Combustion Air Requirements for Power Burner Appliances

Final Report

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FOREWORD

The National Fuel Gas Code® combustion air requirements in section 9.3 were developed primarily for residential-sized non-power burner appliances. The code contains no separate requirements for power-burner type appliances often having large Btu inputs. Therefore, when the code's current combustion air requirements are applied to these high Btu input power burner appliances they usually result in excessively sized outdoor combustion air openings. The objective of this project was to provide the technical justification to establish new combustion air provisions for high Btu input power burner appliances.

The content, opinions and conclusions contained in this report are solely those of the author.

Combustion Air Requirements for Power Burner Appliances Research Project

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Acronyms and Abbreviations

ACH	Air change per hour
AGA	American Gas Association
ANSI	American National Standard Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BHP	Boiler Horsepower
Btu	British thermal unit
C	Celsius
CSA	Canadian Standards Association
cfm	cubic foot per minute
F	Fahrenheit
fpm	foot per minute
ft	foot
GRI	Gas Research Institute
HP	horsepower
hr	hour
IFGC	International Fuel Gas Code
IMC	International Mechanical Code
in	inch
K	Kelvin
kBtu/hr	thousand British thermal units per one hour
kg	kilogram
kJ	kilojoule
kW	kilowatt
lb	pound
m	meter
MBtu/hr	million British thermal units per one hour
mm	milimeter

min	minute
NBBI	National Board of Boiler and Pressure Vessel Inspectors
NFPA	National Fire Protection Association
psi	pounds per square inch
s	second
UL	Underwriters Laboratories
w.c.	water column

Executive Summary

Gas-fired appliances require combustion air to properly function. Adequate air is necessary for supporting combustion of the appliance burner, dilution of flue gas, and proper ventilation of the space where the appliance is installed. Current standards and model codes outline requirements and methods to supply the combustion air. One method is to provide outdoor combustion air through openings or air ducts communicating with the outdoors through natural ventilation. Most standards require the outdoor opening(s) be prescriptively sized based on the total energy input rating of the appliance. However, in the United States, the current standards contain no separate provisions to address the opening size supplying the combustion air for commercial/industrial sized appliances, which typically have a high energy input rating of greater than 300 kBtu/hr and are equipped with a power burner unit. As a result, the opening(s) can be excessively sized when determined based on the current standards.

This research project establishes minimum outdoor combustion air requirements specific to gas-fired appliances utilizing power burners with input ratings no greater than 12.5 MBtu/hr. A review of the available literature, engineering guidelines, and current standards and model codes related to combustion air requirements was performed. This report provides an understanding of the technical basis for the existing provisions for combustion air and their applicability to power burner appliances. This report also identifies the range of energy input ratings for gas-fired appliances equipped with power burners, and compares the combustion air requirements specified by a range of appliance manufacturers. A theoretical model for air flow through openings was developed and the modeling results, together with the data gathered through the literature review, were used to provide a baseline to establish the theorized combustion air requirements suitable for power burner appliances.

New designs of commercial or industrial gas-fired appliances are typically equipped with power burners for high energy efficiency. As used in this report, a power burner relies on a forced-air fan to drive the air movement (in addition to natural ventilation) and premixes the fuel with the combustion air before injecting the fuel-air mixture in the combustion chamber. Because of the

inherent mixing advantage, power burners typically operate at a lower excess air rate in comparison to standard natural-draft burner appliances.

A review of available literature indicates that the current combustion air requirements outlined in National Fire Protection Association (NFPA) 54, *National Fuel Gas Code*, were originally developed based on standard gas-fired appliances sized for residential applications. The current prescriptive schedule for the total outdoor opening area required by NFPA 54 ranges from 0.33 to 1 square inch per kBtu/hr input rating, depending on the number of openings and how they communicate with the outdoors. When applied to high input rating appliances equipped with power burners, these requirements can result in excessively sized openings for outdoor combustion air.

Other engineering guidelines, including Canadian Standards Association (CSA) B149.1, *Natural Gas and Propane Installation Code* and the *Recommended Administrative Boiler and Pressure Vessel Safety Rules and Regulations* (NB-132), contain combustion air requirements specifically for appliances with an energy input rating of greater than 400 kBtu/hr. The total area of openings ranges from 0.08 to 0.14 square inches per kBtu/hr input rating. The combustion air requirements in these guidelines are consistent with providing a lower amount of additional air, approximately 30%, in comparison to excess air of approximately 100% for standard natural-draft appliances. CSA B149.1 also contains separate combustion air provisions for appliances with an input rating exceeding 400 kBtu/hr that are equipped with power burners by providing outdoor openings sized to 0.03 square inches per kBtu/hr of the total burner input rating.

Gas-fired appliances equipped with power burners are typically rated with a high energy input rating. Based on data available from twenty five (25) manufacturers of power burner appliances, the range of the energy input ratings are identified. Boilers equipped with power burners have the highest energy input rating range (60 to 83,600 kBtu/hr), in comparison to water heaters (60 to 40,300 kBtu/hr) and furnaces (30 to 9,800 kBtu/hr).

Combustion air requirements for power burner appliances can be different from those of natural-draft appliances due to the inherent ability of the burner to mechanically draw the necessary air supply. Manufacturers of power burner appliances often outline specific combustion air requirements as part of the installation instructions or the appliance specifications. A majority of the manufacturers (60%) included in this study reference NFPA 54 for combustion air requirements (0.33 to 1 square inches per kBtu/hr input) for power burner appliances with energy input ratings ranging from 30 to 92,000 kBtu/hr. Of the 25 manufacturers, eight recommend the combustion air be provided by openings sized to 0.03 to 0.75 square inches per kBtu/hr of the total appliance input rating from 150 to 83,600 kBtu/hr. The remaining manufacturers recommend combustion air requirements based on a specified volumetric flow rate from 0.24 to 0.48 cfm per kBtu/hr of appliance input rating.

A simplified steady-state flow model was developed to examine the air flow through combustion air openings, independent of the fuel gas type. Two types of power burner appliances were considered: 1) a power burner appliance equipped with a draft control device that requires dilution air for venting and 2) a power burner appliance that requires no dilution air.

Power burners use fans to draw the amount of air required to support combustion, therefore, air entrained through the openings is at minimum the amount of air for stoichiometric combustion plus excess air. For power burner appliances equipped with a draft control device, dilution air is also required, and the total amount of air flow through openings varies with the opening size. The manufacturer's recommended combustion air flow rate corresponds to opening sizes that are smaller than those required by NFPA 54, but are larger than the requirement for power burner appliances by the Canadian standard, CSA B149.1-10.

Percent dilution air with respect to opening size was investigated for power burner appliances equipped with a draft control device. A ratio of the dilution air to the maximum possible amount of dilution (dilution variation) was used to determine the size of the combustion air opening. Selecting 80% dilution variation results in an opening area of 0.2 square inches per kBtu/hr; this corresponds to 128% dilution air (more than twice the typical value). This level of dilution air will likely improve vent operation.

The velocity of air flow and the opening size can impact the level of air pollution in buildings and the potential for rain/snow intrusion. A selected maximum air velocity of 500 fpm results in an opening area of 0.2 square inches per kBtu/hr for power burner appliances with a draft control device. The same velocity corresponds to an opening area of 0.1 square inches per kBtu/hr for power burner appliances that require no dilution air. These opening sizes also produce a pressure drop across the opening of 0.015 inches w.c., approximately 70% less than the maximum pressure drop suggested by boiler manufacturers. This 0.015-inch w.c. pressure drop is unlikely to have an impact on the operation of standard gas-fired appliances.

Based on the review of available literature, the review of the manufacturer's requirements for combustion air, the investigation of the combustion air required for power burners, and the theoretical analysis on air flows through openings, the following sizing criteria for combustion air openings for power burner appliances are theorized:

- A minimum opening area of 0.2 square inches per kBtu/hr input rating for power burner appliances equipped with a draft control device; and
- A minimum opening area of 0.1 square inches per kBtu/hr input rating for power burner appliances that require no dilution of flue gases.

Based on the theoretical analysis provided in this study, these theoretical results for combustion air requirements for power burner appliances should provide an adequate amount of combustion air for proper appliance operation and should optimize overall building efficiency by reducing unnecessary area in openings. It is strongly recommended that the theorized sizing criteria be validated through full-scale field experiments across the range of the applicable power burner appliances, which will provide a basis for new code development. Validation of these theoretical results is beyond the scope of this study.

1 Introduction

National model codes mandate combustion air requirements for gas-fired appliances. A sufficient amount of air is needed to support the combustion and venting process, and to provide ventilation cooling for the casing and the space where the appliance is installed. The required combustion air can be supplied from outdoor and/or indoor sources through natural venting. Combustion air provisions typically outline the number of openings and the aggregate opening size required based on the total energy input rating of the appliance.

In recent years, energy efficient gas-fired appliances have become more prevalent in both residential and commercial occupancies. Power burners, often used in commercial/industrial gas-fired appliances with high input ratings, utilize fans to draw combustion air (in addition to natural ventilation) and operate at lower excess air in comparison to standard natural-draft burners. However, National Fire Protection Association (NFPA) 54, *National Fuel Gas Code*, contains no separate provisions to address the opening size supplying the combustion air for the power burner appliance. As a result, the ventilation opening(s) to the exterior can be excessively sized when determined based on the current standards, which can produce adverse building environmental conditions.

1.1 Objective

The objective of this research project is to establish provisions for outdoor combustion air suitable for gas-fired appliances utilizing power burners with an input rating of no greater than 12.5 MBtu/hr.[1]

1.2 Methodology

The scope of this research project focuses on gas-fired appliances utilizing power burners, such as boilers, water heaters, and space conditioning furnaces. This research consists of two distinct tasks: 1) review of available literature, current standards and model codes, and manufacturer's

[1] Appliances with an energy input rating greater than 12.5 MBtu/hr are part of a separate study conducted under the auspice of the NFPA..

specifications related to the combustion air requirements and identification of the range of energy input ratings for gas-fired appliances equipped with power burners and 2) development of the combustion air requirements for power burner appliances.

To understand the technical basis of the existing combustion air requirements and their applicability to power burner appliances with large energy input ratings, this report provides a summary of the current combustion air requirements for gas-fired appliances available in standards, guidelines, engineering practices, and scientific articles. A comparison of the current combustion air requirements from various sources is provided. Data for the range of the energy input and the combustion air requirements obtained from the manufacturers of power burners and the manufacturers of appliances equipped with power burners are presented.

Based on the manufacturer's data, the amount of combustion air required for power burners was estimated. Using this information, a theoretical model for air flow through combustion air openings was developed for power burner appliances. The results obtained from the model were used as a basis for the development of theoretical combustion air requirements for power burner appliances.

2 Literature Review

Combustion air requirements for gas-fired appliances are addressed in existing standards and model codes. Understanding the basis of the existing requirements is an important step in forming fundamental criteria for development of combustion air requirements suitable for large energy input ratings. This chapter provides a review of available literature related to combustion air requirements and a summary of the applicable current standards, model codes, and engineering guidelines.

2.1 Background

Adequate air supply for combustion and ventilation is necessary for proper operation of gas-fired appliances. Combustion air in gas-fired appliances serves three purposes: 1) air to support primary combustion; 2) excess air to help complete combustion and reduce harmful emissions; and 3) dilution air for venting of flue gases. A shortage of combustion air can result in incomplete combustion and production of poisonous gases, such as carbon monoxide, or appliance overheating. Ventilation air provides cooling for the appliance casing and internal control. Inadequate ventilation of the space in which an appliance is installed can result in elevated ambient temperatures that stress the appliance itself or other appliances in the vicinity.

Theoretically, the amount of air necessary to support combustion is at the stoichiometric ratio (i.e., the amount of air to react with all available fuel in an ideal complete combustion situation). Due to gas phase kinetics and other phenomena that occur in the real world, excess air must be provided to enhance the mixing of air and fuel to ensure complete combustion. Most hydrocarbon based fuels stoichiometrically require approximately 10 cubic feet of air for every kBtu of the fuel input energy. The amount of excess air is dependent on the burner design of the appliance. The excess air can range from 10% to 100%, but a typical value is 50%[2] by volume of the stoichiometric requirement (5 cubic feet per kBtu of fuel input energy). The amount of

[2] National Fuel Gas Code Handbook 2006, p. 171

air required for dilution of flue gas and ventilation depends on the specific drafting device, but is typically specified at 6 cubic feet per kBtu of fuel input energy.[3]

In general, the required combustion air is approximately 21 cubic feet per kBtu of the appliance input rating. For certain types of appliances, such as a fan-assisted combustion appliance[4], dilution air is not required in venting of flue gas, and as a result the combustion air for can be estimated at 15 cubic feet per kBtu.[5]

Gas-fired combustion systems are used in a wide range of appliances, including boilers, storage water heaters, and central heating or forced-air furnaces. Gas-fired combustion systems also vary based on the type of burner and the means by which combustion products are moved through the system. Atmospheric or natural-draft burners operate without a fan or other mechanical means to assist air movement. Fuel gas is injected from a pressurized gas supply and entrains primary combustion air into a mixing chamber. The fuel-air mixture enters the burner ports, where burning occurs and secondary air is entrained to complete combustion. Natural-draft burners are partially-aerated burners[6], where the primary combustion air is mixed with the fuel gas ahead of the flame. Natural-draft burners are common in residential-sized water heaters and central heating furnaces.[7]

Premix power burners (power burners) are power operated burners in which all or nearly all of the combustion air is mixed with the fuel gas before arrival at the flames. Either fuel gas, air, or both, are supplied at a pressure exceeding the line pressure for gas and the atmospheric pressure for air. Power burners provide relatively complete combustion and tend to have better combustion efficiency and emission performance than natural-draft burners.[8] Although the amount of excess air required by power burners varies based on the specific design of the

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[3] National Fuel Gas Code Handbook 2006, p. 171

[4] Appliance equipped with an integral mechanical means to either draw or force products of combustion through the combustion chamber or heat exchanger, NFPA 54-2006 Section 3.3.6.4.

