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Ventilation and the Indoor Environment

Canada

Ventilation and the Indoor Environment

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Également disponible en français sous le titre :
La ventilation et le milieu intérieur

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This publication can be made available in alternative formats upon request.

Publication date: March, 2018

Cat.: H144-54/1-2018E-PDF
ISBN: 978-0-660-25488-3

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EXECUTIVE SUMMARY

Canadians spend approximately 90% of their time indoors. Efficient ventilation helps improve indoor air quality (IAQ) as it reduces pollutant and moisture levels that may directly or indirectly result in poor occupant comfort and/or adverse health effects.

Residential ventilation may occur naturally or mechanically. Occupants generally have little control over natural ventilation, aside from opening and closing windows. Ventilation solely by window opening can lead to excessive energy costs, particularly due to heat loss in the winter or loss of conditioned air in the summer. Window opening can also create challenges in managing relative humidity in the winter and summer.

Mechanical ventilation is an important tool for supplying fresh air to Canadian homes, and is required to achieve good IAQ in air tighthouses. There are several types of mechanical ventilation systems including exhaust-only, supply-only and balanced systems, and their selection depends on the nature of the house, its occupants, and the budget available. Exhaust-only systems are a good choice when looking for a simple, relatively inexpensive and easily installed method of mechanical ventilation, which still remains one of the most widely used systems in Canadian houses. Supply-only systems are also available, but are rarely used in Canada as they have issues that impact their ability to be effective in newer, more tightly-built homes. In general, the more effective mechanical systems are balanced systems which are calibrated to balance the exhaust and supply air flows. These include 1) basic balanced systems which are rarely used due to technical and operating limitations, as well as 2) heat recovery and 3) energy recovery systems which capture heat and humidity during their operation, allowing a better control of indoor air quality conditions.

Several factors can affect ventilation in homes. Occupant activities, airtightness, seasonal changes, location of the home and the presence of pollutants in outdoor air can all impact the quality of the air found indoors.

PREAMBLE

Canadians spend approximately 90% of their time indoors. While the first step to ensure good indoor air quality (IAQ) is to reduce indoor sources of pollution, ventilation is also an essential strategy. Proper ventilation reduces pollutant and moisture levels that may directly or indirectly result in poor occupant comfort and/or adverse health effects.

Residential ventilation is complex due to the high number of types of systems and approaches to ventilating homes. This document provides technical information regarding ventilation systems in residences, and discusses popular ventilation systems used in Canadian homes as well as factors that can affect ventilation.

A sound understanding by public health officials, home inspectors, and building professionals of how the various types of residential housing ventilation systems work, along with their advantages and limitations, can help provide meaningful advice to occupants regarding the selection and operation of these systems.

For the purpose of this document, a *residence* is described as a detached house, duplex or row house having its own individual heating and ventilation equipment. *House*, *home*, and *residence* are used interchangeably. The National Building Code uses the term *dwelling unit* rather than *residence*.

INTRODUCTION

In this document, the term *ventilation*, which has many different interpretations, describes the movement of air into or out of houses. The term *house envelope* (or *building envelope*, which is also used), “includes all the building components that separate the indoors from the outdoors [and includes] the exterior walls, foundations, roof, windows, and doors,” as defined by BC Housing (2011).

Natural ventilation describes the air flow caused by pressure differences between the inside and the outside of the house through intentional openings in the building envelope. Infiltration is also due to pressure differences but occurs unintentionally through cracks in the building envelope. The amount of air movement from natural ventilation and infiltration is usually hard to predict. Mechanical ventilation refers to air flows intentionally created through the use of fans, ducting, and designed openings in the house envelope. These include devices such as exhaust fans, clothes dryer exhausts, range hoods, and heat or energy recovery ventilators.

A century ago, Canadian houses had excessive natural ventilation in winter, resulting in drafts, dry air, and high fuel consumption. Due to an increased focus on reducing heat loss, buildings in Canada have become more air tight. Passive ventilation is generally no longer sufficient and building codes now require some form of mechanical ventilation.

This document outlines the following basic elements of ventilation in Canadian houses:

- Strategies to maintain acceptable IAQ;
- Natural ventilation, including house air leakage, and air pressures inside and outside the house;
- Mechanical ventilation and the different available options, each with their benefits and drawbacks, including a description of related issues such as system maintenance, filter selection, and ventilation system controls; and
- Factors affecting ventilation needs and efficiency in Canadian houses.

This document also describes the basic concepts of air quality and house ventilation. Whether the interest is in planning, building, buying or retrofitting a house, this resource explains ventilation system configurations and functions. A table at the end of this document (Appendix 1) summarizes the ventilation choices available to most Canadians.

STRATEGIES TO MAINTAIN ACCEPTABLE INDOOR AIR QUALITY

Recent studies of Canadian activity patterns show most of our time is spent in conditioned spaces[1] or enclosures where the indoor air may differ from that of outside. Homes are the conditioned spaces where most time is spent, followed by offices, schools or workplaces and commercial establishments, as well as cars and buses (Matz, Steib and Brion 2015). As such, for the majority of Canadians, the quality of air inside homes and workplaces/offices has the greatest impact on individual exposures to air pollutants. Children, elderly people, and other vulnerable populations are at a greater risk of adverse effects from poor IAQ than the average homeowner.

