Addressing Kitchen Contaminants for Healthy Low-Energy Homes

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ABSTRACT

Cooking and cooking burners emit pollutants that can adversely affect indoor air quality in residences and significantly impact occupant health. As building envelopes become tighter, more of these pollutants remain in the living space. Effective kitchen exhaust ventilation can reduce exposure to cooking-related air pollutants as an enabling step to healthier, low-energy homes. This report identifies barriers to the widespread adoption of kitchen exhaust ventilation technologies and practice and proposes a suite of strategies to overcome these barriers. The recommendations have been vetted by a group of industry, regulatory, health, and research experts and stakeholders who convened for two web-based meetings and provided input and feedback to early drafts of this document. The most fundamental barriers are (1) the common misconception, based on a sensory perception of risk, that kitchen exhaust when cooking is unnecessary and (2) the lack of a code requirement for kitchen ventilation in most US locations. Highest priority objectives include the following: (1) Raise awareness among the public and the building industry of the need to install and routinely use kitchen ventilation; (2) Incorporate kitchen exhaust ventilation as a requirement of building codes and improve the mechanisms for code enforcement; (3) Provide best practice product and use-behavior guidance to ventilation equipment purchasers and installers, and; (4) Develop test methods and performance targets to advance development of high performance products. A specific, urgent need is an over-the-range microwave that meets the airflow and sound requirements of ASHRAE Standard 62.2.

Purpose and Scope

The purpose of this report is to develop an agenda to achieve high performance kitchen ventilation or alternative solutions that will significantly reduce the potential negative indoor air quality impacts of cooking-generated contaminants while simultaneously enabling reductions in residential sector energy use. This agenda identifies needs and opportunities for advances through the mechanisms of policy, technology development, public awareness, and building industry tools and training. This report combines a review of the current state of the art of kitchen ventilation with input from industry stakeholders. The focus is on common residential cooking equipment and mitigation technologies suitable for use in new construction, retrofit, and product replacement in existing homes. This is a condensed version of a larger report (Stratton and Singer 2014).

Background

The Purpose of Kitchen Ventilation

The purpose of kitchen exhaust ventilation is to remove pollutants, moisture, smoke and odors generated during cooking; an overview is provided by Parrott et al. (2003).

Pollutant emissions from cooking burners and the cooking of food can substantially and adversely impact air quality in homes. Natural gas burners commonly emit nitrogen dioxide

(NO_2) and under some conditions emit substantial quantities of carbon monoxide (CO), formaldehyde (HCHO) and ultrafine particles (UFP) (Moschandreas, Relwani et al. 1986; Moschandreas and Relwani 1989; Dennekamp, Howarth et al. 2001; Wallace, Emmerich et al. 2004; Singer, Apte et al. 2010). Studies have shown associations between increased exposures to NO_2 in homes and increased respiratory symptoms in children including chest tightness, shortness of breath, wheeze, and increased number of asthma attacks (Garrett, Hooper et al. 1998; Belanger, Gent et al. 2006; Hansel, Breysse et al. 2008). Electric coil resistance burners produce UFP (Dennekamp, Howarth et al. 2001). Cooking activities produce fine and ultrafine particles and a wide range of irritant and other potentially harmful gases including acrolein and polycyclic aromatic hydrocarbons (Fortmann, Kariher et al. 2001; Fullana, Carbonell-Barrachina et al. 2004; Buonanno, Morawska et al. 2009; Seaman, Bennett et al. 2009; Zhang, Gangupomu et al. 2010; Abdullahi, Delgado-Saborit et al. 2013). Gas burners and cooking can also release substantial quantities of water vapor that could contribute to moisture-related indoor air quality problems (Parrott, Emmel et al. 2003). Individual cooking events can produce short-term $PM_{2.5}$[1] concentrations exceeding 300 $\mu g/m^3$ and UFP concentrations exceeding $10^5/cm^3$ (Booth and Betts 2004; He, Morawska et al. 2004; Wallace, Emmerich et al. 2004; Afshari, Matson et al. 2005; See and Balasubramanian 2008; Buonanno, Morawska et al. 2009; Zhang, Gangupomu et al. 2010; Abdullahi, Delgado-Saborit et al. 2013)

Kitchen exhaust ventilation can be provided via any of the following designs: a range hood or other exhaust device – including a combination microwave range hood – mounted above the cooktop (or cooktop / oven combination cooking range); a downdraft exhaust system mounted alongside the cooktop burners; an exhaust fan in the room containing the kitchen; an exhaust fan elsewhere in the home. Kitchen ventilation is most effective when it is closest to moisture and pollutant sources. A range hood, downdraft exhaust vent and potentially even a well-placed wall or ceiling exhaust fan can be much more effective than an exhaust fan placed elsewhere in the kitchen or home.

