Kitchen Ventilation Systems: Part 1
Evaluating the 2009 IRC Requirement for Makeup Air

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INTRODUCTION

The 2009 International Residential Code (IRC) requires the introduction of makeup air when kitchen exhaust equipment capacity exceeds 400 cubic feet per minute (CFM). This brief investigates whether the code threshold for requiring makeup air is justified, and what rates of exhaust might pose risks in modern residential construction. Note that the quantitative evaluation of the 400 CFM threshold does not consider other mechanical exhaust systems that may be operating simultaneously with a range hood. In addition, the only way to be sure that the risks discussed in this brief are acceptably low is to have the house tested by a qualified professional.

Large kitchen exhaust equipment might adversely affect the performance of other mechanical equipment within a house and could create uncomfortable or possibly even hazardous conditions. Without adequate makeup air, a large exhaust fan, coupled with a well-sealed building enclosure can produce large pressure differentials, which could lead to problems such as backdrafting of appliances, radon introduction or door operation problems.

Basic concepts are introduced in this brief that will help to explain the effects of kitchen exhaust on building pressure and why these effects could be problematic.

BUILDING PRESSURE

Events that drive changes in building pressure can be separated into two categories: *naturally occurring phenomena* and *mechanical systems operations*. The magnitude of the pressure differences at any given moment depends on the interaction of these independent forces.

Naturally Occurring Phenomena

The two naturally occurring phenomena that are important when discussing building pressure and air movement are *wind* and the *stack effect*.

Wind acting on a building's exterior creates pressure imbalances around the structure. The windward side of a structure experiences positive pressurization and the leeward side experiences negative pressurization. As illustrated in Figure 1, pressure differentials create air movement from areas of positive pressure to areas of negative pressure.

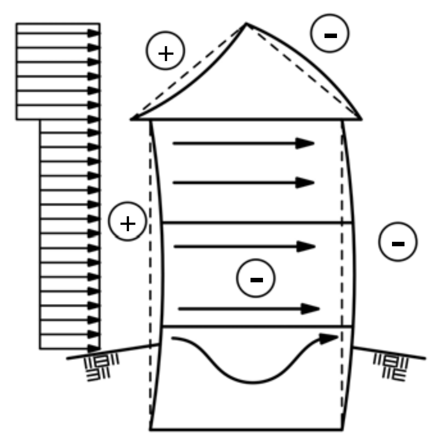

Figure 1. Wind creating pressure differentials across the building enclosure. Wind striking the house creates a positive pressure on the windward side and a negative pressure on the leeward side. Both positive and negative pressures create air leakage through cracks and holes in the building enclosure.

The second phenomenon, known as the stack effect, is created by differences in temperature between the interior and the exterior of a house. Hot air rises due to thermal buoyancy and creates a pressure imbalance within a building. This generates airflow across the building enclosure[1].

In colder climate zones the stack effect is most prevalent in the winter due to greater temperature differentials between the indoors and outdoors. Air within the structure is heated, causing it to rise. This rising hot air positively pressurizes the upper portion of the building causing air to flow outward across the enclosure. Meanwhile, a negative pressure is created at the bottom of the building causing air to flow inward across the enclosure. At some height between the top and bottom of the building there is a point where the interior air pressure is the same as the exterior air pressure. At this height, known as the *neutral pressure plane* (NPP), there is no airflow across the enclosure.

As illustrated in Figure 2 (Scenario #1), all points above the NPP are positively pressurized and exfiltrating, while all points below the NPP are negatively pressurized and infiltrating. A negative pressure develops in the lower portion of the house. Cold outside air is driven into the house by the greater air pressure on the exterior as compared to the interior. The pressure differential across the enclosure is likely to be 0-4 Pascals (Pa), depending on the difference between outdoor and indoor temperatures. With mechanical exhaust, this pressure differential can be significantly higher depending on the exhaust rate and house tightness.

Mechanical Systems Operations

Mechanical systems within a house can produce large unintended pressure differentials between the interior and exterior of the enclosure, as well as between individual rooms within the enclosure. The most common causes of unintended pressure imbalances are leaking HVAC ducts, restrictive HVAC return air pathways, combustion appliance draft, and mechanical ventilation.