There are many strategies available to maintain and improve IAQ in homes. The first strategy recommended by Health Canada is to minimize sources of indoor air contamination. Examples of indoor source control include not smoking; ensuring proper maintenance of all fuel-burning appliances (e.g. fireplaces, stoves); avoiding car idling or generators operating in the vicinity of windows, doors, and air intakes; avoiding the use of barbecues or any other combustion equipment in attached garages; controlling humidity levels and avoiding dampness indoors (e.g., by repairing water leaks); using low level emitting volatile organic compound (VOC) consumer products and building materials; and limiting or avoiding the use of products such as candles and deodorizers.

The second most important strategy for improving IAQ is to ensure efficient ventilation to introduce outside air into the building and exhaust polluted indoor air in order to remove or dilute it. Bringing in relatively clean outside air and mixing it with indoor air will reduce concentrations of gas-phase pollutants that have accumulated inside. There are many standards and codes that specify the minimum amount of outdoor air that should be supplied to the house to achieve good IAQ (ASHRAE 2016a, 2016b; CAN/CSA 2014; NBC 2010). These standards and codes vary somewhat and are often expressed in different units. The Canadian ones are expressed in metric units of litres per second (L/s). Generally, they require ventilation rates of about 5 to 10 L/s of outdoor air for each house occupant or roughly a complete house air change every three hours, but these rates vary according to the number of occupants, house volume, occupant activities, and the presence of indoor sources of pollutants. In a typical house, these target ventilation rates are established to dilute air pollutants generated within the house (including carbon dioxide, humidity, and odours) as well as some pollutants off-gassing from the house structure, building materials, furniture, and consumer products. However, in the case of a home located in an area with poor outdoor air quality, increasing ventilation may not improve IAQ. Ventilation could then be scheduled during periods of low outdoor pollution levels (e.g., non-rush hour periods or when smog levels are low).

The third strategy is to remove pollutants that are already in the air through the use of air cleaners or filtration. Filtration is most effective for pollutants such as particles and has been shown to be an effective method for reducing the risk of particle-related mortality (Fisk and Chan 2017). Filtration appears to have contributed to improvement in lung function in a study

[1] Conditioned spaces refer to indoor environments where the air may be warmed, cooled, humidified, dehumidified and/or filtered.

examining smokers who used an electrostatic precipitator to remove airborne particles (Weichenthal et al 2013). It should be noted that filtration/air cleaning can be expensive or ineffective for gaseous indoor air pollutants such as carbon monoxide.

This document deals primarily with the ventilation of houses as a means to manage IAQ, though it will also touch on filtration issues. Health Canada and other agencies have produced several documents regarding source control and other approaches to achieving good IAQ (Health Canada 2016, 2015a, 2015b, 2015c, 2015d, 2014).

NATURAL VENTILATION

Ventilation is caused by a difference in air pressure between the inside and outside of the home. Air moves from areas of high pressure to areas of low pressure. This is easily achieved with mechanical ventilation—usually a fan—which creates a pressure differential that moves air through openings in the building envelope, such as a duct leading into or out of the house. Natural ventilation is far more complex as this pressure differential can be generated by several factors, including temperature difference between the air inside and outside of the house, wind blowing against the side of the house, and direction of wind blowing.

Both house *air leakage* (i.e., infiltration) and *airtightness* are terms used to describe unintentional air movement into and out of houses. An open door or window in a house is a large opening or leakage area through which air can enter or leave. A screen in that opening will slightly reduce this air flow. An open chimney for a fireplace, furnace or a fuel-fired water heater is also a large leakage area, as is a dryer exhaust vent without a backdraft damper.

The more inconspicuous and difficult to see leakage areas are the cracks and joints in the building envelope. These unintentional openings and other air leakage paths contribute to the overall leakiness of the house envelope. For instance, even if window glass is impermeable to air, there can be air leakage where the glass meets the frame, and through the window weatherstripping and the window frame built into the house. In general, the leakage area of newer energy-efficient houses will be significantly smaller than that of older, less airtight houses.

A method referred to as a blower door test is used to quantify unintentional leakage areas (CAN/CGSB 2005). Improvements in construction practices have reduced these unintentional leakage areas by up to 90% in the last several decades (Parekh, Roux and Gallant 2007). Nonetheless, even when all the windows are closed, there are leakage areas in various places in the house envelope which allow air to move, resulting in natural ventilation.

The difference between the air pressure indoors and outdoors will produce ventilation by infiltration (movement of air from the outside to the inside of the building) typically at ground or lower levels, and exfiltration (movement of air from inside of the building to the outside) typically at upper levels, through cracks and openings in the building envelope. If a window is opened slightly and air enters the house, then the house is said to be under negative pressure. If air leaves through the open window, this means that the air pressure inside the house is higher than outside, and the house is under positive pressure.