[5] National Fuel Gas Code Handbook 2006, p. 162

[6] A burner in which only a portion of the stoichiometric air quantity is mixed with fuel prior to the combustion, an example is a Bunsen burner

[7] 2008 ASHRAE Handbook – HVAC Systems and Equipment, Automatic Fuel-Burning Systems, p. 30.4

[8] Ibid, p. 30.3

burner[9], power burners often operate at a lower excess air level, typically 15 to 20%[10], which increases flame temperature and enhances heat exchange efficiency. Power burners are used in industrial and commercial appliances with a large input capacity, typically greater than 300,000 Btu/hr.[11]

Burning of fuel gas in an appliance combustion chamber generates combustion products, mainly carbon dioxide gas and water vapor. These combustion products can be moved through appliances by natural draft or by a mechanical means. Natural-draft systems rely on the buoyancy of the hot combustion product to propel gases through the appliance and out through the venting system. Fan-assisted combustion systems (or fan-assisted appliances) use a fan to either push the combustion product (force-draft system) or pull the combustion product (induced-draft system) through the combustion chamber and heat exchanger of the appliance. Some fan-assisted appliances use natural-draft burners and apply mechanical force to push (or pull) the flue gas flow in order to enhance the heat exchanging process, increasing overall efficiency. A fan-assisted appliance may or may not be equipped with a power burner. A power burner explicitly uses a fan to drive the combustion air to mix with fuel gas and inject the air-fuel mixture to the burner.

2.2 Literature Related to Combustion Air Requirements

Early research works focusing on combustion air supply for gas-fired appliances located inside structures dates back to the late 1940s. A technical bulletin[12] by the American Gas Association (AGA) examines the effect of air supply and ventilation on the performance of gas-fired appliances installed in a confined space and provides a technical basis for combustion air requirements. The study recommends two air openings for appliances located in a confined space, each with 1 square inch free area per kBtu/hr combined appliance input and communicating with an unconfined interior space. Subsequent to this study, a guideline for two openings for combustion air from adjacent indoor space was included in an early edition (1950)

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9 Energy Tips- Steam, "Upgrade Boilers with Energy-Efficient Burners", No 24, January 2006

10 2008 ASHRAE Handbook – HVAC Systems and Equipment, Automatic Fuel-Burning Systems, p. 30.3

11 Technical Fact Sheet, "Boiler Replacement", Center of Energy and Environment

12 Rutherford, R. J., "The Effect of Confined Space Installation on Central Gas Space Heating Equipment Performance", AGA Research Bulletin 54, 1947

of NFPA 54 (then called the *Standard for Installation of Gas Appliances and Gas Piping*). An additional bulletin by AGA[13] and an experimental study by Roose et al. (1954)[14], utilizing a gas-fired furnace having a rated input of 90,000 Btu/hr, further support the requirement for two openings. In these studies, a single opening with 1 square inch area per 5,000 Btu/hr appliance input reportedly also provides satisfactory operation of gas-fired appliances when no adverse conditions, such as blocked vent, are present.

Previous studies supporting a single combustion air opening also include work performed by Berry et al. (1970)[15] in the United Kingdom. The study cites unpublished experimental results and concludes that a permanent opening area to the outdoors of 1 square inch per 5,000 Btu/hr aggregate input of natural-draft appliances is necessary to ensure adequate combustion air for safe operation. The burner types and heat input ranges for this study are unknown.

Subsequent to the Berry study, Warren and Webb (1976)[16] utilized a mathematical model to predict the required areas of opening for combustion air under a wide range of parameters and operating conditions. The predictive method was shown to be in agreement with their experimental measurements of flue gas flow rates and was used to identify a cautionary limit for an adequate open area to prevent spillage of combustion products. Again, the burner types and heat input ranges studied are unknown.

A technical report[17] published by the Gas Research Institute (GRI) provides an extensive review of combustion air requirements for the existing standards, as well as state and model codes at the time of its publication in 1994. The report describes the history and evolution of the NFPA 54 for sizing combustion air openings connecting to the outdoors. The report indicates that the NFPA 54 requirements were primarily based on an extrapolation from the combustion air

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[13] Stone, R.L. and Kirk, W. B., "Combustion and Ventilation Air Supply to Gas equipment in Small Rooms", AGA Research Bulletin 67, 1954

[14] Roose, R. W. et al., "Outdoor-Air Supply and Ventilation of Furnace Closet Used in a Warm-Air Heating System, University of Illinois Engineering Experiment Station Bulletin No. 427, 1954.

[15] Berry, E.W., et al., "Installation and Ventilation, Gas Council Research Communication GC177, 1970

[16] Warren R.R and Webb, B.C., "Air Supply for Domestic Combustion Appliances, 1976

[17] Rutz, A.L., et al., "Analysis of Combustion Air Openings to the Outdoors: Preliminary Results", Topical Report, GRI-93/0316, Gas Research Institute, 1994.

openings to the indoors, which was originally based on the experimental work by AGA.[18] NFPA 54 requires two openings, each with 1 square inch per 4,000 Btu/hr appliance input, communicating directly with the outdoors or through vertical ducts. For openings connecting to horizontal ducts, NFPA 54 requires a minimum opening area of 1 square inch per 2,000 Btu/hr input.

As a supplement to the existing standard at the time, the GRI report provides technical justification for a single combustion air opening to the outdoors for both natural-draft and fan-assisted appliances based on computer modeling (FLUENT and VENT-II) and field experimentation. No power burner appliances were included as part of the experiments. The GRI report examines the impact on combustion air, dilution air, and the enclosure temperature, as well as the appliance performance based on different opening configurations and a series of gas-fired appliances (both fan-assisted and natural-draft types). The appliances included in the field experiment had energy input ratings up to approximately 105,000 Btu/hr. Based on the analytical results and criteria for the predicted amount of dilution air available for venting, the GRI report recommends a single opening with an area of not less than 1 square inch per 3,000 Btu/hr of the total appliance input, given the appliances have a minimum clearance from the enclosure and the air supply opening area is no smaller than the vent flow area. The GRI analysis also reveals the potential for reducing the combustion air opening sizing requirements for fan-assisted appliances. Subsequent to this finding, the provision for the single opening for combustion air was incorporated into the 1996 edition of NFPA 54, but the reduction of outdoor opening size for fan-assisted appliances was not included.

Requirements for combustion air adopted in local jurisdictions tend to deviate from the requirements found in model codes and standards (e.g., NFPA 54). Applicable at the time of its publication, the GRI report also cites two state-mandated mechanical codes, the 1990 Minnesota Mechanical Code and the 1992 Michigan Mechanical Code, on the combustion air requirements specifically for commercial appliances with a combined input rating greater than 400,000 Btu/hr. The 1990 Minnesota Mechanical Code (based on the 1988 Uniform Building Code with amendments) requires openings for combustion air for appliances with an input rating greater

[18] Rutherford, R. J., "The Effect of Confined Space Installation on Central Gas Space Heating Equipment Performance", AGA Research Bulletin 54, 1947

than 400,000 Btu/hr to communicate directly to the outdoors. The openings for natural-draft burners are sized to 1 square inch per 5,000 Btu/hr input rating, and no less than 100 square inches. For appliances with power burners, the 1990 Minnesota Mechanical Code requires the openings be sized to 0.5 square feet per 1,000,000 Btu/hr combined appliance input rating. Different criteria for outdoor combustion air openings are provided in the 1992 Michigan Mechanical Code (based on the 1990 BOCA National Building Code). For appliances with a combined input rating from 400,000 to 2,000,000 Btu/hr, the required outdoor opening ranges from 1 to 14 square feet. For the total combined appliance input ranging from 2,000,000 to 10,000,000 Btu/hr, the required opening size is up to 25 square feet. These state-mandated requirements are superseded by modernized model codes and are no longer enforced in the current editions of the Minnesota Mechanical Code and the Michigan Mechanical Code.

External weather conditions can have an impact on the combustion air supplied through permanent openings connecting to the outdoors. Douglas, J.D. et al. (1997)[19] conducted an experimental study to examine the influence of weather conditions on the combustion air flow rate through different sizes of openings and the use of motorized dampers for openings with forced air flow control during appliance standby and operating conditions. The study shows that the air flows through passive openings depends not only on the size of the openings but other factors, including wind speed, wind direction, ambient temperature, appliance operation, and the leakage characteristic of the building. The study notes that the amount of air in excess of the stoichiometric requirement used by any combustion device is specific to that device and the value ranges from 10% to 100% of the stoichiometric requirement. Based on an appliance with a 250,000 Btu/hr input rating, the study finds that openings sized in accordance with the requirements in NFPA 54 (1 square inch per 4,000 Btu/hr appliance input) can supply sufficient outdoor air to meet the demand for combustion air (with 30% excess air for combustion and extra 30% for dilution), although air flows of approximately 300% of the demand rate were observed under low temperature and high wind speed. The study concludes that the mechanical supply of combustion air in combination with motorized dampers was observed to be the most reliable means in providing the adequate amounts of air under all examined weather and building conditions.

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[19] Douglas, D.J. et al., “Field Study of Combustion Air Intake System for Cold Climates”, ASHRAE Transactions, Vol. 103, No. 1, pp. 910-920, 1997

Available data for combustion supplies air specific to natural-draft or fan-assisted types of appliances are not abundant in the literature. Work by Hayden (1988)[20] presents air supply requirements of various combustion appliances based on experiments and field determinations. Hayden reports that for conventional atmospheric gas-fired appliances, air flow of 30 cfm would be required for combustion and 143 cfm for dilution. The study also reports a combustion air flow rate of 26 cfm for fan-assisted gas appliances with no dilution air. The required air flow rates suggested by Hayden are based on appliance type in general and do not directly relate to the appliance input rating. The data from the Hayden study is cited in the *Northwestern Weatherization Field Guide*[21], as well as the *Weatherization Standards and Field Guide for Pennsylvania*.[22] Both documents also state the range for combustion air to be delivered to appliances is between 17 and 600 cfm. The documents recommend 2 square inches of net free opening area for every 1000 Btu/hr of the combined appliance input rating.

In addition to the data from Hayden, combustion air supplies based on appliance types is also provided by the 2009 American Society of Heating, Refrigerating, and Air-Conditioning Engineer (ASHRAE) Handbook[23] as part of a design guideline for building ventilation. The handbook estimates the combustion air requirement for new forced-draft appliances at 0.25 cfm per kBtu/hr input rating. The handbook recommends the requirements for existing natural-draft appliances be estimated at twice the amount of the combustion air requirements for new appliances. The recommendations for combustion air openings provided in the handbook are similar to the combustion air requirements specified in the current edition of NFPA 54.

Industrial and commercial boilers are typically rated at a high input capacity, typically greater than 300,000 Btu/hr.[24] The combustion air requirements for boilers are sometimes specified by

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[20] Hayden, A.C.S, "Residential Combustion Appliances: Venting and Indoor Air Quality", Environmental Progress, Vol 7, Issue 4, p 241-246, November 1988

[21] Krigger, J., Northeast Weatherization Field Guide, the Department of Energy's Weatherization Assistance Program and the States of Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont

[22] Krigger, J. and Van der Meer, B., Weatherization Standards and Field Guide for Pennsylvania, February 2001 Edition, the Department of Energy Weatherization Assistance Program and the State of Pennsylvania.

[23] 2009 ASHRAE Handbook – Fundamental, Residential Cooling and Heating Load Calculations, p 17.7

[24] Technical Fact Sheet, "Boiler Replacement", Center of Energy and Environment

the manufacturer and can differ from the provisions outlined in NFPA 54. Two articles[25] published by popular boiler manufacturers were reviewed and provide a guideline for boiler room air supply. Based on the total maximum boiler horsepower (BHP), the total recommended air flow rate into the boiler room is 10 cfm per BHP or approximately 0.3 cfm per kBtu/hr (8 cfm per BHP for combustion air and 2 cfm per for ventilation air), when installed and operated up to 1,000 feet elevation above sea level. For installation above 1,000 feet elevation, the articles recommend adding 3% additional air for each 1,000 feet to allow for the density change in air at higher altitudes. The net free open area is determined by dividing the total required air flow rate by the recommended air velocities in boiler room: 250 feet per minute (fpm) for openings located no higher than 7 feet above the floor, and 500 fpm for openings located above 7 feet high. Based on the recommended combustion air and assuming an allowable air velocity of 250 fpm, the outdoor opening is approximately 1 square inch per 5,800 Btu/hr appliance input rating. The articles also specify a minimum of two permanent air supply openings in the outer walls of the boiler room with a minimum total free area of 1 square foot. Additionally, the articles recommend the air inlet be provided with weather protection and never be covered with a fine mesh wire screen. The articles also warn of the danger of running water, oil, or steam lines in the direct path of the potential cold air entering from the outside openings.

Provisions for combustion air in most standards and model codes allow for engineered systems to provide adequate air supply for combustion, dilution of flue gas, and ventilation.[26] An article by Ballanco, J. (2008)[27] describes a method to size the outdoor combustion air opening for water heaters and boilers. The method is based on the estimated amount of air required to support combustion of the gas-fired burner with an addition 10% excess air and 20% additional air for draft hood and ventilation. The article suggests an air supply of 12.5 cubic feet per kBtu. Based on an estimated natural-draft air flow velocity of 200 to 300 fpm[28], the outdoor combustion air

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[25] "Combustion Air Requirements for Boilers", CleverBrooks, Tip Sheet November 2010, and "Boiler Room Air Supply", Johnston Boiler Company

[26] Ballanco, J. Plumbing & Mechanical, "Water Heater and Boiler Combustion Air", Vol 25, No. 8, pp 88 – 90, Oct 2007

[27] Ballanco, J. Plumbing & Mechanical, "Engineering Combustion Air", Vol 25, No. 12, pp 72 – 74, Feb 2008

[28] Ballanco, J. (2008) cites the ASRAE Standard for the listed value of natural-draft air velocity of 200 to 300 ft per minute

opening can be sized to 0.1 to 0.15 square inches per kBtu/hr of appliance input rating (or approximately 1 square inches per 6,600 Btu/hr to 1 square inches per 10,000 Btu/hr).

2.3 Current Standards, Model Codes, and Guidelines

In North America, several standards outline provisions for the minimum required combustion air for gas-fired appliances. This section summarizes the combustion air requirements in the present standards, model codes, and engineering guidelines available in the United States and Canada.

2.3.1 NFPA 54

The 2012 edition of NFPA 54 outlines requirements and methods to supply combustion air for gas-fired appliances. These methods include indoor air supply, outdoor air supply, a combination of indoor and outdoor air supply, mechanical air supply, and engineered systems. When appliances with large input ratings are located in a small enclosure, the indoor air supply alone can be insufficient for proper appliance operation. NFPA 54 contains provisions for obtaining combustion air via natural draft directly from the outdoors or from space freely communicating with the outdoors. The requirements are summarized in Table 1.