The functions of pollutant, smoke, and odor removal theoretically can be provided by filtration and air cleaning equipment included in a recirculating range hood, provided through a local kitchen air cleaning device, or incorporated into a household central system. While there are many recirculating range hoods on the market that claim to be effective at removing smoke and odors, and some that claim to remove some pollutants, we know of no residential product that claims to remove CO or water vapor. There is significant doubt concerning recirculating range hoods' efficacy of removal for all these components and pollutants.

Increased Need for Kitchen Ventilation

In homes with low levels of airtightness, the outdoor air infiltrating indoors serves to dilute kitchen pollutants. Building codes and standards across the US are increasingly requiring higher levels of airtightness for residential buildings. For example, the 2012 version of the International Energy Conservation Code (IECC) allows a maximum, blower door-measured envelope leakage of 3 or 5 air changes per hour at 50 pascals (Pa) of pressure difference between inside and outside (ACH_{50}), depending on the climate zone. In homes with these higher levels of airtightness, kitchen pollutants are not readily diluted by infiltrating outdoor air and may remain at unhealthy concentrations within the home if not removed through a local kitchen exhaust.

[1] Particles having a diameter of 2.5 micrometers or less.

Factors Determining Effectiveness

The following elements impact the effectiveness of a kitchen ventilation system:

- **System geometry and equipment type.** Ventilation/filtration equipment location (e.g., above cooktop, adjacent, elsewhere in room), type (e.g. vented range hood, recirculating hood, downdraft exhaust, general exhaust) and operation (e.g., continuous/intermittent, manual/automatic) are key efficacy determinants.
- **Equipment design and performance characteristics.** Exhaust flow rate, hood volume, size and shape, and burner coverage all impact plume capture and pollutant removal.
- **Exhaust ducting.** The ducting beyond the exhaust fan sets the system airflow resistance characteristics that establish the pressure at the exhaust fan at a given airflow.
- **Installation details.** Installation affects fan energy consumption, pollutant removal effectiveness, and noise level, and can substantially impact performance.
- **Use patterns.** Systems must be used to be effective. Use behavior may be significantly impacted by noise.

The elements noted above have important interactions. For example, if the exhaust duct system is designed or installed in a manner that produces high air flow resistance, it is more important to select an exhaust device that operates effectively while connected to ducts with high air flow resistance. High airflow resistance will increase noise, which tends to decrease use and therefore efficacy.

A note on over the range (OTRs) combined microwave/range hood devices. Our hypothesis from our own observations and from talking with building professionals and homeowners around the US is that the OTR microwaves are most commonly installed to operate as recirculating range hoods, as opposed to exhaust devices. Our understanding is that these appliances are commonly shipped with the internal airflow baffles set to recirculation mode and we have anecdotal evidence that some OTRs that are installed with venting to the outdoors may nevertheless be operating as recirculation devices because the internal baffle was not adjusted to direct airflow to the vent. Capture is impeded by the basic design premise of an OTR: flat bottom, small intakes and filters, flow obstructed by the heating chamber, and insufficient depth to extend beyond the front burners.

Kitchen Exhaust Ventilation Currently in U.S. Homes

The major international building codes, on which many U.S. state codes are based, do not require kitchen exhaust ventilation. Since 2006, 2008, and 2010[2] respectively, Oregon, Washington, and California have required kitchen ventilation in their state building codes. Other states may have requirements and, even within states that do not require it, in some areas the inclusion of kitchen ventilation may be an established building practice.

[2] California's 2008 energy code that first required kitchen ventilation did not come into effect until Jan 1, 2010.