Wind pressure can be both positive and negative. Wind creates positive pressure outside the building on the windward side, forcing air inward, and negative pressure on the leeward side and over the roof, drawing air outward. The extent of the infiltration and exfiltration of air will depend on how sheltered the home is to the wind, wind velocity, and airtightness of the building envelope. As ventilation rates vary with wind speed and direction, the magnitude of natural ventilation is difficult to predict. However, in Canada, the largest contributor to infiltration is the temperature difference between the inside of the house and the outside causing in a phenomenon called stack effect.

This is created by differences in air density and buoyancy. In winter, stack effect occurs when a warm home is surrounded by colder, denser outside air. Cold air will enter the home near the bottom and warm air will exit through leaks, cracks, and open windows closer to the top. Therefore, the house acts like a chimney or stack, moving air in a way similar to such a structure. Stack-induced infiltration is usually a far greater ventilation factor than wind due to the significant temperature differences between the inside and outside of the building (Reardon 2008). In the spring or fall, when differences between indoor and outdoor temperatures are small, stack pressures may be almost completely absent (Haysom and Reardon 1998). Air leakage from wind can be the dominant ventilation factor on a windy day in spring, summer, and fall, when stack effects are lower.

MECHANICAL VENTILATION

Several types of mechanical ventilation systems are used in Canadian houses to increase ventilation and improve indoor air quality. These include:

- Exhaust-only systems
- Supply-only systems
- Balanced systems (combined exhaust and supply)
    - Without heat recovery
    - With heat recovery
        - Heat recovery ventilators (HRVs)
        - Energy recovery ventilators (ERVs)
- Forced air furnaces
- Combinations of these systems

Appendix 1 summarizes these ventilation equipment options.

Exhaust-only systems

Among the three main categories of mechanical ventilation systems, the exhaust-only system (e.g., bathroom exhaust fans, vented kitchen range hoods) still remains one of the most widely used systems in existing Canadian houses, where pollutants from more highly contaminated or humid areas, such as bathrooms and kitchens, are removed at their source. It is an efficient way to minimize IAQ problems. The exhaust-only system is a requirement of the National Building Code. Household appliances such as dryers, power-vented water heaters, and central vacuum cleaning systems can also exhaust significant amounts of air.

Exhaust-only systems are simple, relatively inexpensive, and easily installed. However, since the replacement air is supplied by air leaks and is therefore uncontrolled, it can carry pollutants from outdoors or from construction materials in the wall cavities and the attic, and possibly soil gases such as radon. These systems depressurize the interior of the house as they remove air from the building. While using a vented kitchen range hood is a good method for increasing ventilation in the home, it is important to ensure that the hood is provided with an appropriate makeup air system (Holladay 2013). A combination of airtightness and exhaust flows producing high levels of house depressurization (e.g., 5 Pa) can cause backdrafting in appliances that use chimneys for venting (e.g., open fireplaces, natural draft water heaters) (CMHC 2004b). Failure to provide sufficient makeup air can result in air being drawn through water heater flues or wood burning chimneys via backdrafting, though some homes may have valves installed in the exhaust path to prevent backdrafting. The use of combustion spillage-resistant appliances (e.g., sealed combustion appliances) helps avoid this situation. Depressurization-related problems can be prevented by supplying sufficient makeup air via open windows, air intakes or intake fans, however, this can significantly complicate both system installation and operation. If there is a need to exhaust and supply air simultaneously, it is preferable to install a balanced system.

Another limitation of exhaust-only systems is that ventilation may be restricted to rooms where exhaust fans are installed. To be effective for the house as a whole, such a system requires a simultaneously operating air distribution system. This could be as simple as the circulation fan of the furnace being set to run continuously while the exhaust fan is on; however, many exhaust-only systems have no wired connection to a furnace or a central air distribution system. This can be achieved by having a professional install a fan cycler to connect the exhaust fan to the furnace circulation fan.

A further shortcoming of exhaust-only systems is that they are used sporadically in most Canadian houses. Studies on ventilation and air quality testing in houses have indicated that bathroom exhaust fans are not used for long periods of time, if at all. On average, bathroom fans are operated under 30 minutes a day, and range hoods 15 to 45 minutes a day on average (Van Ryswyk 2017, unpublished). In winter, excessive operation of exhaust-only systems can lead to increased heating costs.

Central exhaust is another exhaust-only option. This consists of either multiple ventilation fans wired together or a single exhaust fan ducted to many rooms (e.g., three bathrooms). Such systems are now rarely used in Canadian single family dwellings even though they provide more comprehensive ventilation than independent bathroom and kitchen fans. They are more complex and expensive to install. In addition, central systems also increase the potential for backdrafting and promote soil gas entry (e.g., radon) as they tend to move more air than a simple bathroom fan. In the past, central exhaust systems were located far away from quiet areas of a house to minimize noise. Today, quieter exhaust fans are available, making remote fan installation less important.

In summary, exhaust-only systems have the following benefits:

- They can be inexpensive and simple to install.
- They can remove indoor-generated pollutants at the source.
- Higher quality fans can be quiet and discreet.
- They can be relatively inexpensive to operate and require little maintenance.