Table 1 NFPA 54 Summary of outdoor combustion air requirements

Number of Opening	Opening Location	Minimum Opening Free Area*
Two Permanent Openings	One within the 12 inches below the ceiling and one within the 12 inches above the floor	When communicating directly with the outdoors, or when communicating through vertical ducts, each opening is sized to 1 in^2 per 4,000 Btu/hr [550 mm^2/kW] combined appliance input rating.
		When communicating with the outdoors through horizontal ducts, each opening is sized to 1 in^2 per 2,000 Btu/hr [1,100 mm^2/kW] combined appliance input rating.
One Permanent Opening	Within the 12 below the ceiling	Opening is sized to 1 in^2 per 3,000 Btu/hr [700 mm^2/kW] and the area is no smaller than the sum of areas of all vents.

* The free area refers to the net opening area after a reduction of the blockage area due to louvers or grilles

The required outdoor opening free areas are generally based on the total input rating of all appliances located in the enclosure. As noted in the previous section, these requirements were developed based on either natural-draft or fan-assisted appliances with rated inputs of no greater than 150,000 Btu/hr [44 kW]. The previous studies[29], which give the technical basis for the standard on the outdoor combustion air requirement, primarily focus on the typical residential-sized appliance, and do not necessarily account for appliances that utilize a power burner unit having a forced-fan to draw the required combustion air. The standard contains no separate requirements for appliances with a large input rating or for appliances utilizing power burners.

The combustion air requirements provided in NFPA 54 do not apply to direct vent appliances constructed and installed so that all air for combustion is obtained directly from the outdoors and all flue gases are vented to the outdoors. Direct vent appliances do not draw air for combustion and dilution from within the building. The standard recommends the combustion air for direct vent appliances be provided in accordance with the manufacturer's instructions.

As an alternative to the natural-draft air supply described in Table 1, a mechanical air supply system can be used to provide outdoor combustion air. NFPA 54 requires a minimum air flow rate of 0.35 cfm per kBtu/hr [0.034 m^3/min per kW] aggregate input rating for all appliances located within the space housing the appliances. The required minimum air flow rate is consistent with the required amount of combustion air at 21 cubic feet per kBtu/hr for typical natural-draft appliances. In addition, engineered combustion air installations are also allowed per NFPA 54, provided the systems can supply the calculated amount of air needed for proper combustion, dilution, and space ventilation.

2.3.2 IMC and IFGC

In the United States, the International Mechanical Code (IMC) and the International Fuel Gas Code (IFGC) are widely adopted in most states and several local jurisdictions. The 2009 edition of the IMC references the 2009 edition of the IFGC for combustion air requirements. The code provisions for combustion air outlined in the 2009 IFGC are similar to that of the current edition

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[29] Rutherford, R. J (1947), Stone, R.L. and Kirk, W. B (1954), Roose, R. W. et al (1954), and Rutz, A.L., et al. (1994).

of NFPA 54, which appears to form the basis for the code language with regard to the combustion air opening sizing and location.

2.3.3 CSA B149.1

In Canada, the 2010 edition of Canadian Standards Association (CSA) B149.1-10, *Natural Gas and Propane Installation Code*, draws a distinction between appliances with input ratings above and below 400,000 Btu/hr for combustion air requirements. For appliances with a combined input rating up to and including 400,000 Btu/hr, the code contains a provision for a single outdoor opening sized at approximately 1 square inch per 7,000 Btu/hr input rating for appliances with a draft control device, and at approximately 1 square inch per 14,000 Btu/hr input rating for appliances without a draft control device. The actual opening free area is shown in Table 2. The single opening is required to be located within 1 foot above and 2 feet horizontally from the air inlet of the appliance with the largest input rating. In all cases, the dimension of the outdoor opening is no less than 3 inches.

Table 2 CSA B149.1-10 Outdoor combustion air requirements for appliances with combined Input up to and including 400,000 Btu/hr

Combined Appliance Input Rating*, Thousands of Btu/hr [kW]	Minimum Opening Free Area, in^2 [mm^2]	
	With Draft Control Device	Without Draft Control Device
50 [15]	7 [4,500]	4 [2,600]
100 [30]	14 [9,000]	7 [4,500]
200 [60]	29 [19,000]	14 [9,000]
300 [90]	43 [28,000]	22 [14,000]
400 [120]	58 [37,000]	29 [19,000]

* Only selected values are reproduced herein for reference. The table in the standard body provides data at 25,000 Btu/hr increment.

For larger appliances with a combined input rating exceeding 400,000 Btu/hr, CSA B149.1-10 requires the combustion air be provided from the outdoors and sized based on the type of the appliance burner, as described in Table 3. In addition to the opening for combustion air, the code also requires an additional ventilation opening sized at not less than 10% of the combustion air opening. Note that when appliances utilize power burners and no natural-draft appliances are located within the same space, the code is less restrictive and requires only 1 square inch per 30,000 Btu/hr of input rating.

Table 3 CSA B149.1-10 Outdoor combustion air requirements for appliances with combined Input exceeding 400,000 Btu/hr

Type of Appliance Burner	Opening Location	Minimum Opening Free Area
Natural-draft, Partial fan-assisted, Fan-assisted, or power draft-assisted burners	No more than 18 inches [450 mm] or less than 6 inches [150mm] above the floor level	One permanent opening sized at 1 in^2 per 7,000 Btu/hr input [310 mm^2/kW] up to 1,000,000 Btu/hr plus 1 in^2 per 14,000 Btu/hr [155 mm^2/kW] input
Power burner	No interference with ventilation air opening	Opening(s) sized at 1 in^2 per 30,000 Btu/hr [70 mm^2/kW] of the total rated input of the power burner(s)

2.3.4 NB-132

The National Board of Boiler and Pressure Vessel Inspectors (NBBI) outlines recommendations for combustion air supply and ventilation of boiler rooms in NB-312, *Recommended Administrative Boiler and Pressure Vessel Safety Rules and Regulations*. NB-312 (Rev 8) applies specifically to fuel-burn appliances with an input rating exceeding 200,000 Btu/hr. For natural ventilation, the guideline contains a schedule of opening free areas and the required combustion air flow rate based on the total rated inputs of all burners and appliances in the boiler room, as shown in Table 4. On average, the outdoor openings are sized to approximately 1 square inch per 8,400 Btu/hr.

Table 4 NB-132 Combustion air requirements for boilers

Combined Boiler Input Rating, Thousands of Btu/hr [kW]	Required Combustion Air Flow Rate, cfm [m^3/min]	Minimum Opening Free Area, ft^2 [m^2]
500 [147]	125 [3.5]	1.0 [0.09]
1,000 [293]	250 [7]	1.0 [0.09]
2,000 [586]	500 [14]	1.6 [0.15]
3,000 [879]	750 [21]	2.5 [0.23]
4,000 [1,172]	1,000 [28]	3.3 [0.31]

5,000 [1,465]	1,250 [35]	4.1 [0.38]
6,000 [1,758]	1,500 [42]	5.0 [0.46]
7,000 [2,051]	1,750 [50]	5.8 [0.54]
8,000 [2,345]	2,000 [57]	6.6 [0.61]
9,000 [2,638]	2,250 [64]	7.5 [0.70]
10,000 [2,931]	2,500 [71]	8.3 [0.77]

When mechanical means are used to supply the combustion air and ventilation, NB-132 also requires the velocity of the air through the ventilating fan not exceed 500 fpm and total air delivered be equal to or greater than the amount of air determined by the required volume flow rate suggested in Table 4. In other words, the minimum opening or duct area for mechanical ventilation can be determined by dividing the required volume flow rate by the maximum air velocity of 500 fpm.

2.4 Appliance Certification Standards

Modern gas-fired appliances are required to be certified to applicable product certification standards. The American National Standard Institute (ANSI) Z21.47 series standards outline the certification requirements for gas furnaces and the ANSI Z21.10 series covers the requirements for gas-fired water heaters. The certification requirements generally consist of criteria for appliance construction and performance testing, such as combustion testing on level of CO production, draft tests, temperature tests for appliance components, and temperature tests for combustible surfaces (wall, floor, and ceiling) adjacent to the appliance. The performance tests related to temperature and draft hoods are conducted in an enclosure with two indoor combustion air openings sized at 1 square inch per kBtu/hr input rating. This opening size is consistent with the requirements for indoor combustion air openings required by NFPA 54.[30] No tests are specified for combustion air openings sized for communicating with the outdoors.

2.5 Section Summary

In the United States, the requirements for combustion air outlined in the current standards and model codes are fairly uniform. Previous studies that provide a technical basis for NFPA 54 and

[30] Section 9.3.2.3 of NFPA 54 - Indoor Opening Size and Location.

national model codes do not account for large input rating appliances utilizing power burners. In Canada, CSA B149.1-10 provides different criteria specific to appliances with a large rated input (exceeding 400 kBtu/hr) and to appliances utilizing power burners. Engineering guidelines for industrial/commercial boilers specify criteria for combustion air requirements for boilers with an input rating exceeding 200 kBtu/hr. Available literature data provides a technical basis that can be used to develop the combustion air requirements for large input appliances utilizing a power burner. Standards for certification of gas-fired appliances, the ANSI Z21 series, provide no performance tests for outdoor combustion air openings. Table 5 is a summary of the combustion air requirements based on a review of available literature and the current national codes and standards.

NFPA 54 requires the largest outdoor openings for combustion air in comparison to the other referenced guidelines. The opening free area required by NFPA 54 ranges from 0.33 to 1 square inch per kBtu/hr input rating, depending on the number of the openings and how they communicate with the outdoors. The other guidelines require combustion air openings with free area ranging from 0.08 to 0.14 square inches per kBtu/hr, which is consistent with providing additional approximately 30% air supply to the combustion process. CSA B149.1-10 contains a separate provision for appliances equipped with power burners to supply combustion air with outdoor openings sized to 0.03 square inches per kBtu/hr of the total burner input rating.

Table 5 Outdoor combustion air requirement summary

Reference	Criteria	No of openings	Total Opening Free Area, in^2 per kBtu/hr Input Rating [mm^2/kW]
NFPA 54-2012, 2009 IFGC and 2009 IMC	Openings communicate directly with outdoors or through vertical ducts	2	0.5 [1,100]
	Openings communicate with outdoors through horizontal ducts	2	1 [2,200]
	Single opening communicate directly with outdoors	1	0.33 [700]
CSA B149.1-10	≤ 1,000,000 Btu/hr [290 kW]	1	0.14 [310]
	> 1,000,000 Btu/hr [290 kW]	1	0.08 to 0.14 [155 to 310]
	> 400,000 Btu/hr [120 kW] with power burner	1	0.03 [70]
NB-132 Rev 8	> 200,000 Btu/hr [59 kW]	1	~0.12 [262]
Article A[31]	Based on boiler horsepower and assuming air velocity 250 fpm [76 m/min]	2	~0.17 [380]
Article B[32]	Based on 10% excess air, 20% additional air for dilution and ventilation, air velocity 250 fpm [76 m/min]	N/A	~0.12 [275]

[31] "Combustion Air Requirements for Boilers", CleverBrooks, Tip Sheet November 2010, and "Boiler Room Air Supply", Johnston Boiler Company

[32] Ballanco, J. Plumbing & Mechanical, "Engineering Combustion Air", Vol 25, No. 12, pp 72 – 74, Feb 2008

3 Manufacturer Data

Gas-fired appliances equipped with power burners are typically rated with a high energy input. To establish the combustion air requirements for power burner appliances, the range of the appliance input ratings must be identified. The combustion air requirements for power burner appliances can be different from those of natural-draft appliances due to the inherent ability of the burner to mechanically draw the necessary air supply. Manufacturers of power burner appliances often outline specific combustion air requirements as part of the installation instructions or the appliance specifications. This section provides data for the range of the energy input and the combustion air requirements obtained from the manufacturers of power burners and the manufacturers of appliances equipped with power burners.

3.1 Appliances Utilizing Power Burners

Data were compiled from a total of 55 gas-fired appliances from 25 manufacturers. The data are based on the manufacturers' published specifications and/or through direct communications with manufacturer representatives. The energy input ratings of power burner appliances, including boilers and water heaters are provided in Table 6 to Table 7. Most appliances included in this study are for commercial or industrial applications, with an average combustion efficiency of 82% for boilers and 83% for water heaters.

In addition to the data obtained from appliances equipped with power burners, the specifications for power burners from eleven manufacturers are also compiled in Table 8. The type of appliances typically equipped with each power burner model is included as denoted by (B) for boilers, (WH) for water heaters, and (F) for heating furnaces. Based on these data, the energy input rating for power burner boilers can range from approximately 60 to 83,600 kBtu/hr. The energy input rating range for water heaters equipped with power burners is approximately 60 to 40,300 kBtu/hr. The power burner equipped furnaces have rated energy input ranges from 30 to 9,800 kBtu/hr. Six (6) of the 28 manufacturers considered in this study produce certain models of power burner appliances with the upper range of the input rating exceeding 12.5 MBtu/hr, which is outside the scope of this study.[33]

Table 6 Boilers with power burners

Manufacturer ID	Model	Energy Input Rating (Thousands of Btu/hr)	Combustion Efficiency	Source*
Triad (B-1)	Series 300	210 – 375	87%	S
	Series 900	600 – 900	85%	S
	Series 1600	1,400 – 1,700	83%	S
	Series 2000	1,800 – 2,100	83%	S
Parker (B-2)	203 to 205 Series	432 – 6,250	80%	S, D
Burnham (B-3)	FD Series	331 – 2,019	80%	S, D
	V9	447 – 2,367	78%	S, D
Hurst Boiler (B-4)	Series 100	285 – 27,215	N/A	S
Bryan Boiler (B-5)	DR Series	250 – 850	84%	S
Columbia Boiler (B-6)	GL/L	196 – 700	80%	S
	CT	252 – 2,100	80%	S
Rite Boilers (B-7)	Power burner	398 – 10,456	80%	S
Precision Boilers (B-8)	FTS	1,050 – 2,100	85%	S, D
Johnston Boiler (B-9)	N/A	1,673 – 83,687	N/A	S

Note: * S-Manufacturer's published specifications or manuals; D-Direct telephone conversation with manufacturer representatives

[33] Appliances with energy input rating greater than 12.5 MBtu/hr are part of a separate study conducted under the auspice of the NFPA.