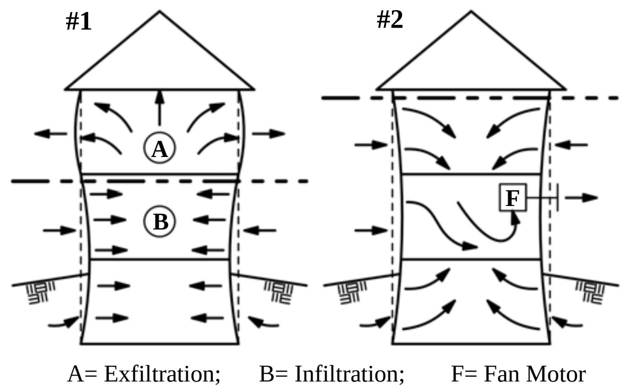

Figure 2. Air infiltration patterns with and without the operation of a kitchen exhaust system. Scenario #1 depicts the stack effect in a house under natural winter time conditions. Scenario #2 depicts how mechanical exhaust can alter the pressure pattern creating a negative pressure throughout the house.

Kitchen exhaust is one of the most common types of mechanical ventilation. It is typically operated intermittently by the building's occupants to evacuate heat, moisture, and kitchen odors. The fan may be in operation anywhere from a few minutes to a few hours.

In order to operate efficiently and without adverse effects, the fan requires a constant source of air to exhaust. If there is no dedicated source of outside air then the fan will attempt to draw air in from the outside through openings in the building enclosure, including cracks, penetrations, chimney flues and other leakage sites.

INFILTRATING AIR

The infiltration rate of a house depends on weather conditions, equipment operation, and occupant activities. Conscientious engineers and HVAC designers will estimate the air infiltration rate of a

[1] The term "building enclosure" represents the pressure and thermal boundary of a structure. In other words, it is the boundary between conditioned space and the outdoors or unconditioned spaces. Synonymous terms include "building thermal envelope" and "building shell".

home in order to properly size its mechanical systems. To gauge the risk of unwanted pressure imbalances across the building enclosure, it is necessary to have a good estimate of how leaky or how tight the enclosure is.

There are many methods and models available for estimating the quantity of infiltration air. They can be broken into two basic categories: empirical methods and post-construction testing methods.

Empirical Infiltration Estimates

Empirical methods work to estimate total crack area in a house. Many assumptions are needed to perform the calculations accurately. Most calculations are based on criteria such as house square footage, height, geographical location, weather conditions, and construction quality. The accuracy of the calculation depends heavily on the validity of the assumptions.

The ACCA (Air Conditioning Contractors of America) publication "Manual J" has two different simplified empirical methods available for use in HVAC equipment sizing. The ASHRAE (American Society of Heating, Refrigeration, and Air Conditioning Engineers) Handbook of Fundamentals contains more detailed procedures for estimating both infiltration and building pressure.

Blower Door Testing

A more accurate method of determining the quantity of infiltrating air is to measure the actual quantities of air entering or exiting a particular house. In recent years it has become relatively common to perform a blower door test to quantify air leakage levels. Blower door testing has also made its way into building codes and is mandatory in some jurisdictions around the country.

The ASTM E779 and CAN/CGSB-149.10-M86 test procedures require the operator to use an approved portable blower door kit to either depressurize or pressurize the house. Next, a technician takes a series of airflow and differential pressure measurements (relative to the outside). These values are input into computer software to produce a standardized test result.

One common output is known as a CFM50. This is the rate of airflow (CFM) through cracks in house at a house pressure of 50 Pa with respect to the outdoors. To enable a comparison of houses of different sizes, a CFM50 reading can be converted to *air changes per hour* at 50 Pa (ACH50). This is the unit that is used in the 2009 IRC. For more information, refer to the above standards or the PHRC Builder Brief BB0201 *Blower Door Testing*.

HOUSE DEPRESSURIZATION

While the blower door test is a powerful tool for estimating the air leakage of a house, the test procedure is also useful in determining when dangerous house depressurization levels might occur as a result of operating mechanical exhaust equipment.

Depressurization occurs when a building's interior pressure becomes negative with respect to the exterior atmospheric air pressure. Depressurization is typically not a large concern in cases where differentials are less than 3 Pa. The potential for significant depressurization exists in tightly constructed houses with large exhaust air systems.

The typical house built today is significantly tighter than in previous decades. This trend to tighten up houses is largely driven by model building codes, rising energy costs, and educated homebuyers. Local building codes typically require newly constructed houses to install items such as air barrier systems and high-performance windows. Additionally it is becoming more common to find enhanced air sealing instructions for enclosures, within mechanical and energy codes. Fireblocking and water-resistive barrier requirements are also contributing to the increase in house tightness. In addition, Chapter 11 (Energy Efficiency) of the 2009 IRC requires air tightness verification through a visual inspection, or a blower door test at less than 7 ACH50.