However, they have the following drawbacks:

- They depressurize the house, which can lead to the infiltration of soil gases (such as radon) and/or backdrafting of combustion appliances.
- The replacement air will enter the house through unintended pathways such as cracks and holes. This may not provide a clean source of fresh outside air, and may cause local discomfort to house occupants and lead to the degradation of the building envelope.
- They require a distribution system to provide fresh air to all parts of the house.
- Their impact on ventilation rates is difficult to predict due to the variability of the sources of incoming air.
- As common exhaust-only appliances (such as bathroom fans and kitchen fans) are not recognized by occupants as a ventilation system, they are only used sporadically in most houses, leading to under-ventilation in tighter homes.

Supply-only systems

Unlike exhaust-only systems, supply-only systems pull air into the house by a fan, pressurizing the indoor space. This results in warm, moist house air leaking out of all cracks and holes in the house envelope during the winter months. As this warm, moist air comes into contact with colder surfaces as it leaves the house, condensation and mould problems may occur, possibly leading to damage to the building envelope and/or IAQ issues.

A detailed description of supply-only systems will not be provided here, as they are rarely used in Canada. Almost all supply-only systems installed in Canada are inlet ducts delivering fresh outdoor air to the return air duct of a furnace. They do not ventilate adequately because (1) the flow rate is generally too low; (2) the cold air brought in from outside can cause condensation problems on the furnace heat exchanger; and (3) the furnace fan has to be on continuously for proper air distribution to all rooms. On the other hand, these systems are very effective when the required ventilation rate is low; therefore, supply-only ventilation is a simple cost-effective option that should not be readily dismissed. Pressurization of the house can be controlled by existing openings such as exhaust fan discharge ducts and gravity chimneys. The advantages of these systems are the low cost and maintenance requirements. They are not recommended for tight new structures, but are an attractive retrofit option for older homes.

Balanced systems

Unlike exhaust-only and supply-only ventilation systems, balanced systems create both exhaust and supply (or intake) flows of roughly the same magnitude. Therefore, the house pressure should not change when the system is operating since the amount of air flow in or out of house leakage areas is unaffected by the ventilation system. This type of ventilation system should always be calibrated upon installation and regularly tested to ensure it remains balanced over time.

Basic balanced ventilation systems

Basic balanced ventilation systems both supply and exhaust air through the house envelope at approximately equal flow rates. This can be accomplished with two fans, one pulling air into the house and one exhausting air out of the house. The system could also consist of an exhaust fan connected to a return air duct system. Some systems also incorporate a mixing box where incoming air and exhaust air are combined, transferring some of the heat from the exhaust air to the incoming air. However, these systems have several problems. It is not clear how much fresh air is being delivered to the house, and how much is being exhausted as soon as it comes in. These systems are also prone to frost/condensation in winter. Basic balanced ventilation systems will not be discussed any further, as they are rarely used and have been upgraded to include heat recovery.

Heat recovery systems

There are two main categories of balanced systems currently being sold: heat recovery ventilators (HRV) and energy recovery ventilators (ERV). They both transfer heat from the outgoing air stream to the incoming air stream. The ERV also transfers moisture from the more humid air stream to the drier air stream. With new homes becoming increasingly airtight, building codes have been revised to require the supply and distribution of fresh air and the removal of stale air to prevent indoor air quality problems. This has led to a steady increase over the past 10 years of HRV/ERV installations in new home construction.

<u>Heat recovery ventilators</u>

Heat recovery ventilators were developed for air tight houses that require mechanical ventilation systems to maintain adequate IAQ. An HRV has a lower operating cost than other ventilation systems while providing the same amount of air flow (CMHC 2015). In winter, heat from the exhaust air is transferred to the incoming air stream, thus warming the fresh air and reducing heating costs. When it is warm outside and heating is not required, the HRV reverses this heat exchange process, removing some of the heat from the incoming fresh air and transferring it to the outgoing stale air, which helps to keep the interior cooler. By removing some of the heat from the incoming air, most HRVs also reduce the load on the air conditioner, which also reduces cooling costs. However, any mechanical ventilation system used during the summer can increase house humidity, generating extra work for the air conditioner. To avoid excessive indoor humidity in summer, it is preferable to use an ERV instead of an HRV or a separate dehumidifier.

An HRV system can also dry a house out in winter, which may not necessarily be a good thing. For instance, if a house with high occupancy or where several moisture-generating activities take place (e.g., cooking, showering, extensive indoor gardens) has frequent window condensation in winter, then increasing the ventilation rate of the HRV will reduce the indoor relative humidity by dilution with dry outdoor air. If a house already has low humidity, using an HRV can result in overdrying. In contrast, because an ERV transfers both moisture and heat, it does not tend to dry a house out in winter (Lajoie 2015).

Heat recovery ventilators usually come with more sophisticated controls than exhaust-only or supply-only systems, allowing for adjustments to be made to the ventilation rates in the following scenarios:

- a low continuous rate when the HRV is only needed to supplement natural ventilation;
- a higher ventilation rate for high occupancy periods, during activities that generate higher levels of pollutants or during periods of higher relative humidity;
- a predetermined ventilation rate specified for the house by the National Building Code; or
- a selected ventilation rate within the capacity of the HRV.