Table 7 Water heaters with power burners

Manufacturer ID	Model	Energy Input Rating (Thousands of Btu/hr)	Combustion Efficiency	Source*
Hubbell (WH-1)	DF	199 – 6,300	N/A	S
Bradford White (WH-2)	Power burner	300 – 3,650	83%	S
AO Smith (WH-3)	Cons. Large Vol. PB	140 – 2,500	80%	S, D
	Cons. Small Vol. PB	140 – 370	80%	S
Bock Corp (WH-4)	Commercial Series	155 – 623	80%	S
	Industrial Series	400 – 1,500	80%	S
RBI (WH-5)	Futera Fusion	500 – 1,999	97%	S

Note: * S-Manufacturer's published specifications or manuals; D-Direct telephone conversation with manufacturer representatives

Table 8 Power burners

Manufacturer ID	Model	Type of Appliance Equipped*	Energy Input Rating (Thousands of Btu/hr)	Source**
Webster Engineering (P-1)	JBS2	B, F	1,600 – 7,000	S, D
	JBSX2	B, F	2,000 – 5,500	S, D
	JBS3	B, WH	6,300 – 17,000	S, D
	JBSX3	B, WH	5,200 – 13,600	S, D
	HDRV	B, WH	12,000 – 40,300	S, D
	HDRMB	B	250 – 2,500	S, D
	JB series	B	400 – 16,800	S, D
Power Flame (P-2)	X4	F	90 – 725	S, D
	Type C	F	98 – 19,100	S, D
	Type FD	F	30 – 3,500	S
	Type FDM	F	30 – 3,500	S
	Type JA	N	50 – 2,200	S, D
	Type NPM	B	300 – 2,200	S, D

Manufacturer ID	Model	Type of Appliance Equipped*	Energy Input Rating (Thousands of Btu/hr)	Source**
Industrial Combustion (P-3)	XL/NLXL	N	67,200 – 92,400	S
	E/LNE	B	8,400 – 42,000	S
	V/LNV	B	1,300 – 16,800	S
	FP	B	550 – 4,200	S
Ward Heating (P-4)	HSG	F, B, WH	60 – 400	S
	EHG	F, B, WH	425 – 700	S
Carlin (P-5)	EZ Gas	N	50 – 275	S
	301 Gas	N	401 – 1,100	S
Weishaupt (P-6)	Monarch	B	183 – 19,500	D
	LB	N	200 – 37,000	D
Fuel Master Pendell (P-7)	CG20 - 60	B, F	420 – 3,080	S
	CG100 -230	B, F	2,520 – 9,800	S
Midco International (P-8)	EC200-300	N	70 – 300	S
	RE	N	132 – 850	S
	MPG	N	150 – 2,500	S
	G, GB, A	N	300 – 6,000	S
Limpsfield (P-9)	LCN	B	75 – 7,000	S
Cleaver Brooks (P-10)	ProFire K	N	1,250 – 14,500	S
Beckett (P-11)	CG10	N	300 – 1,200	S
	CG15-CG50	N	800 – 5,000	S

Note: * B-Boilers; WH-Water Heaters; F- Furnace; N-Non Specific

** S-Manufacturer’s published specifications or manuals; D-Direct telephone conversation with manufacturer representatives

3.2 Combustion Air Requirements Recommended by Manufacturers

The requirements for combustion air specified by the manufacturer of large input appliance are provided in Table 9. Of the 25 manufacturers, 15 recommend providing combustion air in accordance with NFPA 54 for all appliances with a rated input ranging from 30 to 92,000 kBtu/hr (0.33 to 1 square inch per kBtu). One manufacturer recommends combustion air per

NFPA 54 for appliances with a lower range of input ratings (70to 850 kBtu/hr) and specifies a less restrictive requirement for appliances with large input ratings (150 to 6,000 kBtu/hr). Two manufacturers require a volumetric flow rate of air supply ranging from 0.24 to 0.47 cfm per kBtu/hr. The remaining seven manufacturers recommend providing the required combustion air through openings with a total free area ranging from 0.03 to 0.75 square inches per kBtu/hr of the total rated input approximately between 150 and 83,600 kBtu/hr. For power burner units, information on excess air required to help complete combustion is specified by the manufacturers of the power burner units, although no such information is provided from the manufacturers of the appliances equipped with power burners.

Table 9 Combustion air requirements recommended by appliance manufacturers

Manufacturer ID	Energy Input Rating (Thousands of Btu/hr)	Combustion Air Requirements	Burner Specified Excess Air*
Triad (B-1)	210 – 2,100	NFPA 54	-
Parker (B-2)	432 – 6,250	NFPA 54	-
Burnham (B-3)	311 – 2,367	NFPA 54	-
Hurst Boiler (B-4)	285 – 27,215	0.5 in^2 per kBtu/hr	-
Bryan Boiler (B-5)	250 – 850	NFPA 54	-
Columbia Boiler (B-6)	196 – 2,100	0.63 in^2 per kBtu/hr	-
Rite Boilers (B-7)	398 – 10,456	NFPA 54	-
Precision Boilers(B-8)	1,050 – 2,100	0.5 in^2 per kBtu/hr	-
Johnston Boiler (B-9)	1,673 – 83,687	0.12 to 0.18 in^2 per kBtu/hr	-
Hubbell (WH-1)	199 – 6,300	0.14 in^2 per kBtu/hr	-
Bradford White (WH-2)	300 – 3,650	NFPA 54	-
AO Smith (WH-3)	140 – 2,500	NFPA 54	-
Bock Corp (WH-4)	155 – 1,500	NFPA 54	-
RBI (WH-5)	500 – 1,999	NFPA 54	-
Webster Engineering (P-1)	400 – 40,300	0.24 cfm per kBtu/hr	12 to 30%
Power Flame (P-2)	30 – 2,200	NFPA 54	10 to 50%
Industrial Com. (P-3)	550 – 92,000	NFPA 54	18 to 45%
Ward Heating (P-4)	60 – 700	NFPA 54	25%
Carlin (P-5)	50 – 1,100	NFPA 54	20 to 45%

Manufacturer ID	Energy Input Rating (Thousands of Btu/hr)	Combustion Air Requirements	Burner Specified Excess Air*
Weishaupt (P-6)	183 – 37,000	0.47 cfm per kBtu/hr	10 to 25%
Fuel Master Pendell (P-7)	420 – 3,080	- 0.03 in^2 per kBtu/hr (w/o draft hood or barometric draft control) - Not less than 100 in^2 for the first 400,000 Btu/hr plus 1 in^2 per 14,000 Btu/hr (Natural draft with hood or barometric draft control)	20 to 45%
Midco International (P-8)	70 – 850	NFPA 54	~20%
	150 – 6,000	- 0.072 in^2 per kBtu/hr (with barometric draft control) - 0.216 in^2 per kBtu/hr (with draft hood)	
Limpsfield (P-9)	75 – 7,000	0.75 in^2 per kBtu/hr	12 to 18%
Cleaver Brooks (P-10)	1,250 – 14,500	NFPA 54	12 to 45%
Beckett (P-11)	300 – 5,000	NFPA 54	15 to 30%

Note: * Percent excess air from stoichiometric requirement to complete combustion – See Section 4.1

3.3 Section Summary

Energy input ratings and combustion air requirements for gas-fired power-burner equipped appliances were collected from available published manufacturer's specifications and through direct communication with the appliance manufacturers. Based on the types of power burner appliances, the input ratings are as follows:

- Boilers: 60 to 83,600 kBtu/hr;
- Water heaters: 60 to 40,300 kBtu/hr; and
- Furnaces: 30 to 9,800 kBtu/hr.

A majority of the manufacturers (60%) included in this study reference NFPA 54 for combustion air requirements (0.33 to 1 square inches per kBtu/hr input) for their power burner appliances with an energy input ranging from 30 to 92,000 kBtu/hr. Of the 25 manufacturers, eight recommend that combustion air be provided by openings sized to 0.03 to 0.75 square inches per kBtu/hr of the total appliance input rating from 150 to 83,600 kBtu/hr (one of these eight manufacturers also recommend combustion air per NFPA 54 for a lower range of input rating). The opening size in accordance with these eight manufacturers is approximately 25% to 97% smaller than that of the NFPA 54 requirements. The remaining manufacturers recommended combustion air based on a specified volumetric flow rate from 0.24 to 0.47 cfm per kBtu/hr of appliance input rating.

A review of the manufacturers' requirements suggest that power burner equipped appliances require smaller and possibly fewer exterior openings in buildings for combustion air as prescriptively required through the current model codes.

4 Combustion Air for Power Burner Appliances

Combustion air must be adequately provided for gas-fired appliances to properly function. Power burners use a mechanical means to draw the required amount of air to support combustion. When equipped with a natural-draft venting device (barometric draft control), power burner appliances also rely on natural ventilation to provide dilution air for proper venting of the flue gases. When combustion air is supplied from the outdoors, opening(s) must be properly sized so that not only an adequate amount of air is provided for the appliances, but the potential for adverse building environmental conditions is minimized. This section establishes sizing criteria for outdoor combustion air opening(s) suitable for power burner appliances.

4.1 Combustion Air for Power Burners

For ideal combustion, fuel is burned with air at a stoichiometric ratio and no excess fuel or air is left in the flue gases. In real word situations, air in excess of the stoichiometric amount is necessary for the combustion process to ensure near complete combustion and to prevent toxic emissions. This section provides an estimate for the amount of combustion air required for power burners based on data compiled from various models of power burner appliances from ten (10) different manufacturers.

A power burner mechanically mixes fuel and air before injecting the mixture into the combustion chamber. Because of this improved mixing process, the amount of excess air required to help complete combustion for power burner appliances is generally less than that for conventional atmospheric-burner appliances. The level of excess air depends on the design of the burners, although in general, power burners typically operate at 15 to 20% of the stoichiometric amount.[34]

The amount of excess air can be adjusted[35] on the power burner to achieve the desired efficiency and flame temperatures. Some amount of excess air is always required to bring the fuel

[34] 2008 ASHRAE Handbook – HVAC Systems and Equipment, Automatic Fuel-Burning Systems, p. 30.3

[35] A damper is typically equipped on power burners to control the amount of air flow into the burner.

concentrations close to zero in the combustion reactions, i.e. complete oxidation of carbon monoxide (CO) to carbon dioxide (CO_2). However, because the excess air will absorb a fraction of the heat release, burners are designed to minimize heat losses by achieving a near complete combustion with minimal excess air levels. To achieve this condition, power burner manufacturers commonly specify acceptable concentration ranges of oxygen (O_2), CO_2, and CO in the flue gases. These specified concentrations can be used to determine the amount of excess air required for combustion based on the thermochemistry principle. The following analysis provides an estimation of the required excess air for power burners based on the manufacturer's specified concentrations.

Assuming natural gas as only methane (CH_4)[36], the combustion chemical equation under stoichiometric conditions is given by,

$$CH_4 + 2(O_2 + 3.76\,N_2) \longrightarrow CO_2 + 2H_2O + 7.52N_2 \qquad (1)$$

Under stoichiometric conditions, all the available O_2 is consumed, resulting in products of combustion with no excess air. Assuming combustion of methane with 25% excess air, the combustion chemical equation becomes,

$$CH_4 + 1.25 \times 2(O_2 + 3.76\,N_2) \longrightarrow CO_2 + 2H_2O + 0.5O_2 + 9.4N_2 \qquad (2)$$

The concentration of excess O_2 in the flue gases is given by,

$$\%\,O_2 = 100 \times \frac{0.5\,[O_2]}{1\,[CO_2] + 2\,[H_2O] + \;0.5[O_2] + 9.4\,[N_2]} \approx 4\%. \qquad (3)$$

Excess air of 25% would result in a concentration of O_2 in the flue gases of about 4%. Based on Equation (3), a relationship between excess air and the concentration of O_2 in the flue gases can be determined as follows,

$$\%\,O_2 = 100 \times \frac{\frac{\%[air]}{100}\gamma_{O_2}}{\gamma_{CO_2} + \gamma_{H_2O} + \frac{\%[air]}{100}\gamma_{O_2} + 3.76\left(1 + \frac{\%[air]}{100}\right)\gamma_{O_2}}. \qquad (4)$$

[36] Approximately 81% of natural gas is methane, Commentary Table 1.1 of NFPA 54.

Figure 1 provides the estimated percent excess air as a function of O_2 concentration in the flue gases based on Equation (4).

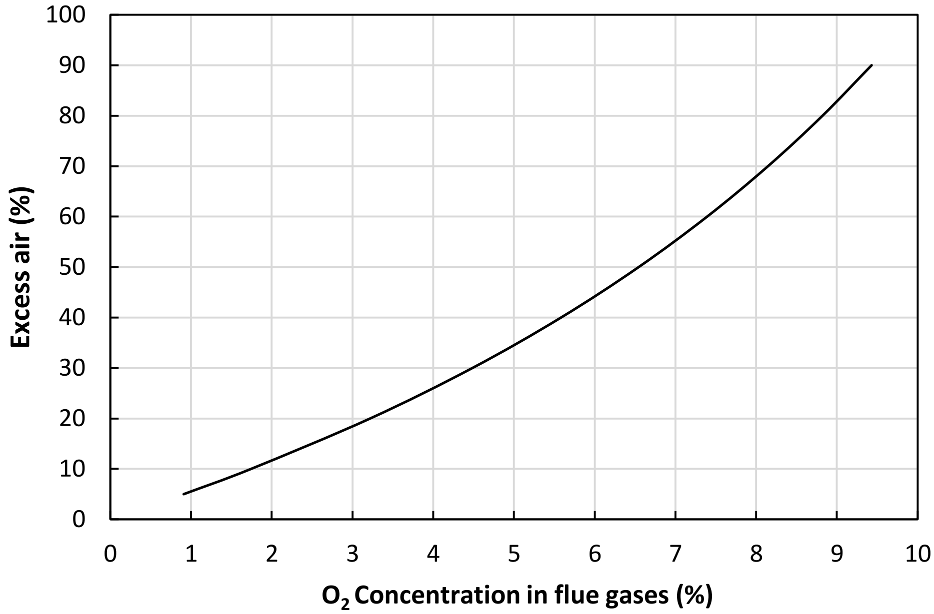

Figure 1 Percent excess air vs. O_2 concentration in flue gases

Based on the concentration of O_2 specified by the power burner manufacturers, a theoretical value for percent excess air required for operation can be estimated using Figure 1. It is possible that the actual excess air versus O_2 curve for power burners is slightly different than the theoretical values presented in Figure 1, due to the multiple step chemical reactions in real world conditions and the unique design characteristic of different burners. Some manufacturers provide the O_2 curve specific to their burners and the required excess air can be directly determined. The excess air curve is dependent on the fuel type, but the variation is minimal among hydrocarbon fuels and is assumed negligible in this analysis. Based on the manufacturer's specified concentration of O_2, a summary of the percent excess air for power burners considered in this study is presented in Table 10.