Improvements in enclosure air tightness can lead to reductions in initial HVAC system cost and seasonal energy costs, but can also increase the potential for house depressurization. The inclusion of makeup air requirements for large kitchen range exhaust hoods in the 2009 IRC is evidence of increasing concern with regard to the dangers of house depressurization. Based on the authors' experience, it is common for homeowners to install range hood exhaust fans capable of exhausting between 400-1500 CFM of air.

As illustrated in Figure 2 (Scenario #2) when a large exhaust system is turned on without a dedicated source of makeup air, the neutral pressure plane is immediately raised and the house experiences a pressure drop relative to the outside. Negative pressure on the interior of the house will cause air flow across the enclosure. The amount of air flow across the enclosure depends on a combination of weather conditions, the size and nature of the enclosure openings (i.e. cracks, holes, etc.), and the mechanical exhaust rate.

In terms of mechanical systems operation, house depressurization is a function of house tightness and exhaust rate. The tighter the house, or the higher the rate of exhaust, the greater the level of house depressurization will be.

Potential Problems from Depressurization

Unintended depressurization of a house could cause several issues. When the interior pressure of a house is negative with respect to the outside, the NPP is raised, and the majority of the house is infiltrating air. Air will be drawn through any available opening when the pressure differential becomes large enough. This means the air can come from basically anywhere and can be introduced anywhere. Indoor air quality issues can arise when air is drawn from garages, mechanical rooms, and storage spaces. Chemical fumes, exhaust, radon or unwanted outdoor odors can be brought into the house. Additionally, infiltrating air could cause occupant discomfort by creating drafts.

In regions experiencing periods of hot, humid weather, occupants cooling their houses run the risk of introducing moisture into floor, ceiling, or wall cavities. The negative pressure within the house induces inward airflow, drawing moisture-laden air across the exterior wall of an enclosure. If the interior surface of the wall is relatively cold, and the moisture content of the incoming air is relatively high, condensation may form on the interior surface. Prolonged periods of wetting may lead to mold growth and decay of organic materials.

A major safety hazard that can occur due to house depressurization is known as backdrafting. Backdrafting is a term describing the situation where the upward draft of a combustion appliance's chimney or vent is overpowered by negative house pressure. This causes the flow of hazardous products of combustion to reverse and reenter the house as illustrated in Figure 3. This is a concern for fireplaces and fuel-fired water heaters, boilers and furnaces.

Backdraft conditions could result from whole house depressurization, individual room pressure differentials, or natural conditions. At times, the depressurization effects of wind or temperature could be greater than those induced by mechanical equipment. ASTM standard E 1998 compares different methods for assessing the potential for, or existence of, backdrafting and spillage from vented residential combustion appliances.

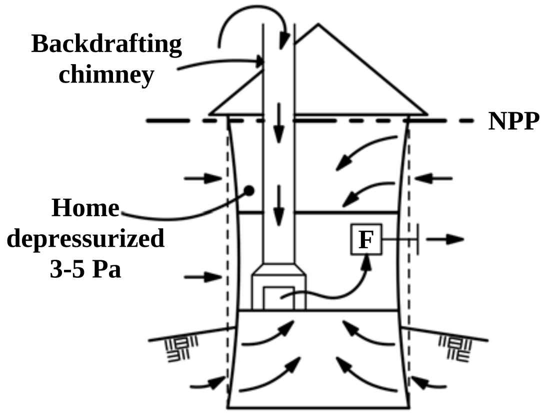

Figure 3. Certain levels of house tightness and exhaust rates may combine to create pressures high enough to cause the draft of combustion appliances to reverse.

The appliances most susceptible to backdrafting are those that rely on thermal buoyancy and naturally-induced drafts. In fact, many experts agree that open-combustion appliances are inappropriate for modern, tight construction. NFPA 54 standard groups these as Category I appliances. Table 1 contains a short list of depressurization limits for several types of appliances and conditions assembled by the Canada Mortgage and Housing Corporation (CMHC) in their document titled, *Chimney Safety Test Users Manual*.

ASSESSING THE RISKS

The 2009 IRC recognizes that make up air may be needed in certain situations. Section M1503.4 requires that makeup air be provided for, "exhaust hood systems capable of exhausting in excess of 400 CFM."

