating fuel type.
- Gas cooking appliances with electronic ignition should be selected when possible.
- Permanently mounted unvented combustion appliances should be installed according to manufacturers installation instructions and local codes and performed by a qualified installer.
- A reassessment of ventilation should be made when air-sealing measures have been implemented to a building containing an unvented appliance, with ventilation added when appropriate.
- Unvented gas-fired room heaters listed to a pre-1983 edition of ANSI Z21.11.2 and not equipped with an Oxygen Depletion Safety (ODS) device should be replaced immediately.
- Unvented kerosene room heaters should be removed unless listed to UL 647 and new installations should be avoided unless future research demonstrates adequate indoor air quality when they are used.
- Unvented denatured alcohol appliances should be removed unless listed to UL 1370 and new installations should be avoided unless future research demonstrates adequate indoor air quality when they are used.
- Research should be performed that investigates the effects of unvented space heater combustion on indoor air quality in residential buildings. Particular questions of interest include:

    1. the suitability of the ANSI Z21.11.2 emission standards for NO_2
    2. the performance of units subject to ANSI Z21.11.2-2005 or later in the field with regard to NO_2
    3. particle emissions and their effect

- Research should be performed on kerosene and denatured alcohol appliance emissions and resulting indoor air quality.
- Research should be performed that investigates the effects of gas cooking combustion on indoor air quality in residential and commercial buildings.
- Particular questions of interest include:

    1. disaggregating the gas combustion from the cooking process
    2. emissions of NO_2, CO, and particles from modern units
    3. differences between range top cooking compared to oven cooking

- Industry sizing and installation guidance should be revisited in light of changes in housing stock.
- Code- and standard-making entities should require installers to be certified.
- Appliance standards should be reviewed and updated as needed in light of more recent understanding and standards/guidelines on acceptable levels of NO_2.
- Appliance standards should be reviewed and updated as needed in light of evidence that extended use is not uncommon and can result in unacceptable levels of CO, with considerations made to incorporating controls that prevent excessive durations of uninterrupted operation. These standards should also require that product information include language on the risks from extended use.
- Ventilation standards, particularly those concerned with residential buildings, should consider addressing unvented combustion appliances and establishing appropriate technical requirements.

REFERENCES

ANSI Z21.1-2010. Household Cooking Gas Appliances. New York, NY: American National Standards Institute.

ANSI Z21.11.2.-2007. ANSI Standard for Gas-Fired Room Heaters, Vol. II, Unvented Room Heaters. New York, NY: American National Standards Institute.

ANSI Z223.1-2006/NFPA 54-2009. National Fuel Gas Code. New York, NY: American National Standards Institute, and Quincy, MA: National Fire Protection Association.

ASHRAE. 1989. *Standard 62-1989, Ventilation for Acceptable Indoor Air Quality.* Atlanta: ASHRAE

ASHRAE. 1992. Standard 55-1992, Thermal Environmental Conditions for Human Occupancy. Atlanta: ASHRAE

ASHRAE. 2004. Standard 55-2004, Thermal Environmental Conditions for Human Occupancy. Atlanta: ASHRAE

ASHRAE. 2008. Standard 160-2008, Criteria for Moisture Control Design Analysis in Buildings. Atlanta: ASHRAE

ASHRAE. 2010. Standard 62.2-2010, Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings. Atlanta: ASHRAE

CPSC. 2001a. The Inside Story A Guide to Indoor Air Quality. U.S. Consumer Product Safety Commission, Washington D.C. http://www.cpsc.gov/CPSCPUB/PUBS/450.html, accessed Jan. 2012.

CPSC. 2001b. Carbon Monoxide Fact Sheet. U.S. Consumer Product Safety Commission, Washington D.C, 2001. http://www.cpsc.gov/CPSCPUB/PUBS/466.html, accessed Jan. 2012.

CU. 2005. Unvented Gas Fireplaces Can Go Almost Anywhere. But Are They Safe? CITY: Consumers Union, Consumer Reports March 2005, http://www.consumerreports.org/cro/appliances/heating-cooling-and-air/fireplaces-gas/gas-fireplaces-306/index.htm, accessed Jan. 2012.

Girman, J.R., M.G. Apte, G.W. Traynor, J.R. Allen, and C.D. Hollowell. 1982. Pollutant emission rates from indoor combustion appliances and sidestream cigarette smoke. Environ. Int. 8:213-221.

Fisk, W.J., Q. Lei-Gomez, and M.J. Mendell. 2007. Meta-analyses of the associations of respiratory health effects with dampness and mold in homes. Indoor Air 17(4):284-296.

Francisco, P.W., J.R. Gordon, and B.Rose. 2010. Measured Concentrations of Combustion Gases from the Use of Unvented Gas Fireplaces. Indoor Air 20(5):370-379.

Health Canada. 2011. Residential Indoor Air Quality Guidelines, http://www.hc-sc.gc.ca/ewh-semt/air/in/res-in/index-eng.php, accessed Jun 2011.

Hedrick, R.L., and E.K. Krug. 1995. Conventional Research House Measurements of Emissions from Unvented Gas Space Heaters. Gas Research Institute Topical Report, GRI-95/0205.

HUD. 2005. Healthy Homes Issues: Carbon Monoxide. Washington DC: U.S. Department of Housing and Urban Development.

ICC. 2012. ICC International Fuel Gas Code. Washington DC: International Code Council, Inc.

IOM. 2004. Damp Indoor Spaces and Health. Institute of Medicine, Committee on Damp Indoor Spaces, Board on Health Promotion and Disease Prevention. Washington DC: National Academy of Sciences Press.