Heat recovery ventilators usually have a defrost cycle as the heat exchange core can freeze in winter. The water from the defrost system must be led to a drain. Some defrost systems simply stop the supply air fan for a period of time, essentially transforming the HRV into an exhaust fan. Such systems can lead to excessive house depressurization, similar to using a large-capacity kitchen range hood (NRCan 2015; Holladay 2013).

<u>Energy recovery ventilators</u>

Energy recovery ventilators are very similar to HRVs in their construction and operation, with one major difference: ERVs transfer both moisture and heat between the air streams. An ERV can be a better choice for the ventilation of houses that already have low relative humidity in winter. During the winter months, a portion of the heat and humidity of the outgoing air stream is transferred to the incoming fresh air, which helps keep the house relative humidity from decreasing when dry cold outside air is introduced into the house. An ERV can also be a good option in the summer for an air conditioned house with all the windows closed. In this case, the house will still require adequate ventilation, but bringing in unconditioned warm moist outdoor air can lead to indoor relative humidity levels exceeding Health Canada's recommended level of less than 50% (Health Canada 2016).With an ERV, a portion of this outdoor humidity is transferred to the outgoing house air. If there is an air conditioner, it will not need to work as hard to cool and dehumidify incoming fresh outside air, thus reducing cooling costs.

Both HRVs and ERVs require an air circulation system within the house. As they incorporate their own fans, they can be run without using the furnace fan, unlike most exhaust-only and supply-only systems. The use of energy-efficient HRV/ERV fans and air distribution through ventilation system ducting can lead to even lower operating costs. Ducting configured specifically for the ventilation system can also be set up so that exhausts come from areas with lower IAQ (e.g., kitchens, bathrooms, basements) while the fresh outdoor air is delivered to bedrooms or living rooms.

In general, balanced systems are not installed with their own ductwork if there is a forced air furnace (which requires ductwork) in the house. To avoid the expense and complexity of installing separate ventilation ducting, HRV and ERV ducting is usually connected to the furnace ducting system. Air exhausted by the HRV or ERV is therefore overall house air (not from specific rooms) and fresh outdoor air brought into the house is well mixed with the overall house air. Older furnaces often have inefficient recirculation fan motors, meaning that distributing the ventilation air requires a 500 to 800 W furnace fan, instead of the 30 W fan motor integrated into the most efficient HRVs. New furnaces generally incorporate high efficiency fan motors, which are much less expensive to operate. While the homeowner may save on capital costs by connecting the balanced ventilation system to the furnace ducting, flexibility is lost in terms of the supply and exhaust locations for the ventilation. An older and less efficient furnace recirculating fan can also lead to increased operating (electrical) costs.

In summary, HRVs and ERVs have the following benefits:

- They can be the most cost-effective systems to operate continuously.
- They can maintain lower humidity in winter by introducing dry air.

- They can be flexible in terms of where they extract stale air and deliver fresh air.
- They are relatively quiet in operation.
- Newer dual-core systems now exist that allows homeowners to remove the heat transfer core to be either an HRV (best in the summer) or an ERV (best in the winter).

However, they have the following drawbacks:

- They are the most expensive systems to purchase and install.
- They can be complicated to operate and control panels are often not intuitive.
- They require more maintenance than the alternatives and homeowners do not often realize that this maintenance is needed.

Considerations

Selecting an appropriate ventilation system

A ventilation system relies on both the equipment and ductwork to function properly. Each component must be correctly selected and installed in order to achieve the expected efficiency.

For new houses, ventilation system installation must be compliant with the respective provincial building code and done by a certified technician. If given the opportunity while purchasing a house, the homebuyer should first choose between an exhaust-only system and a balanced system. Then the homebuyer must decide whether the ventilation system should have its own ducting or have the ventilation air ducted within the furnace air circulation system. If there is no furnace (e.g., electric baseboards, radiant flooring), then the balanced ventilation system would require its own ducting.

Before retrofitting a ventilation system into an existing house, many questions need to be addressed, including:

- Given the airtightness of the house, what are the air flow requirements for the ventilation system?
- Can ducting be retrofitted into the house?
- What are the costs related to the retrofit and the operation of the ventilation system?

Some jurisdictions mandate the installation of HRVs in new construction, but balanced systems and exhaust-only systems (despite their limitations) may be more applicable to retrofit applications. The ventilation contractor hired by the homeowner must ensure that any installed exhaust-only system does not create house depressurization problems and that it can function properly with the already existing heating and/or cooling equipment.

Maintenance

To function properly, ventilation equipment must be regularly maintained and correctly operated. Exhaust fan maintenance requires nothing more than dusting the fan blades periodically and ensuring that the dampers on the outside grille can open and close properly. Heat and energy recovery ventilators require more extensive maintenance tasks, including cleaning or replacing air filters, clearing air inlets and outlets of any obstructions, cleaning the heat exchange core and the condensate drain and pan annually, and servicing the fans and motorized dampers as required. Research has shown that many people with HRVs or ERVs do not take the time to perform these tasks, even though then can be completed in a matter of minutes. A lack of adequate maintenance will affect the performance of the ventilation system. A 2010 Canada Mortgage and Housing Corporation document details the maintenance requirements for HRVs (CMHC 2010).