Relevant Codes, Standards, and Guidelines

ASHRAE Standard 62.2: ventilation and acceptable indoor air quality in low-rise residential buildings. In the US, ASHRAE Standard 62.2[3] is the most important standard with kitchen ventilation requirements. The 2010 and 2013 versions of this standard require the following for kitchen ventilation:

For intermittent fans:

- Sound must be Home Ventilating Institute (HVI) rated for 3 sones or less at 100 cubic feet per minute (cfm);
- To use the prescriptive duct sizing compliance pathway[4], duct system must meet dimension requirements and fan must be HVI rated for 100 cfm at 62.5 Pa (0.25 inches of water column (IWC)) of static pressure; otherwise
- Fan airflow must be measured as installed to move at least 100 cfm;
- If the fan's airflow is equal to or greater than 5 kitchen air changes per hour (ACH), then the fan may be a local kitchen exhaust fan or a range hood;
- If the fan's airflow is less than 5 kitchen ACH, the fan is required to be a range hood

For continuous fans:

- Must be HVI rated or measured as installed to move an airflow that corresponds to 5 kitchen ACH with a rated sound level of 1 sone or less

For some homes, the procedure for determining the airflow rate to provide 5 ACH for a kitchen is ambiguous. The ASHRAE 62.2 committee is currently considering a proposal that would clarify and simplify that determination procedure.

Portions of ASHRAE 62.2 have been adopted into California building code, and the US Department of Energy's (DOE) Weatherization Assistance Program (WAP) requires contractors to meet ASHRAE 62.2.

ENERGY STAR range hoods. Range hoods can earn an ENERGY STAR rating by moving 2.8 cfm per watt (W) at ≤ 2 sone and having a maximum airflow rate of 500 cfm. ENERGY STAR range hoods must be airflow and sone rated using HVI or ANSI/AMCA test procedures[5].

Home Ventilating Institute (HVI). HVI is a nonprofit trade group that certifies airflows measured using HVI Procedure 916[6] and sound levels measured using HVI Procedure 915[7] and publishes the certified values for a large number of hoods and settings in the HVI Certified

[3] Available at: (http://openpub.realread.com/rrserver/browser?title=/ASHRAE_1/ashrae_62_2_2013_1024).
[4] To use the ASHRAE 62.2 prescriptive duct compliance pathway for new homes, the range hood fan flow must be rated by the Home Ventilating Institute procedures 915 and 916 at 62.5 Pa (0.25 IWC) of static pressure.
[5] http://www.energystar.gov/index.cfm?c=vent_fans.pr_crit_vent_fans
[6] http://www.hvi.org/ratings/Publication_916_09102013.pdf
[7] http://www.hvi.org/ratings/HVI915_091013.pdf

Products Directory[8]. HVI also provides guidance on "minimum" and "recommended" airflow rates for wall-backed and island cooktops[9].

International Residential Code (IRC). The 2012 International Residential Code (IRC)[10] provides specifications, but does not per se require kitchen exhaust ventilation.

International Mechanical Code (IMC). The 2009 IMC provides guidance on the installation of range hoods, but does not per se require kitchen ventilation of any kind.

International Energy Conservation Code (IECC). The 2012 IECC[11] states that mechanical ventilation must meet the requirements of the International Residential Code or the International Mechanical Code.

The IRC, IMC, or IECC has been adopted by multiple US states, in some cases in altered form.

International Green Construction Code (IgCC). The 2012 IgCC states that kitchen ventilation and exhaust systems shall be in accordance with the International Mechanical Code and with additional make-up air requirements for high airflow systems.

Since its inception in 2012, portions of the IgCC have been adopted by several US states and municipalities.

High Performance Homes Programs

DOE Challenge Home. The DOE Challenge Home National Program Requirements (Revision 02)[12] specifies that homes must meet the Environmental Protection Agency's (EPA) Indoor airPLUS Construction Specifications, which in turn require that homes meet ENERGY STAR for Homes or ASHRAE 62.2 requirements for kitchen ventilation.

ENERGY STAR for Homes (ESH). ENERGY STAR for Homes (Version 3.0, Revision 7) requires that kitchen exhaust is vented to the outside of the home. The ESH kitchen ventilation airflow rates are identical to those of ASHRAE 62.2, except that ESH explicitly defines the process of determining kitchen area for determining the required airflow rate.