Jarvis D., S. Chinn, C. Luczynska, and P. Burney. 1998. The association of respiratory symptom and lung function with the use of gas for cooking. Eur Respir J 11: 651-8.

Knol, A. B., et al. 2009. Expert Elicitation on Ultrafine Particles: Likelihood of Health Effects and Causal Pathways. Particle and Fibre Toxicology 6:19.

MMWR 1997. Use of unvented residential heating appliances – United States, 1988-199. MMWR 46(51):1221-1224; (http://www.cdc.gov/mmwr/preview/mmwrhtml/00050535.htm, accessed May, 2008).

Moschandreas, D., S. Relwani, D. Johnson, and I. Billick. 1986. Emission rates from unvented gas appliances. Environ. Int. 12:247-253.

Mudarri, D. and W.J. Fisk. 2007. Public Health and Economic Impact of Dampness and Mold. Indoor Air 17:226-235.

NFPA. 2012. NFPA Standard 101-2012, Life Safety Code. Quincy: National Fire Protection Agency.

NFPA. 2010. NFPA Standard 501-2010, Manufactured Housing. Quincy: National Fire Protection Agency.

NYSDH. 2000. Supplemental Space Heaters. Albany: New York State Department of Health, http://www.health.ny.gov/publications/3104.pdf, accessed Jan. 2012.

Rogge W.F. et al. 1993. Sources of fine organic aerosol. 5. Natural gas home appliances. Environ. Sci. Technol. 27:2736-2744.

Ruiz, P.A. et al. 2010. Effect of gas and kerosene space heaters on indoor air quality: a study of homes in Santiago, Chile. J. Air & Waste. Manage. Assoc. 60:98-108.

Singer, B.C. et al. 2010. Natural Gas Variability in California: Environmental Impacts and Device Performance: Experimental Evaluation of Pollutant Emissions From Residential Appliances. Report CEC-500-2009-099-APG, California Energy Commission, Public Interest Energy Research Program.

Stölzel, M. et al. 2007. Daily mortality and particulate matter in different size classes in Erfurt, Germany. J Exposure Science & Environmental Epidemiology 17(5):458-67.

Switzer, D. U.S. Consumer Product Safety Commission (CPSC) Staff letter to J. Mattingly, GAMA, September 1, 2005.

Traynor, G.W., M.G. Apte, and G-M. Chang. 1996. Pollutant Emission Factors from Residential Natural Gas Appliances: A Literature Review. LBNL-38123, Lawrence Berkeley National Laboratory, Berkely, CA.

Traynor, G.W. et al. 1990. Selected organic pollutant emissions from unvented kerosene space heaters. Environ. Sci. Technol. 24:1265-1270.

UL. 1993. UL Standard 647-1993, Unvented Kerosene-Fired Room Heaters and Portable Heaters. Northbrook: Underwriters Laboratories, Inc.

UL. 2011. ANSI/UL Standard 1370-2011, Outline for Unvented Alcohol Fuel Burning Decorative Heating Appliances. Northbrook: Underwriters Laboratories, Inc.

US DOE. 2012. Resources for Energy Efficient Homes. *Building America.* http://www1.eere.energy.gov/buildings/building_america/publications.html

US EPA. 1993. The Inside Story: A Guide to Indoor Air Quality. Washington, DC: US Environmental Protection Agency, report EPA-402-R-93-013, http://www.epa.gov/iaq/pubs/insidestory.html, accessed Jan. 2012.

US EPA. 2000. Air Quality Criteria for Carbon Monoxide. EPA 600/P-99/001F, US Environmental Protection Agency Office of Research and Development, Research Triangle Park, NC.

US EPA. 2007. Energy Star Indoor Air Package. Washington, DC: US Environmental Protection Agency, http://www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/IAP_Specification_041907.pdf, accessed Jan. 2012.

US EPA. 2010. Fact Sheet: Final Revisions to the National Ambient Air Quality Standards for Nitrogen Dioxide. Washington, DC: US Environmental Protection Agency.

USGBC. 2008. LEED for Homes Rating System. Washington, DC: U.S. Green Building Council, http://www.usgbc.org/ShowFile.aspx?DocumentID=3638, accessed Jan. 2012.

US HUD. 2003. Help Yourself to a Healthy Home. Washington, DC: US Department of Housing and Urban Development, http://www.hud.gov/offices/lead/library/hhi/HYHH_Booklet.pdf, accessed Jan. 2012.

Vinzents, P.S. et al. 2005. Personal Exposure to Ultrafine Particles and Oxidative DNA Damage. Environmental Health Perspectives 113(11):1485–1490.

Wallace, L.A. 1996. Indoor particles: a review. J Air Waste Manag Assoc. 46(2):98-126.

Wallace, L.A., F. Wang, C. Howard-Reed, and A. Persily A. 2008. Contribution of gas and electric stoves to residential ultrafine particle concentrations between 2 nm and 64 nm: size distributions and emission and coagulation rates. Environ Sci Tech 42:8641-8647.

Whitmyre, G.K., and M.D. Pandian. 2004. Probabilistic assessment of the potential impacts of vent-free gas products on indoor relatrive humidity. Building and Environment 39:1179-1185.

Wong T.W., T.S. Yu, H.J. Liu, and A.H.S. Wong AHS. 2004. Household gas cooking: a risk factor for respiratory illnesses in preschool children. Archives of Disease in Childhood 89:631-636.

WHO. 2000. Air Quality Guidelines for Europe, 2nd Edition. World Health Organization Regional Publications, European Series No. 91. World Health Organization, Regional Office for Europe, Copenhagen.