Filters

The infiltrating air of an exhaust-only system does not get “filtered”. Some particulates may be removed from the incoming air as it passes through the structure and sheathing of a house, but no true filtration actually takes place. Other contaminants, such as soil gases, may infiltrate into the house due to negative pressure; however, these gases will enter primarily via the foundation. Heat and energy recovery ventilators have an in-line filter to protect the fans and heat exchange cores from dust and debris. These filters must be vacuumed or washed at least every second month so that air flows are not affected. In addition to the filter on the fresh air supply side, there is also a filter on the exhaust side that requires regular cleaning or replacement to keep the heat exchange core uncontaminated. It should be noted that HRV and ERV filters do not remove very small particles as they are only designed to stop insects and large particles from contaminating the unit. Some HRVs/ERVs equipped with high efficiency particulate air filters are now available. For those concerned about the quality of the outside supply air—for example, if occupants suffer from pollen allergies or are affected by nearby sources of outdoor air pollution such as major roadways or contaminated air from neighbouring dwellings—it can be useful to have a more efficient and comprehensive filtration system on the intake side of the HRV/ERV to supplement the filter contained in the device.

Controls

Various control systems may be used in conjunction with house ventilation systems. These include, but are not limited to, timers, humidistats, and carbon dioxide sensors. Some of these systems are not necessarily intuitive for occupants to control. For example, a humidistat activates the ventilation system when the house relative humidity exceeds a threshold level. This control strategy is based upon winter operation where increased ventilation levels will dry out the house. However, when the occupants wish to increase the ventilation, they tend to increase the setting on the humidistat, thereby increasing the relative humidity at which the ventilation system turns on. As a result, the ventilation system will operate less often. In summer, the humidistat is not an effective control device as the outdoor air is often more humid than indoor air. As well, air conditioning use in the summer will lower relative humidity indoors. Increasing ventilation rates in non-air conditioned houses in summer will usually increase house humidity if no dehumidification system is operating.

In newer houses, the ventilation system should be run continuously at low to medium capacity for most of the year. Occupants should be able to easily increase the ventilation when additional capacity is needed. This can be accomplished by running balanced systems at high speed or by supplementing a balanced system with kitchen or bathroom exhaust fans. For exhaust-only systems, variable speed fans can provide this flexibility when higher capacity is required.

If the furnace fan is used for distribution of ventilation air, studies have shown that it does not have to be on continuously for reasonable mixing, but has to be running regularly for several minutes each hour (NREL 2008). A device called a fan cycling controller can be installed on the furnace and programmed to activate the fan to achieve the required minimum air flow beyond what is required for heating or cooling purposes. In this way, the fan cycling controller keeps track of the time the fan is on for heating and cooling. This reduces the time proportionally for supplemental ventilation, thereby reducing energy use.

Passive ventilation systems

Passive ventilation is a relatively new technology developed in Europe, which is becoming more popular in Canada. This technology relies on careful planning of house location, building shape, insulation, and windows as well as taking local climate into account. Passive houses are built extremely tight to maximize energy efficiency. While seeking out additional information on passive homes is encouraged, they will not be a focus of this document.

FACTORS AFFECTING VENTILATION NEEDS AND EFFICIENCY IN CANADIAN HOUSES

Air distribution within the house

Existing air distribution systems have varying degrees of effectiveness. A house without any ducting systems, such as a house heated exclusively by electric baseboards or by radiators, would face several ventilation issues that would make it more prone to poor IAQ. For example, fresh air entering one room of the house, like the basement, may not reach all the other rooms in the house, like a second floor bedroom with a closed door. However, some air will be mixing and moving in the house due to currents generated by factors such as heat, human movement, and door openings. In most cases, air pressure differences between rooms are very small and inter-room air movements will occur by random diffusion. A house with an open architecture will have indoor air that is relatively well mixed. On the other hand, a house with many closed doors and many corridors will have unmixed air in separate spaces. Places with significant infiltration, such as a basement in winter, can be a source of fresh air as long as the soil and surrounding environment are not contaminated. Alternatively, spaces with closed doors (particularly those with very tiny gaps or no gap above a carpet under the door) will have low air exchange rates as compared to the rest of the house, which may result in the build-up of pollutants in isolated spaces. Humans exhale moisture and carbon dioxide in their breath, which can accumulate in bedrooms overnight. Leaving bedroom doors open during the night will help maintain good IAQ by allowing fresh air to enter the room.

Essentially, ventilation air needs to be delivered to occupied rooms. The ventilation system should be designed and operated to achieve this goal.

Occupants

Occupant behaviours and lifestyle will often play a major role in the efficient delivery of natural ventilation air to homes. Use of windows for ventilation purposes is variable and hard to predict as it depends on factors such as odours (indoors or outdoors), the perception of drafts, the presence of outdoor noise, privacy, and security concerns (CMHC 2004a). It ranges from houses with windows that are always open to those with windows that are never opened.

Airtightness

The airtightness of the building envelope is an important consideration, particularly with respect to the requirements for mechanical ventilation. Before retrofitting a new ventilation system into an existing house, it is worth having the house airtightness measured, as the results can help determine which ventilation system would best meet the homeowner’s needs or predict whether excessive house depressurization may be a concern. Conducting an airtightness test can also help identify major leaks and improperly functioning ventilation systems.