Like ASHRAE 62.2, ESH allows two compliance pathways: airflow measurement or HVI rated airflow (at 62.5 Pa) alongside the 62.2 prescriptive duct-sizing table. But unlike ASHRAE 62.2, and largely to permit the use of over-the-range (OTR) microwave hoods, ESH currently allows the use of non-HVI-rated fans without requiring airflow measurement.

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8 http://www.hvi.org/proddirectory/index.cfm
9 http://www.hvi.org/publications/HowMuchVent.cfm
10 http://publicecodes.cyberregs.com/icod/irc/2012/
11 http://publicecodes.cyberregs.com/icod/iecc/2012/
12 http://www1.eere.energy.gov/buildings/residential/pdfs/doe_challenge_home_requirementsv2.pdf

Environmental Protection Agency (EPA) Indoor airPLUS. The EPA Indoor airPLUS Construction Specifications[13] (Version 1, Revision 2) (EPA 2013) require that homes meet either ENERGY STAR for Homes or ASHRAE 62.2-2010 requirements for kitchen ventilation.

Leadership in Energy and Environmental Design (LEED) for Homes. The LEED for Homes[14] rating system requires that homes meet ASHRAE 62.2-2007[15] requirements for kitchen ventilation. An extra point is given if the exhaust fan's as-installed flow is measured by a LEED for Homes Green Rater[16].

Passive House Institute US (PHIUS). Passive House certification is solely performance-based, not prescriptive, and has no requirements for kitchen ventilation per se. Based on conversations with Passive House representatives, we understand that the recommended approach to kitchen ventilation in passive houses is to use a recirculating range hood and include an Energy Recovery Ventilator (ERV) or Heat Recovery Ventilator (HRV) inlet in the kitchen to provide continuous exhaust[17].

Current Gaps in Kitchen Ventilation Codes, Standards, and Ratings

Pollutant Capture Efficiency

Current best practice for dealing with kitchen contaminants is to have and use a venting range hood that efficiently captures contaminants generated during cooking. There currently are no requirements, nor even a standard test method related to the effectiveness of residential range hoods at removing pollutants and moisture. Capture effectiveness varies widely with the hood morphology, installation location, airflow, and other characteristics (Madsen, Breum et al. 1994; Li and Delsante 1996; Li, Delsante et al. 1997; Lim and Lee 2008; Rim, Wallace et al. 2012).

Measurements in homes and in laboratory testing indicate that many range hoods have highly varying capture efficiency (CE) for burner exhaust pollutants, depending on the fan speed and whether the front or back burner is used (Delp and Singer 2012; Singer, Delp et al. 2012). Many hoods have substantially higher capture efficiency when cooking occurs on back burners compared with front burners.

Current codes and standards implicitly suggest that kitchen ventilation efficacy at removing pollutants is determined by airflow rate.

Recent research on kitchen pollutant capture efficiency (CE) (Delp and Singer 2012; Singer, Delp et al. 2012) suggests that while there is a correlation between a range hood's airflow rate and its CE, the two are not synonymous. At the same airflow rate, CEs of tested range hood models varied by as much as 3x. These performance variations are assumed to result from variations in hood morphology (e.g., flat, shallow sump, deep sump) and the extent to which

[13] http://www.epa.gov/iaplus01/pdfs/construction_specifications.pdf
[14] The most recent version of LEED for Homes was published in 2008, with updates in 2009 and 2010. http://www.usgbc.org/sites/default/files/LEED%20for%20Homes%20Rating%20System_updated%20April%202013.pdf
[15] The kitchen ventilation requirements in ASHRAE 62.2-2013 are the same as those in ASHRAE 62.2-2007.
[16] http://www.usgbc.org/homes/green-rater
[17] One simple modification that could improve the efficacy of this approach would be the inclusion of a control in the kitchen to boost ERV/HRV flows during cooking events.

burners are covered. The study's findings suggest that range hood designs with shapes and geometries that facilitate pollutant capture are capable of achieving 80% capture[18] levels at 200 cfm (double the ASHRAE 62.2 minimum and close to the levels recommended by HVI), even for front burners. The study also showed that for the hood with the most effective capture geometry (deep sump, extending over front burners), the marginal CE increase achieved per cfm increase declines markedly after 250 cfm. Thus, for the typical residential gas range[19], a well-designed range hood does not need to move more than 250 cfm to be effective. Higher capacity ranges may require higher airflow rates. Further research is needed to determine the appropriate CE necessary to reduce exposure to cooking pollutants to acceptable levels.