The original proposer of this code provision notes that homebuilders are installing large exhaust hoods with increasing frequency, but provides no data to substantiate the 400 CFM threshold. Using Figure 4 we can determine whether that threshold is appropriate for houses of various tightness levels.

Table 1. Depressurization limits for fuel-fired appliances. Backdrafting risk exists when the listed appliances exceed the corresponding pressures.

Appliance	Chimney Height	Unlined Chimneys on Exterior Walls	Metal Lined Insulated or Interior Chimneys
	Feet	Pressure (Pa)	
Gas Fired Furnace, Boiler, or Water Heater	13 or less	-5	-5
	16-19.5	-5	-6
	23 or more	-5	-7
Oil Fired Furnace or Water Heater	13 or less	-4	-4
	16-19.5	-4	-5
	23 or more	-4	-6
Fireplace (wood or gas)	N/A	-3	-4
Airtight Wood Stove / Fireplace	N/A	-10	-10
Appliances w/Retrofitted Induced Draft Fans	N/A	-15	-15

Figure 4 (next page) is a tool that can be used to estimate the potential for appliance backdrafting as a result of exhaust system operation in a particular house. To do this, one needs to know two pieces of information: 1) the air tightness of the house; and 2) the exhaust rate of the ventilation appliance or appliances. Note that any exhaust equipment operating simultaneously with a large range hood may exacerbate the risks associated with house depressurization.

For example, in a tight house (e.g. 1500 CFM50 on the horizontal axis) with a large exhaust fan installed (e.g. 400 CFM on the vertical axis) the pressure induced on the house would be around -7 Pa. At this level of pressure the potential exists for non-direct-