Airtightness can become a safety issue when dealing with large kitchen range hoods and other exhaust fans that may contribute to house depressurization. Larger fans (capacity greater than approximately 90–180 L/s [200–400 cubic feet per minute]) require additional venting or ductwork to supply makeup air (Holladay 2013). Without an adequate supply of makeup air, backdrafting of chimneys and gas vents can occur, potentially leading to decreased IAQ and increased carbon monoxide levels. When installing large range hoods or exhaust fans, an installer can help determine the most suitable method of supplying makeup air.

Seasonal changes

During warmer weather, when several windows are open, houses will usually have adequate ventilation which can effectively remove indoor pollutants. It should be noted that in summer, less air will move through window openings as temperature differences between the inside and outside are smaller. However, if the windows are closed (e.g., due to the use of air conditioning), it is likely that tighter houses will be under-ventilated unless a mechanical ventilation system is present. Under-ventilation is also possible in the spring or fall if windows are closed and outdoor conditions are moderate. Inadequate air exchange can cause various environmental problems such as poor IAQ, high humidity, and cold-weather window condensation.

Climate zone/Jurisdiction

Geographic location can have a significant impact on the selection of the ventilation system and its operation. Homeowners living in warmer parts of Canada can leave windows and doors open for a greater part of the year as compared to residents of colder regions of the country, thus allowing them to take advantage of natural ventilation and reduce their energy use. Colder climates require homeowners to use mainly mechanical ventilation to ensure that their homes are adequately ventilated, with HRVs and ERVs likely to be required by local building codes. Canadians living in colder climates are extremely affected by stack effect and require more energy for home heating and mechanical ventilation systems if their house is not airtight.

The fabrication, design, and installation of mechanical ventilation systems and their components are guided by best practices and building code requirements that vary between jurisdictions (BC Housing 2015). Some jurisdictions mandate the installation of HRVs in new construction while balanced and exhaust-only systems may be allowed in retrofit construction. Homeowners should be aware of these jurisdictional constraints when making modifications to their home ventilation systems.

Outdoor air pollutants

The goal of ventilation is to use clean outdoor air to dilute indoor pollutants. However, outdoor air quality can vary considerably depending on geography, time of day, and season. For instance, if the outdoor air has a high concentration of pollens, spores, wood smoke, and various gases, ventilating with outdoor air may be less advantageous and more complicated. Polluted outdoor air can be purified to some extent by intake filters, as they capture large particles but allow fine particles and reactive gases through. During periods of high outdoor air pollution (e.g., smog days), it may be advantageous to decrease ventilation rates (naturally or mechanically) to reduce the entry of outdoor contaminants. It has been shown that adjusting ventilation systems to operate earlier in the morning, prior to high-traffic periods, resulted in significant reductions in traffic-related pollutants in schools (MacNeill et al. 2016). However, some caution should be exercised as reduced ventilation can lead to increased levels of indoor air contaminants.

Local sources of outdoor pollutants are also a determining factor when choosing the location, orientation, and height of air inlets (McKone and Sherman 2003). For example, a barbecue should be kept away from an air intake or an open window to prevent the infiltration of harmful pollutants into the house.

USING VENTILATION TO IMPROVING INDOOR AIR QUALITY

One approach to improving IAQ is to experiment with higher ventilation rates using already existing devices. For example, a home equipped with a forced air furnace already has a system of ducts delivering air to each room and a fan to move this air. Some furnaces also have a fresh air makeup connected to the return air vent of the furnace. If a bathroom or kitchen fan is used to exhaust air from a room, an equivalent amount of fresh air will enter through the furnace or through cracks and holes in the house envelope. If the furnace or the air conditioner is running several times an hour for heating or cooling, then this fresh air will be mixed with the indoor air when refreshing all the rooms. When the heating or cooling system is off, running the fan continuously or via a fan cycling controller will equally mix and deliver fresh air throughout the house. This can be the most suitable solution to ventilation issues. Note that furnaces and their ductwork need to undergo regular maintenance, and that new air filters and periodic cleaning are essential to adequate furnace ventilation. Increasing ventilation can quickly reduce unwanted odours and humidity..

Certain problem areas may require other ventilation solutions. For example, if a particular bedroom is considered too stuffy and the homeowner still prefers the bedroom door closed at night, one possible solution is to run the furnace fan continuously or install a fan cycling controller as discussed above. The ensuite bathroom fan could also run continuously overnight. A quiet fan is optimal for this application—an old, noisy fan can be easily replaced with a low-sone (quiet) fan.

Ventilation options for a house with no furnace fan to mix air are more limited. While opening windows more often is a possibility, this lacks the convenience and reliability (and security) of a mechanical ventilation system.

Retrofitting a ventilation system in a home is complicated—an understanding of the specific home situation and of the factors that affect ventilation therein is essential. It may involve installing an exhaust-only fan, a new furnace system, new ducting, an HRV or an ERV. As the admission of outdoor air will affect heating and cooling loads in the home, any modifications to the home ventilation system must take this into account. These retrofits should be completed by a professional or a person with extensive building or renovating experience.