Table 10 Manufacturers recommended %O_2 in flue gases and corresponding excess of air

Power burner Manufacturer	Recommended O_2 Concentration (%)	Corresponding Excess Air (%)
Webster Engineering (P-1)	2.5 - 4.5	12[a] – 30
Power Flame Inc. (P-2)	2 – 7	10 – 50[b]
Industrial Combustion (P-3)	Low Fire: 5 – 6 High Fire: 3 – 4	Low Fire: 35 – 45 High Fire: 18 – 25
Ward Heating (P-4)	~4.5	25[a]
Carlin (P-5)	3.5 – 6.2	20 – 45
Weishaupt (P-6)	-	10 – 20[a]
Fuel Master Pendell (P-7)	3.5 – 6	20 – 45
Midco International (P-8)	-	~20[a]
Limpsfield (P-9)	2 – 3	12 – 18
Cleaver Brooks (P-10)	Low Fire: 4 – 6 High Fire: 2 – 4	Low Fire: 25 – 45 High Fire: 12 – 25
Beckett (P-11)	2.5 – 4.5	15 – 30

Note: a. Percent excess air provided by manufacturer's published specifications
b. Determined directly from the excess air – O_2 curves provided by manufacturers

Based on the data obtained from various power burner models, the level of excess air depends on the design and application of the burners and the excess air values range from 10% to 50%. The lower end values typically represent high flame temperature applications (high fire) and the higher end values typically represent low flame temperature (low fire). The majority of power burner manufacturers specify the excess air at a level below 30%.

Based on the data from the power burners considered in this study, an overall average of 30% excess air was conservatively selected for the air flow analysis discussed in Section 4.2. The selected average percent excess air is approximately 50% higher than the typical values of excess air reported in the available literature[37].

[37] 2008 ASHRAE Handbook – HVAC Systems and Equipment, Automatic Fuel-Burning Systems, p. 30.3

4.2 Air Flow Analysis

Air flow into and out of a gas-fired appliance room can be driven by a natural draft or a mechanical means, or by both. Power burner appliances use fans to draw the required amount of air to support the combustion. When equipped with a natural-draft venting device (barometric draft control)[38], power burner appliances[39] also rely on natural ventilation to provide dilution air for proper venting of the flue gases. When combustion air is supplied from the outdoors, opening(s) must be properly sized so that not only an adequate amount of air is provided for the appliances, but the potential for adverse building environmental conditions is minimized. To establish sizing criteria for combustion air openings, it is important to understand the impact of control variables, including outdoor temperatures, opening areas, and appliance input ratings on the amount of combustion air available in the appliance room. This section presents a theoretical analysis for air flow through an outdoor combustion air opening for two (2) types of power burner appliances:

1) Power burner appliances equipped with a draft control device that require dilution air for venting; and
2) Power burner appliances that utilize a mechanical or other means to move combustion products (such as fan-assisted combustion appliances), and require no dilution air for venting.

Consider first the case for power burner appliances with a draft control device. Figure 2 presents a conceptual diagram for air flow in a confined power burner appliance room, communicating to the outdoors through a single air supply opening and a natural-draft exhaust vent.

[38] National Fuel Gas Code Handbook 2006, p. 313, Barometric draft regulators perform the same functions as a draft hood, but are generally used in connection with power burner and conversion burner appliances.

[39] More than 50% of power burner equipped appliances considered in this study (boilers and water heaters) are recommended by the manufacturers to be equipped with barometric draft control devices.

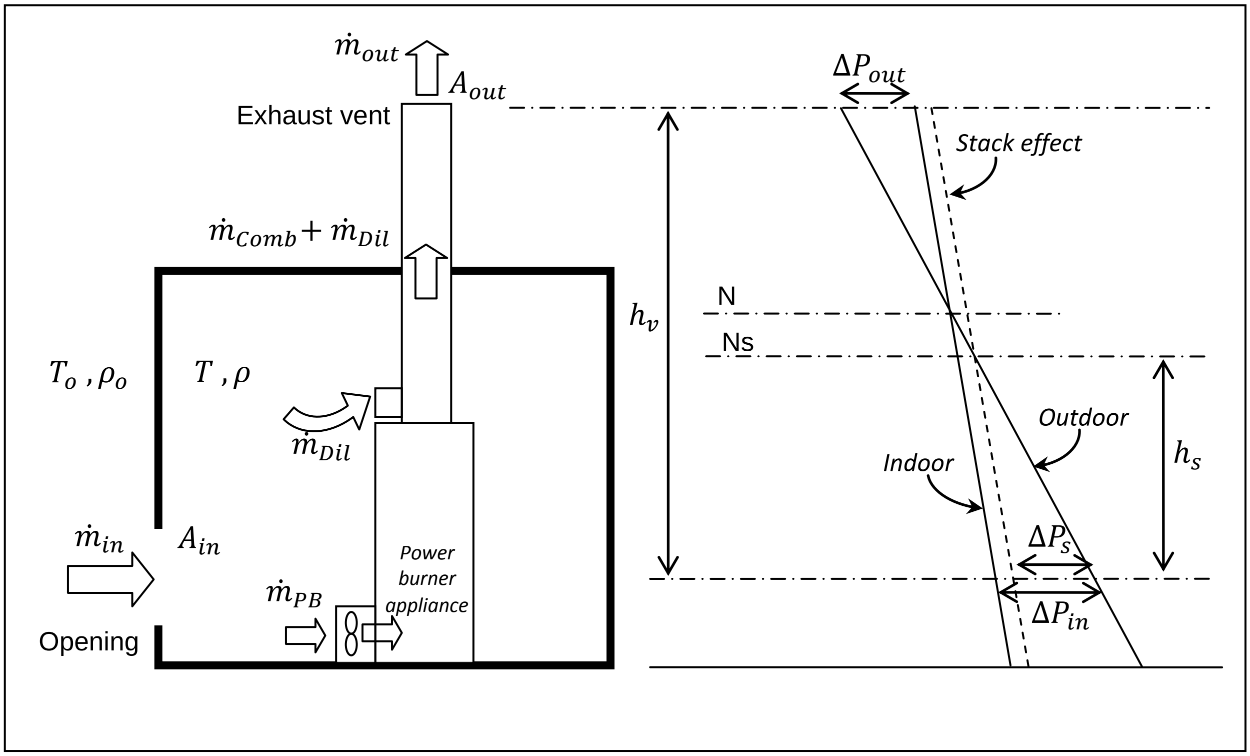

Figure 2 Schematic of air flows for a room with a power burner appliance equipped with draft control device and a single air supply opening (left), outdoor and indoor pressure profiles (right)

The following is assumed:

- The air in the appliance room is well-mixed with a uniform indoor temperature;
- No air enters the appliance room by any means other than through the combustion air opening;
- There is no wind or air movement due to building mechanical ventilation; and
- Steady state conditions exist.

Based on the conservation of mass,

$$\dot{m}_{in} = \dot{m}_{out} \tag{5}$$

$$\dot{m}_{in} = \dot{m}_{Comb} + \dot{m}_{Dil} \tag{6}$$

where $\dot{m}_{Comb}$ is the product of combustion mass flow rate in kg/s and $\dot{m}_{Dil}$ is the dilution air mass flow rate, in kg/s. Assuming the fuel gas flow rate to the appliance is negligible, the mass balance can be written as:

$$\dot{m}_{in} = \dot{m}_{PB} + \dot{m}_{Dil} \tag{7}$$

where $\dot{m}_{PB}$ is the power burner air mass flow rate in kg/s. The power burner unit uses a mechanical draft to draw the required amount of air to support combustion. The total amount of air includes the stoichiometric amount plus 30% excess air, as previously discussed in Section 4.1. The power burner air mass flow rate can be estimated as:

$$\dot{m}_{PB} = \frac{(1.3)r}{\Delta h_c G_F} I \, , \tag{8}$$

Where,

Δh_c is the heat of combustion of the fuel gas in kJ/kg;

r is the stoichiometric air-to-fuel volume ratio;

I is the appliance input rating in kW; and

G_F is the specific gravity of the fuel gas.

Since the power burner mass flow rate is drawn into the appliance room via mechanical means, the dilution air flow rate is assumed to be only driven by the stack effect or the natural draft. Assuming the stack effect pressure difference across the opening, ΔP_s, is constant over the opening height, the dilution mass flow rate, $\dot{m}_{Dil}$, is given as:

$$\dot{m}_{Dil} = C_d A_{in} \rho_o \sqrt{\frac{2\Delta P_s}{\rho_o}} \, , \tag{9}$$

Where A_{in} is the area of the combustion air opening in m^2 and C_d is the flow coefficient, typically 0.6 for a sharp-edged opening. Based on the hydrostatic pressure, $\Delta P_s = (\rho_o - \rho) g h_s$, where ρ is the density of air in the appliance room in kg/m^3, g is gravitational acceleration in m/s^2, and h_s is the vertical distance in m measured from the stack neutral plane (Ns) to the center of the opening. Substituting in Equation (7) results in:

$$\dot{m}_{in} = \frac{(1.3)r}{\Delta h_c G_F} I \; + C_d A_{in} \rho_o \sqrt{\frac{2\left(\rho_o - \rho\right) g h_s}{\rho_o}}. \tag{10}$$

Let v_{in} be the average velocity in m/s of the air flow through the opening, the mass flow rate can be given as:

$$\dot{m}_{in} = C_d A_{in} \rho_o v_{in}. \tag{11}$$

Substituting in Equation (10) yields

$$C_d A_{in} \rho_o v_{in} = \frac{(1.3)r}{\Delta h_c G_F} I \; + C_d A_{in} \rho_o \sqrt{\frac{2\left(\rho_o - \rho\right) g h_s}{\rho_o}}. \tag{12}$$

The above equation is expressed in terms of density of the air inside and outside of the appliance room. In practice, it is common to express these properties of the air in terms of temperature. Assuming the ideal gas law for air and constant atmospheric pressure, it can be shown that $= \rho_o T_o$, where T is the appliance room temperature and T_o is the outdoor temperature in Kelvin. Upon substitution, Equation (12) becomes:

$$C_d A_{in} \rho_o v_{in} = \frac{(1.3)r}{\Delta h_c G_F} I \; + C_d A_{in} \rho_o \sqrt{\frac{2 g h_s (T - T_o)}{T}}. \tag{13}$$

A relationship between indoor and outdoor temperatures can be estimated based on the conservation of energy. For this analysis, all heat sources in the room are assumed to be due to the losses from the appliance and the exhaust vent pipe, approximately 2.5 percent of the total energy input rating.[40, 41] Assuming no heat is lost or gained through the room walls and ceiling, the energy balance is given as:

$$C_p \dot{m}_{out} T = C_p \dot{m}_{in} T_o + 0.025 I \,, \tag{14}$$

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[40] Rutz, A.L., et al., "Analysis of Combustion Air Openings to the Outdoors: Preliminary Results", Topical Report, GRI-93/0316, Gas Research Institute, 1994, pp. 11. The total heat added to the appliance room from all sources can be expressed as a fraction of the appliance input rating. A value of 2.5 percent is typically assumed.

[41] Halley, G., "Boiler/Burner Combustion Air Supply Requirements and Maintenance", National Board of Boiler and Pressure Vessel Inspectors Bulletin, Fall, 1998. Heat loss from boiler jacket could range from 0.5% to 4% of the boiler output.

Where C_p is the specific heat at constant pressure for air in kJ/kg-K. To simplify the analysis, Equation (14) neglects the influence of the heated flue gas on the overall air exchange rate and pressure distribution in the room.[42] From the mass balance, $\dot{m}_{in} = \dot{m}_{out}$, and Equation (11), the energy balance becomes:

$$C_p C_d A_{in} \rho_o v_{in} (T - T_o) = 0.025I. \quad (15)$$

Let $A^* = A_{in}/I$, a scaled opening area based on the appliance energy input rating. Upon rearranging, Equations (13) and (15) reduce to:

$$v_{in} = \frac{(1.3)r}{A^* \Delta h_c G_F \rho_o C_d} + \sqrt{\frac{2gh_s(T - T_o)}{T}} \quad (16)$$

$$C_p C_d A^* \rho_o v_{in} (T - T_o) = 0.025. \quad (17)$$

A stack height, h_s, appearing in Equation (16) is also dependent on temperatures and opening areas. From the mass balance, an expression for h_s can be given:

$$\frac{h_v - h_s}{h_s} = \left(\frac{A_{in}}{A_{out}}\right)^2 \frac{T_o}{T}, \quad (18)$$

Where h_v is the characteristic height between the exhaust vent outlet and the opening and A_{out} is the exhaust vent area. For appliances equipped with draft control device, the vent must also be properly sized to prevent a positive pressure that can lead to spillage of flue gases. NFPA 54[43] outlines requirements for vent sizing based on vent construction, vent height[44], and appliance input rating. Assuming a Type B double-wall gas vent and selecting a minimum vent height of 6 ft[45], an expression for the vent area as a function of the appliance input rating can be given as:

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[42] Ackerman, M.Y., et al., "Design Guidelines for Combustion Air Systems in Cold Climates", ASHRAE Research Project 735-RP, January 1995, pp.47. The pressure differential of 25 to 35 Pa can be expected due to heated flue gas for a 5 m tall stack with flue temperature of 150 to 200°C and -20°C ambient temperature.

[43] Sections 13.1 of NFPA 54-2012, Venting Tables.

[44] Sections 13.2.13 of NFPA 54-2012. A vent height is a total vertical distance measured from the highest draft hood outlet or flue collar up to the level of the exhaust outlet of the common vent.