These findings suggest a need for codes, standards, and test protocols that more accurately evaluate a range hood's effectiveness at performing its fundamental function: to remove kitchen pollutants and moisture at a sound level that does not discourage its use. Airflow rate has so far been the de facto measure of range hood performance. A metric that more directly and accurately describes functional performance is needed.

Disparity between Advertised or Rated and Actual, As-Installed Performance

Research in homes (Fugler 1989; Nagda, Koontz et al. 1989; Singer, Delp et al. 2012; Stratton, Walker et al. 2012) has found that installed range hoods often do not move as much air as certified ratings indicate and can be a small fraction of the non-certified advertised values.

We believe the disparity between rated or advertised airflows and measured installed airflows is due primarily to airflow resistance and resulting static pressures in installed duct systems that are significantly higher than those present when the airflow of the fan is rated.

When there is no field-testing to verify the exhaust flow rate, ASHRAE 62.2 requires rated airflows to be tested using the HVI 916 test procedure at 62.5 Pa (0.25 IWC), which is believed to be a reasonable estimate of the static pressure in a typical installed residential ventilation duct system. However, at the time of this writing, only 5 of the 3694 range hoods listed in the HVI ventilation products directory (HVI 2013) have rated airflows for 62.5 Pa of static pressure.[20]

The advertised airflow values in products without certified ratings appear in many cases to be free air delivery, i.e., the airflow generated by the fan without any restriction. Clearly this is not representative of the installed conditions under which the fan will operate.

Use of Kitchen Exhaust Ventilation in U.S. Homes

There are very limited data about the use of kitchen exhaust ventilation in U.S. homes. The California Energy Commission's research programs have supported survey based studies on kitchen ventilation practices in California (Piazza, Lee et al. 2007; Offermann 2009; Klug, Lobscheid et al. 2011; Mullen, Li et al. 2013). The Piazza et al. study (2007) surveyed range hood use in new California homes and found that when using the cooktop, 28% of respondents always use the kitchen exhaust fan/range hood, 32% only use it when odor or humidity seems to be an issue, 26% "sometimes" use it, and 13% rarely or never use it. When using the oven, 15%

[18] Capture efficiency expressed as an approximate percentage of the relevant pollutants captured by the range hood
[19] Total capacity of all burners and oven < 60 kBtu/hr (63.3 Mj/hr)
[20] The vast majority (92%) of the HVI range hood airflow ratings are at 25 Pa (0.10 IWC).

of respondents always use the kitchen exhaust fan/range hood, 12% only use it when odor or humidity seems to be an issue, 15% “sometimes” use it, and 56% rarely or never use it. Klug et al. (2011) reported that 40 to 60% of respondents indicated that they did not have a window open and did not use a range hood while cooking. Mullen et al. (2013) reported that among those who said they used their kitchen exhaust system regularly, the top three reasons cited were to remove smoke, odors, and steam/moisture. Among those who reported not using their exhaust regularly, reasons cited were “not needed”, “too noisy”, and “did not think about it”. A minority of respondents reported routinely using kitchen exhaust when cooking. Forty percent reported using it “as needed”; but the meaning of “as needed” is subjective and likely varies across respondents.

The Market Perspective

Achieving the objective of effective management of kitchen contaminants in residences – either through kitchen ventilation or alternative, air-cleaning technologies – is both a market transformation and a technical challenge.

At present, the two largest market players responsible for establishing demand for kitchen ventilation are the public and bodies responsible for building codes and standards. These groups on the whole appear to have a limited appreciation of the need to manage kitchen-associated moisture and pollutants for indoor air quality and health protection. For those who recognize the need, established metrics or systematic information about pollutant and moisture removal effectiveness of products and system designs are lacking.

In the absence of code requirements, and with homebuyers in many areas not recognizing kitchen exhaust ventilation as an essential building service, the home building and renovating industry has little incentive to incur (and thus have to recover) the costs of providing more effective kitchen exhaust ventilation systems.

Demand for OTRs. The most broad-based demand signal in the area of kitchen ventilation appears to be the desire of homebuyers for over-the-range (OTR) microwaves. This demand is inferred from the large fraction of new and recently built homes that feature these appliances (Klug, Singer et al. 2011) and affirmed by webinar participants with knowledge of the market.