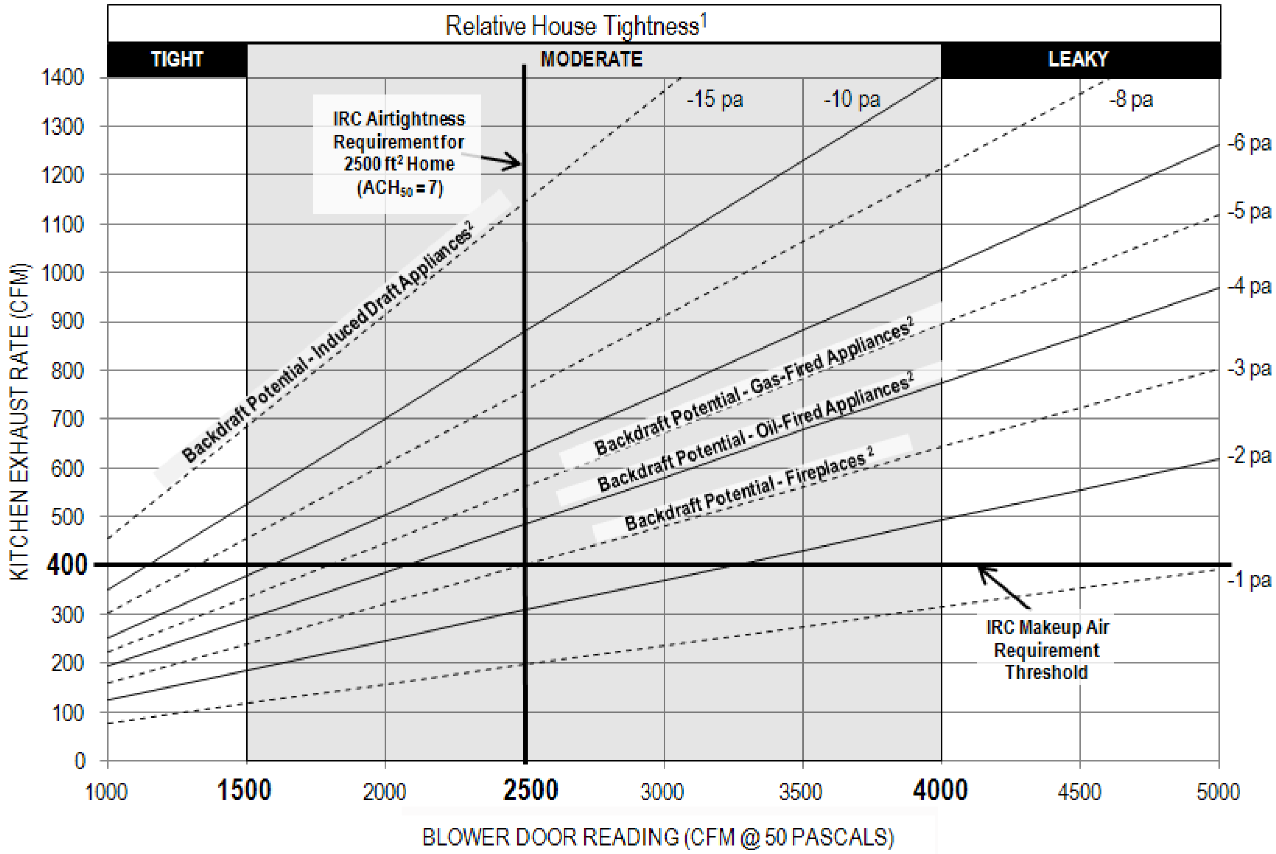

Figure 4. House pressures induced under varying exhaust rates and levels of enclosure tightness. This graph can be used as a tool by builders or HVAC designers to provide a preliminary assessment of the risk of backdrafting fuel-burning appliances. Knowing the relative air tightness, or blower door test results of a house, along with the proposed kitchen exhaust rate, enables a contractor to estimate the pressure that will be induced in that particular house. The pressure levels where backdrafting potential begins are indicated on several pressure curves. These pressure curves are based on what is commonly referred to as the *power law equation*, which appears in the 2011 ASHRAE Handbook of Fundamentals as Equation 40, and in ASTM E779 as Equation 3. This figure was adapted from a graph originally developed by Neil Moyer of the Florida Solar Energy Center.

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1 House tightness designations taken from *ACCA Manual J, Eighth Edition* Envelope Tightness Table 5A for house between 2,000-3000 ft^2

2 Backdrafting potential pressure thresholds taken from, *Chimney Users Safety Test Manual*, Canada Mortgage and Housing Corporation (see Table 1 of this brief)

vent fireplaces and natural draft appliances to backdraft.

Even a moderately tight house with a large range hood runs a risk of fireplace backdrafting. Assuming a blower door test value of 2500 CFM50 (equivalent to the 2009 IRC limit of 7 ACH50 for a 2,500 SF house) and a 400 CFM exhaust system in operation, a -3 Pa pressure will be induced in the house. Note that this example lends support the 2009 IRC's 400 CFM threshold for requiring makeup air, since 400 CFM is the level at which backdrafting potential begins in a house of code-level tightness.

Also note that a very large exhaust system of 1,500 CFM is likely to create appliance backdrafting problems in even the leakiest of houses.

Methodology Limitations

It is important to bear in mind that the above methodology only provides an *estimate* of the potential for backdrafting. In addition, this risk assessment does not account for multiple exhaust systems (e.g. clothes dryers at 200-280 CFM, bath fans at 80-150 CFM) that may be operating simultaneously. These systems may combine to create even greater negative pressures in the house, and increase the risk of backdrafting. In addition, reducing the volume of a space containing combustion appliances may increase the risk of backdrafting. To verify that there is a very low risk for backdrafting, a qualified professional should perform draft, carbon monoxide and spillage tests for all combustion appliances. Alternatively, installing only electric or direct-vent appliances will virtually eliminate risks posed from appliance backdrafting.

CLOSING STATEMENTS

House depressurization can have several undesirable or dangerous consequences, including drawing infiltration air from contaminated or unhealthy sources, radon circulation, and backdrafting of combustion appliances. The nuisance problem of difficulty opening or closing doors may also occur. Without properly designed and installed makeup air, house depressurization may endanger the short-term and long-term health and safety of building occupants.

This brief provides support for the 2009 IRC's requirement for makeup air to be installed when exhaust equipment exceeds a 400 CFM threshold. Given IRC requirements for air sealing, any new house built to code will be in the range of tight to moderately tight construction quality. Installation of large kitchen exhaust systems in these houses could very well result in depressurization levels that are hazardous when combined with the operation of many types of combustion equipment. Even relatively leaky houses may experience dangerous conditions with some of the kitchen exhaust hoods on the market, which sometimes exceed 1,500 CFM.

While the 2009 IRC requires makeup air for large exhaust systems, it provides almost no guidance for *how* it is to be provided. The main installation requirement states that a fan shall be "automatically controlled to start and operate simultaneously with the exhaust system." This leaves it up to the designer or builder to specify an appropriate type of makeup air system. Further, proper installation of the system is important to avoid hazardous conditions and unnecessary construction costs.

The next PHRC Builder Brief will discuss several strategies for properly providing makeup air for an exhaust system. This will include a discussion of effectiveness, efficiency, comfort, and cost.

REFERENCES

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