[45] Section 13.2.29 of NFPA 54-2012. The minimum vent height corresponds to a more conservative value of the allowable appliance input rating.

$$\frac{A_{out}}{I} \approx C_V \,, \tag{19}$$

Where C_V is 0.00038 m^2/kW or 0.17 in^2 per kBtu/hr. Substituting in Equation (18) yields:

$$\frac{h_v - h_s}{h_s} = \left(\frac{A^*}{C_V}\right)^2 \frac{T_o}{T}, \tag{20}$$

The characteristic height, h_v, is a control variable based on the location of the opening and the exhaust vent outlet, and can be selected to represent the "worst case" scenario where the stack effect is minimal. Given a selected value of h_v, a system of Equations (16), (17), and (22) can be solved for the average velocity of the air flow through opening, v_{in}, and for the indoor temperature, T, as a function of the scaled opening area, A^*, and the outdoor air temperatures, T_o.

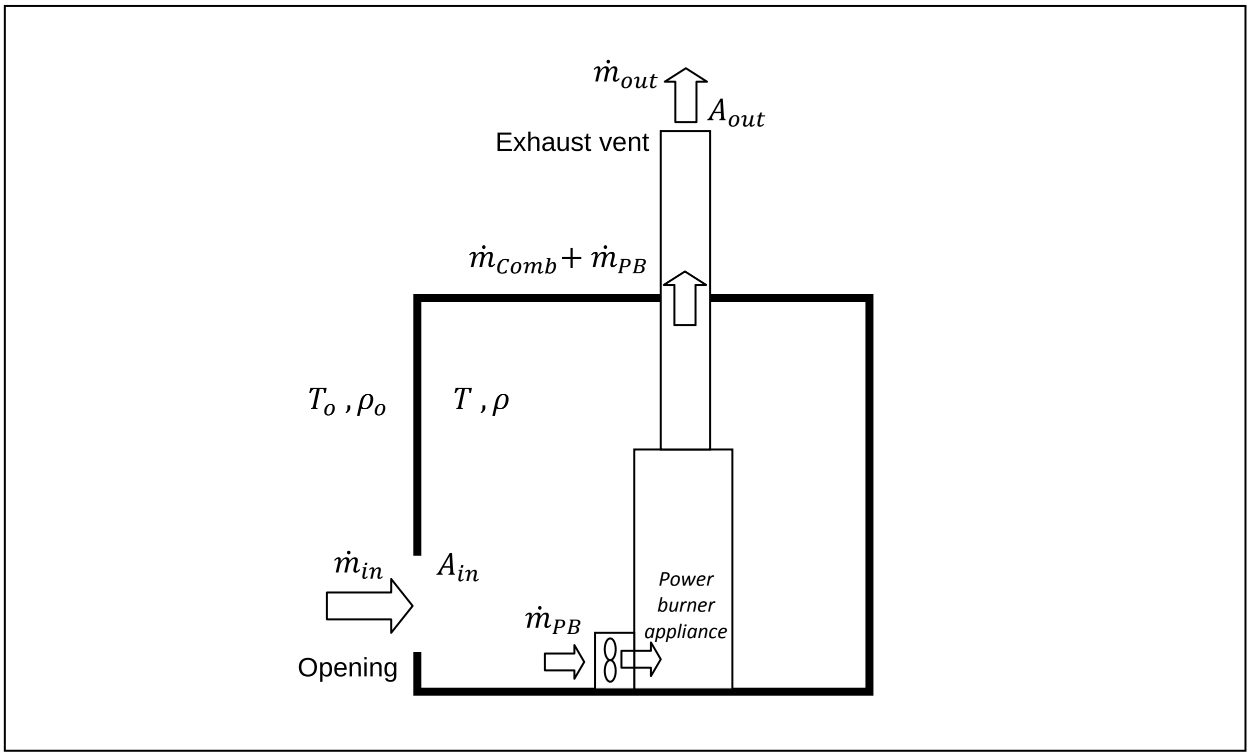

Figure 3 Schematic of air flows for a room with a power burner appliance with no dilution air and a single air supply opening

In the second case, where no dilution air is required for the power burner appliance, all inflow is assumed to be equal to the amount of air drawn by the power burner (see Figure 3). Equation (7) reduces to:

$$\dot{m}_{in} = \dot{m}_{out} = \dot{m}_{PB} = \frac{(1.3)r}{\Delta h_c G_F} I \,. \tag{21}$$

From Equation (11), the air flow velocity can be given as:

$$v_{in} = \frac{(1.3)r}{\Delta h_c G_F C_d A^* \rho_o} \tag{22}$$

When no dilution air is required for power burner appliances, air flow rate through outdoor openings is independent of the outdoor temperatures. The amount of air flow is only governed by the appliance input rating.

Since the heat of combustion per unit mass of air consumed ($\Delta h_c G_F / r$) is nearly constant for most fuel gases, the governing Equations (16) and (22) for power burners are independent of the fuel type. Based on the fundamental equations for mass and energy conservation, a simplified air flow model for power burner appliances has been developed. The dependent variables, including the volumetric flow rate, flow velocity, and room temperature can be examined as the scaled opening area and the outdoor temperature vary. In the following section, the developed air flow model is used to establish the minimum criteria for combustion air openings.

4.3 Combustion Air Openings for Power Burner Appliances

For a power burner appliance equipped with a draft control device, the amount of air available in an appliance room is controlled by the opening area, appliance input rating, and outdoor temperature. For certain designs of power burner appliances that do not require dilution air for venting of flue gases, the amount of air is primarily dependent on the appliance input rating. These control variables (opening area, appliance input rating, and outdoor temperature) also govern air flow velocity and appliance room conditions, such as temperature and pressure drop across openings.

This section provides an investigation on the combustion air openings for power burner appliances based on the following parameters:

- The amount of air supplied through openings;
- The percent dilution air for venting of gases (when applicable);

- Air flow velocity and pressure drop across the openings; and
- Appliance room temperature.

Equations (16), (17), and (22), are used to calculate air flows through openings for power burner appliances. Natural gas is assumed and the inputs for thermal properties are as follows. For natural gas, the heat of combustion, Δh_c, is 23,000 Btu/lb [54,000 kJ/kg], the specific gravity, G_F, is 0.6, and the stoichiometric air-to-fuel volume ratio, r, is 10. The density of outdoor air, ρ_o, is 0.074 lb/ft^3 [1.17 kg/m^3] and the specific heat of air, C_P, is 0.24 Btu/lb [1.003 kJ/kg-K]. The vent height is selected such that it represents a scenario where the stack effect is minimal, resulting in the lowest level of air flow for a given opening size. Based on the prescriptive minimum vent height of 6 ft as required by NFPA 54[46] for natural-draft venting, h_v is assumed to be 6 ft. A range of outdoor temperatures (0°F to 60°F) for cold climates is considered in this analysis.

4.3.1 Air Supplied Through Openings

The effect of the combustion air opening size on the volumetric air inflow rate is presented in Figure 4 at selected outdoor temperatures for power burner appliances with a draft control device. Based on Figure 4, the amount of air entrained increases with the opening size, but the variation with the opening size becomes less significant when the scaled opening area is greater than 0.5 in^2 per kBtu/hr. The air flow rate slightly decreases as the outdoor temperature increases. This is due to the reduction in the stack effect as the outdoor temperature increases. The air flow becomes less dependent on the outdoor temperature as the scaled opening area decreases. Among the outdoor temperatures considered, 60 °F produces the lowest amount of air flow into the appliance room.

[46] Sections 13.2.13 and 13.2.29 of NFPA 54-2012.

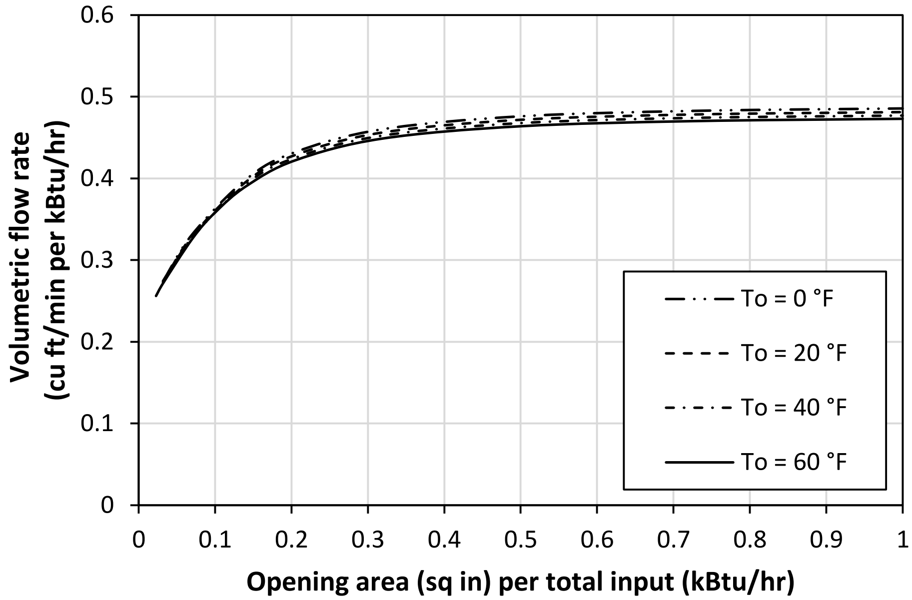

Figure 4 Volumetric air inflow rate at different outdoor temperatures for power burner appliances with a draft control device

Figure 5 shows a comparison of total inflow, dilution air, and air for power burner appliances. The volumetric air flow rates are shown for outdoor temperature at 60 °F, corresponding to the worst case scenario with respect to the least amount of air supply. The volumetric air inflow, denoted by the solid curve in Figure 5, is the sum of the dilution air inflow and the appliance flow. The amount of dilution air increases with the opening size, but the variation with the opening is reduced as the opening size increases. The appliance air flow, consisting of air for combustion and excess air, is mechanically induced by the power burner appliance and the volumetric flow rate is constant for all opening sizes and outdoor temperatures. For power burner appliances with no dilution air required for venting, the appliance air flow equals the total air inflow through the combustion opening, independent of the opening size. In Figure 5, the amount of air entrained through the openings for power burner appliances is at least the amount of air required to support combustion (air for stoichiometric combustion plus excess air). However, for power burner appliances equipped with a draft control device, the amount of dilution air must also be considered in determining criteria for combustion air openings.

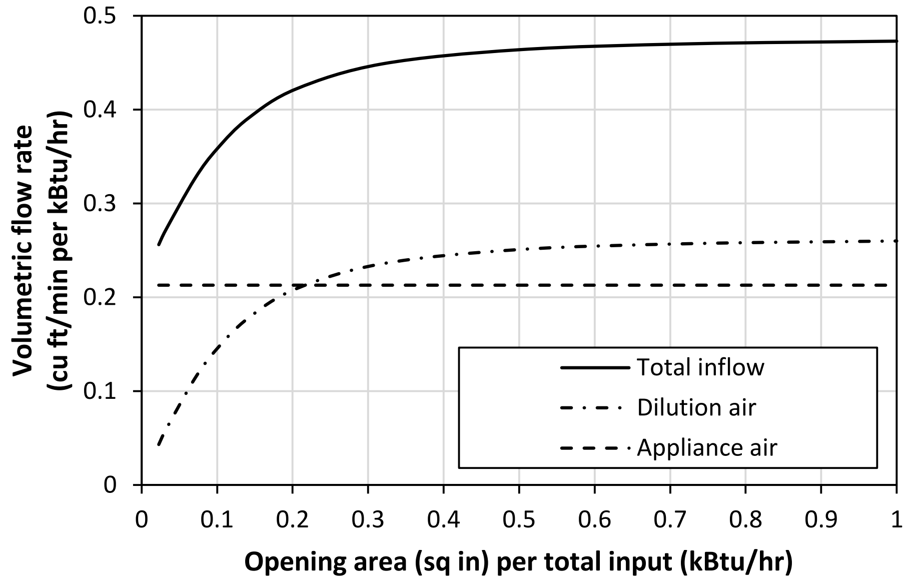

Figure 5 Volumetric flow rates

As previously discussed in Sections 2.2 and 3.2, some power burner manufacturers[47] and an engineering guideline[48] specify the requirements for combustion air based on the volumetric air flow rates, ranging from 0.24 to 0.47 cfm per kBtu/hr. Based on Figure 5, these recommended air inflow rates correspond to the scaled opening areas ranging 0.02 to 0.6 in^2 per kBtu/hr. The combustion air opening area required by NFPA 54 ranges from 0.33 to 1 in^2 per kBtu/hr input rating, depending on the number of openings and how they communicate with the outdoors. The Canadian standard, CSA B149.1-10, contains a separate provision for power burner appliances to supply combustion air with outdoor openings sized to 0.03 in^2 per kBtu/hr. This suggests that the manufacturer's recommended combustion air flow rates correspond to opening sizes that, in general, are smaller than those required by NFPA 54, but are larger than the requirements for power burner appliances by CSA B149.1-10.

4.3.2 Dilution Air

The effect of opening size on percent dilution air at different outdoor temperatures is shown in Figure 6. The percent dilution air is a ratio of amount of air entrained by the natural ventilation

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[47] Based on direct communication with power burner manufacturers (P-1) and (P-6)

[48] "Combustion Air Requirements for Boilers," CleverBrooks, Tip Sheet November 2010, and "Boiler Room Air Supply," Johnston Boiler Company

to the amount of air required by stoichiometric combustion. The percent dilution air increases with the size of the combustion air opening, but reduces as the outdoor temperature increases, due to the reduction in stack effect. The dilution air is nearly independent of outdoor temperatures when the scaled opening area is less than 0.5 in^2 per kBtu/hr.