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APPENDIX 1

Table 1. Common ventilation devices and details regarding cost, maintenance, and overall use

Category	Device	Intended use	Device and installation costs	Operating costs (energy related)	Maintenance requirements	Homeowner acceptance and use
Exhaust-only systems	Bathroom exhaust fan	Exhaust moisture and odours due to bathroom use.	Low.	Low. Some fans can operate at less than 20 W. Use of a timer can minimize operating costs.	Low. Vacuum the ceiling grille periodically.	Commonly accepted. Homeowners reluctant to use noisy fans for extended periods of time.
	Bathroom exhaust fan meeting the code-required house ventilation	Increase house ventilation rate. A mechanical system (e.g., furnace circulation fan) distributes infiltrating fresh air to the entire house. Bathroom vents are sometimes used as an exhaust vent for HRVs and ERVs.	Moderate to high. More durable and expensive fans are needed for this application along with a connection to the house air distribution system (it can become very costly if there is no furnace).	Low to high. Fan operating costs can be low; air circulation costs can be low to high, depending on fan efficiency. As no device recovers heat, it is more expensive to condition air than with an HRV of equivalent flow rate.	Low.	Confusing to installers and homeowners because fan and distribution fan connections are often ignored or poorly made.
	Kitchen exhaust fan	Remove moisture and odours directly over the stove from the kitchen. Non-vented fans just diffuse odours and moisture through the kitchen.	Moderate to high. Varies depending on size/capacity of equipment and complexity of installation. May need makeup air system for high-flow kitchen fans.	Moderate. High flows require equal amount of outdoor air to be conditioned. No heat recovery.	Low. Grille, ducting, and exhaust cap require at least annual cleaning if fan used frequently.	Not usually part of a whole-house ventilation system due to size and location. Could be designated as a house exhaust fan to meet code. Noisier operation than bathroom fans in most cases.

Category	Device	Intended use	Device and installation costs	Operating costs (energy related)	Maintenance requirements	Homeowner acceptance and use
	Central exhaust fan	Additional ventilation. One exhaust fan ducted to multiple bathrooms or other locations.	Moderate.	Low. Relatively low electrical usage but no heat recovery. Use of a timer can minimize operating costs.	Low.	Rare due to newer, more efficient, and quieter bathroom fans.
Supply-only (passive)	Passive supply duct connected to furnace return air ducting	Simple, cost-effective ventilation. Outdoor air is ducted to the return air duct of the furnace; the intake airflow increases when the furnace fan is active. Required as this provides makeup air for a naturally vented gas/oil-fired furnace.	Low.	Low. No heat recovery. Often sized too small for adequate ventilation air entry.	Low. Clean the intake grille every two months.	Once common in Ontario, Saskatchewan, Manitoba, Alberta, and British Columbia. Homeowners usually unaware of its existence. Can lead to cold drafts when the furnace is on. Is not effective when the furnace fan is not in operation.
Supply-only system	Central supply fan	Distribute ventilation air into the house. May include heating element. May be ducted into furnace return air duct.	Moderate. Heating element and controls can increase price.	Moderate. No heat recovery. Heating incoming cold air with electricity can be expensive.	Moderate. Clean the intake grille. Heating devices need at least annual maintenance.	Rare. Not recommended in Canadian houses as it pressurizes the house in winter, possibly leading to moisture damage in the walls.
Balanced systems	Air exchanger	Simple, cost-effective ventilation. Matched exhaust and supply ducting to the house, sometimes mixed in a box.	Moderate. Very basic. Ducting installation necessary.	Moderate. Control is difficult. Quantity of fresh air supplied is difficult to estimate.	Moderate. Clean the intake grille.	Found in Eastern Canada in older houses. Not very effective.

Category	Device	Intended use	Device and installation costs	Operating costs (energy related)	Maintenance requirements	Homeowner acceptance and use
	HRV connected to furnace ducting	Ventilation with heat recovery. HRV ducted to furnace return air ducts.	High to very high. Among the most expensive options.	Low to moderate. Depends on furnace fan and HRV efficiency. Does have heat recovery so heating costs should be lower than other options.	Moderate. Bi-monthly maintenance on filters and grilles. Annual maintenance on core.	Standard ventilation system for all energy-efficient Canadian houses. Systems usually operate continuously. Subsequent owners of house may turn it off. Simple for most homeowners.
	Independently ducted HRV	Ventilation with heat recovery. HRV with separate ducts for exhaust and supply distribution to rooms in the house.	High to very high. Most expensive option; additional costs for ducting.	Low. Can be the cheapest ventilation system to run: saves energy when compared to all other options. Look for high efficiency fan motors for low cost operation.	Moderate. Same as above.	Same as above.
	ERV	Ventilation with heat and moisture recovery. Essentially an HRV with moisture transfer capabilities to reduce indoor air drying in winter and excessive humidity in summer.	High to very high. Equivalent to an HRV.	Low to moderate. Equivalent to an HRV.	Moderate. Equivalent to an HRV.	Equivalent to an HRV.