In reviewing web-based marketing materials – including manufacturer and retailer web sites and product reviews – we found little attention paid to the performance of OTR microwaves as range hoods. It is relatively common for the product specifications to list only a single airflow (at the highest setting) with no information provided about loudness. These advertised airflows are not HVI-rated and at least some products appear to advertise the fan’s free air delivery.

Driving demand for effective ventilation. Without a market driver for devices that achieve high or even moderate performance for pollutant and moisture capture, innovation is challenged.

Pathways to create a robust demand for effective kitchen exhaust ventilation products include (1) establishing codes and standards with appropriate performance-based requirements and (2) raising awareness of the importance of kitchen exhaust ventilation and specifically of the performance characteristics that impact effectiveness for indoor air quality protection. The public education required to achieve the second pathway should also help with the first.

Current innovation in kitchen ventilation is focused on products designed to complement high-end, high-capacity ranges. To have a broad effect on health, the efficacy of mid- and base-level models including OTRs must be improved as well.

Recommendations

The following section begins with our recommendations for key Objectives to bring about a transition to reduced kitchen pollutant exposure in homes. Each Objective is supported by one or more Actions, Research topics, and Technologies. The first major section comprises Objectives; Actions; and Research, Development, and Deployment needed to transform the kitchen ventilation market. The second major section identifies Technology Developments needed to improve kitchen ventilation systems in homes and to ensure their effectiveness.

Market Transformation Objectives

- Expand awareness of the importance of kitchen ventilation and increase its use.
- Publicize existing guidance for building professionals on the basics of kitchen ventilation
- Develop guidance on best practice designs and equipment specifications.
- Provide better performance information and guidance to purchasers of kitchen ventilation products.
- Improve and expand accessibility of guidance for installers and inspectors.
- Raise awareness of kitchen ventilation requirements of ASHRAE Standard 62.2.
- Establish capture efficiency as a key performance measure for range hoods.
- Promote and support development of automatic operation technologies for kitchen ventilation.
- Develop tools and guidance to expand commissioning of kitchen ventilation systems.
- Increase the number of new homes built with vented kitchen exhaust.
- Incorporate effective kitchen ventilation as a standard element of energy retrofits.
- Develop and demonstrate kitchen ventilation systems for low- and zero-net-energy, high performance homes.

Specific Actions

- Make kitchen ventilation required in the IRC, IMC, IECC, IgCC, Uniform Mechanical Code (UMC), and mechanical codes at state and local levels.
- Increase awareness of third-party airflow rating certification; ensure that best practice guides and home performance standards specify airflows certified at an appropriate static pressure.
- Facilitate development and adoption of standard method of test for capture efficiency (pollutant removal effectiveness).
- Incorporate capture efficiency into standards including ASHRAE 62.2, ENERGY STAR label for range hood products, and high performance home standards.
- Align Home Ventilating Institute (HVI) airflow test and sound procedures with ASHRAE standard 62.2 prescriptive compliance pathway to achieve effective performance of installed range hoods.
- Incorporate automatic operation into best practice guides and high performance home standards as products are determined to be reliable based on standard test method.

Research, Development, and Demonstration

- Develop and demonstrate effective methods for commissioning range hoods.

- Characterize in-field use and performance of range hoods.
- Develop a comprehensive contaminant removal effectiveness metric.
- Improve or validate ASHRAE 62.2 “deficit make-up” approach for existing buildings.
- Evaluate reasonable combustion safety allowance for timed auto-off kitchen ventilation.
- Develop standard test method and performance metrics for automatic operation.
- Re-evaluate kitchen ventilation and moisture removal.
- Evaluate potential for effective unvented range hood.

Technology and Product Development Roadmap

- Develop ASHRAE 62.2-compliant microwave range hoods.
- Expand the selection of quiet, effective, affordable and energy-efficient range hoods.
- Establish automatic range hood shut-off to reduce hazard associated with natural draft combustion appliance backdrafting.
- Integrate kitchen exhaust into smart ventilation systems for residences.
- Ensure performance through on-board diagnostics.
- Develop effective range hoods with automatic operation.
- Establish effective low-energy kitchen ventilation options.

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