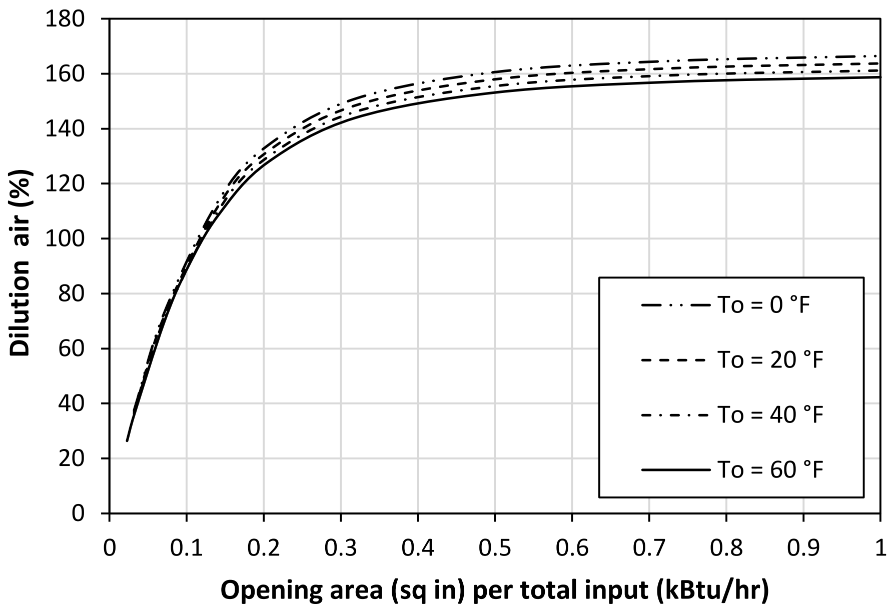

Figure 6 Percent dilution air at different outdoor temperatures

The amount of air required for dilution of flue gas depends on the specific drafting device, but a typical value is approximately 60% of the stoichiometric amount.[49] The 60% dilution air corresponds to a scaled opening area of approximately 0.06 in^2 per kBtu/hr.

A previous GRI study[50] utilized a computer program, VENT-II, to model the amount of dilution air for natural-draft appliances. The study used a parameter called "dilution variation" as a basis to establish a requirement for combustion air openings, 0.33 in^2 per kBtu/hr, which was later adopted by NFPA 54 as part of the outdoor combustion air requirements. The dilution variation or the normalized dilution air is a ratio of the available dilution air to the "maximum" possible amount of dilution air under a given set of boundary conditions (outdoor temperature and a very

[49] National Fuel Gas Code Handbook 2006, p. 171

[50] Rutz, A.L., et al., "Analysis of Combustion Air Openings to the Outdoors: Preliminary Results", Topical Report, GRI-93/0316, Gas Research Institute, 1994.

large opening size). An 80% dilution variation was recommended in the GRI report to ensure a high level of dilution air for satisfactory venting. A similar analysis based on the dilution variation is performed on the current results of the percent dilution air from Figure 6.

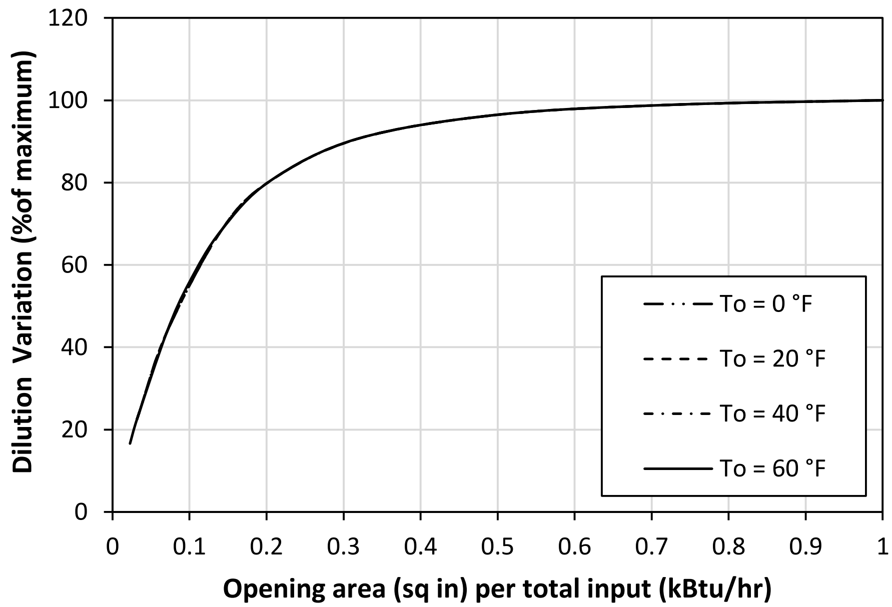

Figure 7 Normalized dilution air as a function of scaled opening area

Normalizing the percent dilution air as shown in Figure 7 allows removing the outdoor temperature as a control variable. The 80% dilution variation corresponds to a scaled opening area of 0.2 in^2 per kBtu/hr. Based on a similar analysis, the opening area for power burner appliances is approximately 39% smaller than the recommended opening area of 0.33 in^2 per kBtu/hr by the GRI report (or NFPA 54 for a single combustion air opening) for atmospheric burner appliances. Based on Figure 6, the scaled opening area of 0.2 in per kBtu/hr would produce approximately 128% dilution air, which is more than twice the typical value of the dilution air normally required for appliances equipped with a draft control device. The opening area (0.03 in^2 per kBtu/hr) required by CSA B149.1-10 for power burner appliances would provide approximately 36% dilution air, which is less than half the typical value for dilution air normally required for appliances with a draft control device.

4.3.3 Air Velocity and Pressure Drop

In addition to the amount of air supply for combustion and dilution, the air flow velocity is considered with respect to the combustion air opening size. In general, a smaller outdoor opening is more preferable for overall building efficiency. However, because the opening size is inversely proportional to the air velocity, an unreasonably small opening can lead to an extreme air flow velocity, which can adversely entrain unwanted outdoor contaminants, such as air pollutants, rain, and snow into the building.

Figure 8 shows the air flow velocity predicted at 0 °F outdoor temperature, as a function of the scaled opening area for power burner appliances that require dilution air for venting (equipped with a draft control device), and power burner appliances that require no dilution. The outdoor temperature of 0 °F is selected to represent the extreme scenario where the stack effect is large, although the predicted results indicate that the air velocity is nearly independent of the outdoor temperature for power burner appliances equipped with a draft control device. Where no dilution air is required, the air velocity is only a function of the opening area and the appliance input rating, as shown in Equation (22).

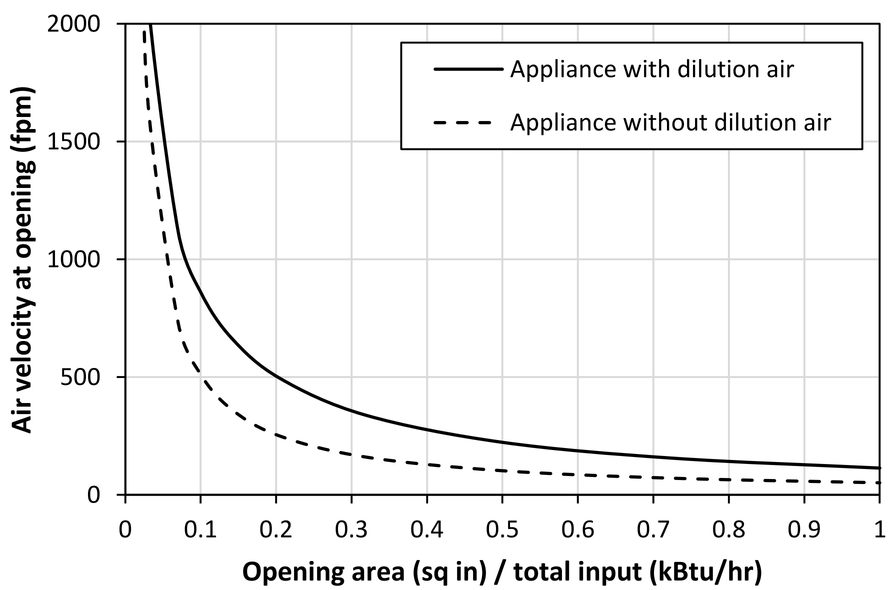

Figure 8 Air velocity at combustion air openings

As shown in Figure 8, the air velocity is inversely proportional to the opening size and sharply increases as the scaled opening area decreases below 0.1 in^2 per kBtu/hr.

The velocity of air flow and the opening size can have an impact on the level of air pollution in buildings and provide a potential for rain/snow intrusion. Two engineering articles[51] published by popular boiler manufacturers specify the maximum allowable air velocity for boilers as 250 fpm for openings located within 7 feet of floor level and 500 fpm for openings located above 7 feet high. ASHRAE Standard 62.1 Section 5.6 recommends a maximum air velocity of 500 fpm to prevent rain/snow intrusion into openings equipped with rain hoods. The ASHRAE recommendation for maximum velocity is for outdoor air intakes of mechanical ventilation systems. Section 9.3.7 of NFPA 54 outlines the requirements for louvers and grilles to prevent the entrance of rain and snow, but does not contain provisions for maximum velocity. Absent other recommendations or guidelines available for preventing adverse building environmental conditions, 500 fpm is used for this analysis as a general limit for the air velocity.

Based on Figure 8, the scaled opening areas corresponding to the air velocity of 500 fpm are 0.2 in^2 per kBtu/hr for power burner appliances with a draft control device and 0.1 in^2 per kBtu/hr for power burner appliances that require no dilution air. The scaled opening area of 0.2 in^2 per kBtu/hr also corresponds to the criteria for dilution air previously discussed.

[51] "Combustion Air Requirements for Boilers", CleverBrooks, Tip Sheet November 2010, and "Boiler Room Air Supply", Johnston Boiler Company

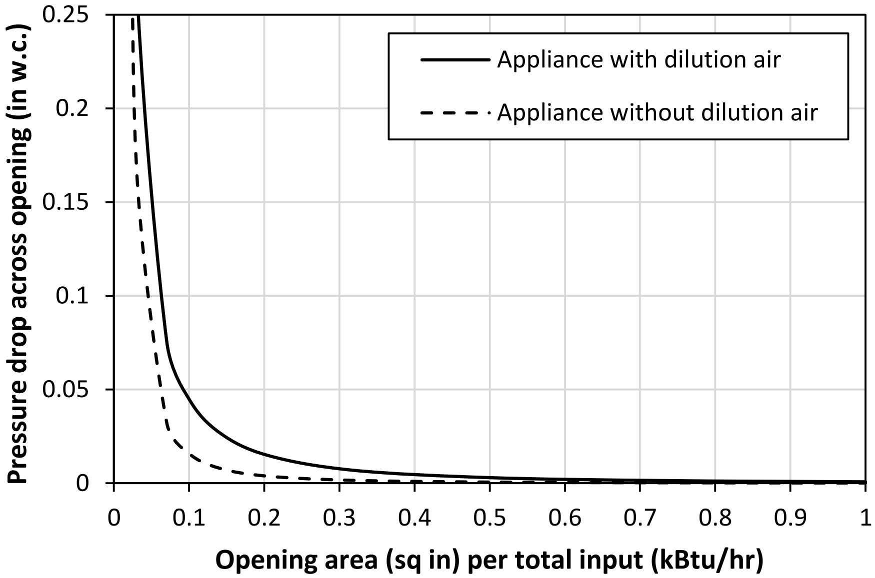

Figure 9 Pressure drop across combustion air opening

Pressure drops across the combustion air opening is another variable considered as part of this analysis. The pressure drops should be minimized to a level that would prevent an adverse impact on the appliance control and operations (such as furnace blowers), or the building ventilation system (when provided). Figure 8 shows the effect of opening size variation on the pressure drop across the opening for power burner appliances with and without dilution air. Boiler manufacturers recommend the pressure drop across duct work supplying combustion air not exceed 0.05 inch w.c. (12.5 Pa)[52].

Based on Figure 9, the scaled opening areas of 0.2 square inches per kBtu/hr for appliances with dilution air would produce a pressure drop across the opening of 0.015 inch w.c. (3.7 Pa). The same level of pressure drop is also expected for the scaled opening of 0.1 square inches per kBtu/hr for appliances without dilution air. This level of pressure drop is approximately one third of the pressure drop suggested by the engineering guideline for boilers.

[52] "Combustion Air Requirements for Boilers", CleverBrooks, Tip Sheet November 2010, and "Boiler Room Air Supply", Johnston Boiler Company

4.3.4 Appliance Room Temperature

The effect of combustion air opening size variation on the appliance room temperature is shown in Figure 10 for the same values of outdoor temperature. The predicted values of room temperature are likely overestimated due to the simplified assumption that the air in the room is well-mixed with no heat loss through walls or ceiling (adiabatic conditions). In real world conditions, the room temperature is likely to be lower than the predicted values and the heat loss from the appliances into the room tend to decrease for appliances with a large energy input.[53] The room temperature is also specific to the building installation, which can vary widely. Additional research is needed to validate the appliance room temperatures and any potential impact of the room temperature on the operation of the appliance.

Despite the potential for overestimated room temperatures, the variation of the indoor temperature with respect to the opening size should remain valid. The room temperature increases as the opening size decreases, but variation in the opening area becomes marginal for the scaled openings greater than 0.2 square inches per kBtu/hr.

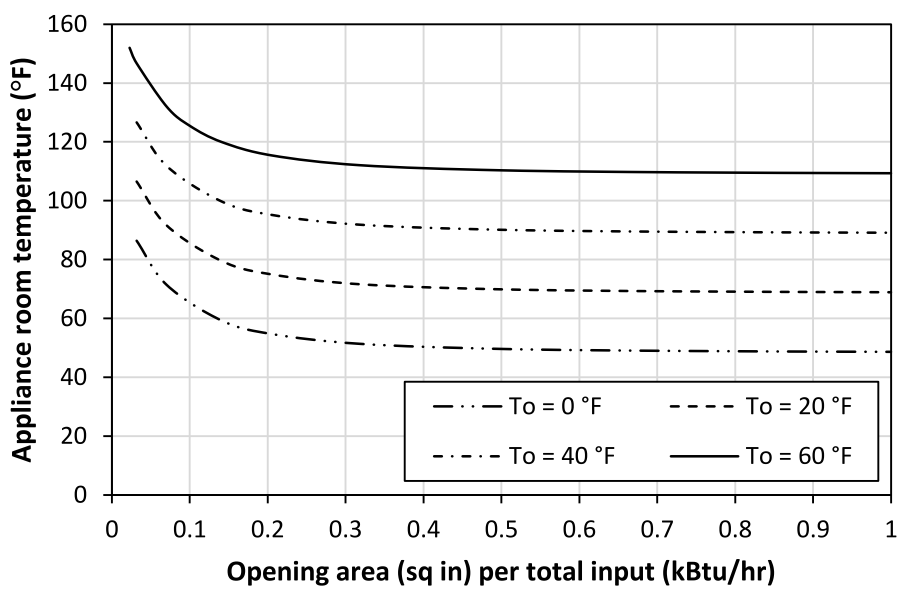

Figure 10 Appliance room temperature vs. scaled opening area

[53] Ackerman, M.Y., et al., "Design Guidelines for Combustion Air Systems in Cold Climates", ASHRAE Research Project 735-RP, January 1995.

4.4 Section Summary

Combustion air for gas-fired power burner appliances was investigated. Because power burners benefit from increased combustion efficiency, the amount of excess air required to help complete combustion is generally less than that for conventional atmospheric-burner appliances. The level of excess air required for power burner equipped appliances depends on the design of the burners. Based on the data obtained from various power burner models, the estimated values of excess air above the stoichiometric amount were estimated to range from 10% to 50%, with an average of 30%.

A theoretical analysis of air flows through outdoor combustion openings was performed. A simplified steady-state flow model was developed based on the fundamental conservation equations. Two types of power burner appliances were considered in the analysis including: 1) a power burner appliance equipped with a draft control device that uses dilution air for venting and 2) a power burner appliance that requires no dilution air. The developed model provides the ability to examine the volumetric flow rates, percent dilution air, flow velocity, pressure drops across openings, and indoor temperature as a function of the outdoor temperature and the scaled opening size, independent of the fuel gas type.

Because power burners use a fan to draw the amount of air required to support combustion, air entrained through the openings is at least the amount of air for stoichiometric combustion plus excess air. For power burner appliances equipped with a draft control device, dilution air is also required and the total amount of air flow through openings varies with the opening size. The manufacturer's recommended combustion air flow rates correspond to opening sizes that are smaller than those required by NFPA 54, but are larger than the requirement for power burner appliances by the Canadian standard, CSA B149.1-10.

The percent dilution air with respect to opening size was investigated for power burner appliances equipped with a draft control device. A value of 60% dilution air, typically required for appliances with a draft control device, was predicted for an opening area of 0.06 square inches per kBtu/hr. Alternatively, a ratio of the dilution air to the maximum possible amount of dilution (dilution variation) can be used to determine the criteria for combustion air openings.

Selecting an 80% dilution variation results in an opening area of 0.2 square inches per kBtu/hr, which corresponds to 128% dilution air (more than twice the typical value of the dilution air). This level of dilution air likely improves venting operation.

The velocity of air flow and the opening size can have an impact on the level of air pollution in buildings and a potential for rain/snow intrusion. A maximum air velocity of 500 fpm results in an opening area of 0.2 square inches per kBtu/hr for power burner appliances with a draft control device. The same velocity corresponds to an opening area of 0.1 square inches per kBtu/hr for power burner appliances that require no dilution air. These opening sizes were also calculated to produce a pressure drop across the opening of 0.015 inch w.c. (3.7 Pa), approximately one third of the maximum pressure drop level suggested by boiler manufacturers.

Based on the assumptions of well-mixed and adiabatic conditions for the appliance room, the room temperature is predicted to increase as the opening size decreases, but variation of the temperature with the opening area is shown to be insignificant when the opening area is greater than 0.2 square inches per kBtu/hr.

Based on a review of the combustion air required for power burners and the theoretical analysis for air flows through openings, the sizing criteria for combustion air openings are theorized as follows:

- A minimum opening area of 0.2 square inches per kBtu/hr of input rating for power burner appliances equipped with a draft control device; and
- A minimum opening area of 0.1 square inches per kBtu/hr of input rating for power burner appliances that require no dilution of flue gases.

Figure 11 provides a summary of the theorized combustion air opening sizing in comparison to the existing requirements. The red line depicts the total volumetric flow rates calculated for power burner appliances equipped with a draft control device, and the blue line represents the predicted total volumetric flow rates for power burner appliances that require no dilution air.

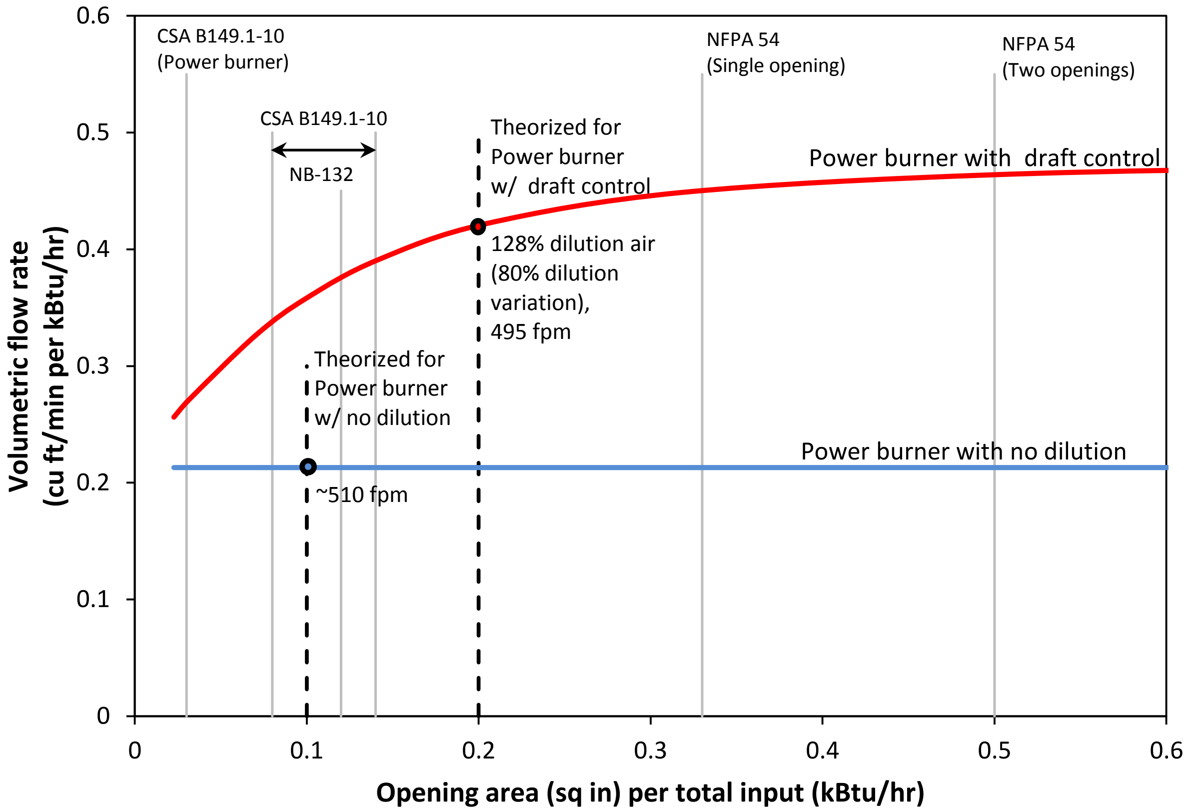

Figure 11 Comparison of predicted air flow for combustion air openings as required by this existing codes and theorized by this study

Based on the theoretical analysis, for power burner appliances with a draft control device, the minimum opening area of 0.2 square inches per kBtu/hr intercepts the flow rate curve where the percent dilution air is 128% of the stoichiometric amount (80% dilution variation) and the predicted velocity is approximately 495 fpm. For power burner appliances that require no dilution air, the predicted volumetric flow is constant for all opening sizes, but the air velocity increases as the opening size decreases. The minimum opening area of 0.1 square inches per kBtu/hr is based on a predicted air flow velocity of approximately 510 fpm.

The theorized outdoor opening sizes for power burner appliances are smaller than the current outdoor combustion air requirements by NFPA 54 (0.5 square inches per kBtu/hr for two openings and 0.33 squared inches per kBtu/hr for a single opening). For power burner appliances that require no dilution air, the theorized opening size (0.1 square inches per kBtu/hr) is within the range of opening sizes recommended by the Canadian standard, CSA 149.1-10 and the NF-312 guideline. In general, the combustion air sizing based on the theoretical analysis from this study is more conservative than the combustion air required by CSA 149.1-10 specifically for power burners (0.03 square inches per kBtu/hr).[54]

[54] No information is available regarding to whether or not the dilution air or a maximum air velocity is considered for sizing of combustion air opening for power burner appliances in the CSA 149.1-10 standard.

5 Conclusion

A review of available literature, engineering guidelines, and current standards related to combustion air requirements was conducted. In the United States, the requirements for combustion air outlined in the current standards and model codes are fairly uniform. Previous studies that provide a technical basis for NFPA 54 and national model codes do not account for large input rated appliances utilizing power burners. In Canada, CSA B149.1-10 provides different criteria specific to appliances with a large rated input (exceeding 400 kBtu/hr) and appliances utilizing power burners. Engineering guidelines for industrial/commercial boilers specify criteria for combustion air requirements for boilers with an input rating exceeding 200 kBtu/hr.

NFPA 54 requires the largest outdoor openings for combustion air in comparison to the other referenced guidelines. The opening free area required by NFPA 54 ranges from 0.33 to 1 square inch per kBtu/hr input rating, depending on the number of the openings and how they communicate with the outdoors. The other guidelines require combustion air openings with free area ranging from 0.08 to 0.14 square inches per kBtu/hr, which is consistent with providing an additional approximately 30% air supply to the combustion process. CSA B149.1-10 contains a separate provision for appliances equipped with power burners to supply combustion air with outdoor openings sized to 0.03 square inches per kBtu/hr of the total burner input rating.

Energy input ratings and combustion air requirements for gas-fired power-burner equipped appliances were collected from available published manufacturers' specification and through direct communication with the appliance manufacturers. Power burner boilers have the highest range of energy input ratings (60,000 to 83,600,000 Btu/hr) in comparison to that of water heaters (60,000 to 40,300,000 Btu/hr) and furnaces (30,000 to 9,800,000 Btu/hr). A majority of the manufacturers (60%) included in this study reference NFPA 54 for combustion air requirements (0.33 to 1 square inches per kBtu/hr input) for their power burner appliances with energy inputs ranging from 30 to 92,000 kBtu/hr. Of the 25 manufacturers, eight recommend that combustion air be provided by openings sized to 0.03 to 0.75 square inches per kBtu/hr of the total appliance input rating from 150 to 83,600 kBtu/hr. The opening size in accordance with these eight manufacturers is approximately 25% to 97% smaller than that of the NFPA 54 requirements. The remaining manufacturers recommend combustion air requirements based on a specified volumetric flow rate from 0.24 to 0.47 cfm per kBtu/hr of appliance input rating.

Combustion air for gas-fired power burner appliances was investigated. The level of excess air depends on the design of the burners. Based on the data obtained from various power burner models, the amount of excess air over the stoichiometric rate were estimated to range from 10% to 50%, with an average of 30%.

A theoretical analysis of air flows through outdoor combustion openings was performed. A simplified steady-state flow model was developed to examine the volumetric flow rates, percent dilution air, flow velocity, pressure drop across opening, and indoor temperature as a function of the outdoor temperature and the scaled opening size, independent of the fuel type and appliance input capacity. Two types of power burner appliances were considered in the analysis including, 1) a power burner appliance equipped with a draft control device that requires dilution air for venting and 2) a power burner appliance that requires no dilution air.

For appliances equipped with power burners, air entrained through the openings is at least the amount of air for stoichiometric combustion plus excess air. For power burner appliances equipped with a draft control device, dilution air is also required and the total amount of air flow through openings varies with the opening size. The manufacturer's recommended combustion air flow rates corresponds to opening sizes that are smaller than those required by NFPA 54, but are larger than the requirement for power burner appliances by the Canadian standard, CSA B149.1-10.

The percent dilution air with respect to opening size was investigated for power burner appliances with a draft control device. A ratio of the dilution air to the maximum possible amount of dilution (dilution variation) was used as a basis to determine the combustion air opening. Selecting 80% dilution variation resulted in an opening area of 0.2 square inches per kBtu/hr, which corresponds to 128% dilution air. This level of dilution air likely improves vent operation.

The velocity of air flow and the opening size can have an impact on the level of air pollution in buildings and provide the potential for rain/snow intrusion. A selected maximum air velocity of 500 fpm results in an opening area of 0.2 square inches per kBtu/hr for power burner appliances with a draft control device. The same velocity corresponds to an opening area of 0.1 square inches per kBtu/hr for power burner appliances that require no dilution air. These opening sizes are calculated to produce a pressure drop across the opening of 0.015 inch w.c. This pressure drop is unlikely to have an impact on the operation of standard gas-fired appliances.

Based on the review of available literature data, a review of the manufacturer's requirements for combustion air, the investigation of the combustion air required for power burners, and the theoretical analysis of air flows through openings, sizing criteria for combustion air openings for power burner appliances are theorized as follows:

- A minimum opening area of 0.2 square inches per kBtu/hr input rating for power burner appliances equipped with a draft control device; and
- A minimum opening area of 0.1 square inches per kBtu/hr input rating for power burner appliances that require no dilution of flue gases.

Based on the theoretical analysis provided in this study, these theorized combustion air requirements should provide an adequate amount of combustion air for proper appliance operation and will optimize overall building efficiency by reducing unnecessary area in openings. It is strongly recommended the theorized sizing criteria be validated through full-scale field experiments, which will provide a basis for new code development.

Limitations

This study was conduct under the auspice of the Fire Protection Research Foundation and is limited to its scope, as well as codes, rules, and regulations that were in place at the time. Any re-use of this report or its findings presented herein for any other purpose are at the sole risk of the user. The findings formulated during this assessment are based on observations and information available at the time of the investigation. Exponent strongly recommends performing full-scale validation tests to confirm the theorized sizing criteria for combustion air openings for power burner appliances.

The findings presented herein are made to a reasonable degree of engineering and scientific certainty. We have made every effort to perform an accurate and thorough investigation. If new data becomes available or there are perceived omissions or misstatements in this report regarding any aspect of those conditions, we ask that they be brought to our attention as soon as possible so that we have the opportunity to fully address them. Although Exponent has exercised usual and customary care in providing the analysis in this study, the responsibility for the design, construction, installation, and operation of power burner equipped gas-fired appliances remains fully with the engineering of record, general contractor, designer, installer, owner, and/or operator as applicable. Theories discussed herein may require additional considerations, engineering design, and specifications for implementation beyond the scope of this study.