

Air Ventilation: Health and Environmental Benefits of Fully Dedicated vs. Partially Dedicated Systems



Centrotherm
solutions beyond

By:

Mallory Epstein, BSME

Centrotherm Eco Systems

Executive Summary

Indoor environments play a vital role in the well being of occupants and the outdoor environment. Architects and builders have long prioritized a move towards sustainable infrastructure but are now shifting to an emphasis on indoor elements as the benefits of healthier living environments have come to light. Homeowners place the focus of their comfort on temperature control, but typically stop there without acknowledging the effects indoor air quality has on their wellbeing. Improving air quality can be achieved through mechanical ventilation, like HRV's, by bringing fresh air into the building while extracting inadequate air outside. This report provides an evaluation of the health and environmental benefits of implementing fully dedicated versus partially dedicated ventilation systems in a residential setting.

Partially vs. Fully Dedicated Systems

Fully dedicated systems are comprised of individual ducts designated to specific rooms for both supply and exhaust and therefore provide optimal air circulation. Partially dedicated systems contain delegated extract runs, like that of a fully dedicated system, however the supply air is integrated with existing furnace ductwork rather than individually assigned to specific rooms. These are the most common ventilation systems since the installation expense is lowered by eliminating supply air ductwork, but this comes at the cost of occupant health and excessive energy consumption.

The advantage of separating ventilation from the heating system is that air inlet and outlet valves can be strategically placed to achieve the best airflow based on the layout of the building. Moreover, the volume of air can be dictated for each room, allowing for an optimal indoor environment and subsequently occupant health.

Sustainability

Regarding sustainability, connecting the HRV to the furnace ductwork requires continuous operation of the air handling unit since the ductwork is oversized. This leads to unnecessary electricity consumption, and consequently increases the homeowner's carbon footprint and monthly electricity bill. By comparison, a fully dedicated system has the potential to save over 50 trees and \$300 per year as a direct result of not running the air handling unit continuously. A fully dedicated system can even pay for itself after only four years in some circumstances.

Conclusion

Implementing a fully dedicated system creates a healthier environment, both inside and outside, and should therefore be at the forefront of innovative building design.

Introduction

The average adult takes 20,000 breaths a day (1), so it's no wonder why fresh air is vital to maintain proper health. However, ensuring proper indoor air quality (IAQ) is increasingly harder to achieve due to harmful pollutants and chemicals that lead to adverse health effects. While fresh air is readily available outdoors, studies show indoor air comparatively contains between 2-5 times the contaminants (2). Considering that Canadians spend about 90% of their time indoors (3), it is clear that the importance of indoor air quality needs to be emphasized through improving ventilation. As society pushes for sustainable infrastructure to meet growing energy demands while minimizing environmental impact, it becomes prudent that ventilation systems must be energy efficient.

Background

Indoor air quality was not originally a concern for many homeowners. Before insulation became widespread in construction fresh outdoor air was easily able to enter a building through cracks within windows and walls. Even after the development of insulation, leaky windows served as a mode for fresh air to enter through. Consequently, as air was able to enter a building, heat was able to escape. As the price of oil increased over time, so did the cost of heating a building. This, combined with a growing awareness of the positive environmental impacts of sustainable buildings, paved the way for new insulative technology including tighter windows, sealants, caulking, sprayed foam, etc. Although these developments allowed for buildings to be more energy efficient, they came at the cost of inhibiting the natural circulation of air, ultimately lowering IAQ, and hindering the occupant's health.

Another contributor to poor IAQ comes from the rise of pollutants and chemicals within buildings. These can be found in cleaning and cooking products, aerosols, mold, and building materials. The addition of rugs, furniture, and other absorbing materials trap these chemicals, which can cause lung damage when inhaled over extended periods of time (4).

The impacts of poor air quality extend further than just taking a toll on the lungs. Other physical consequences from extended exposure include worsening asthma, headaches, and fatigue.

With the Coronavirus pandemic, people are not only using more chemicals to clean surfaces but are also staying at home for extended periods of time. Damage to lung health increases one's risk of becoming more susceptible to the virus and developing severe symptoms. On top of that, the virus itself is airborne, with respiratory droplets being detectable for as long as three hours, according to the National Institute of Health (5).

Essentially, there is an increase in indoor pollutants, a lack of air circulation, and a longer exposure to this polluted air. These factors all point to one conclusion, indoor air quality is more important now than ever.

Outdoor air quality has also deteriorated due to pollutants and greenhouse gases, accelerating the rate of climate change. Although there are copious tactics to reduce greenhouse gas emissions, lowering energy consumption by increasing energy efficiency is the key approach since this delivers savings, which will not only pay for itself over time, but can also be used to reinvest in other sustainable solutions.

Maintaining indoor environments consumes over one third of global energy (6) and 43% of all energy use in the United States (7), suggesting that solutions to reduce a building's energy consumption are in high demand, as this would have one of the largest impacts on lowering global energy use. Increasing airtightness (i.e., insulation, caulking, etc.) inhibits conditioned air from escaping, improving the energy efficiency of the building. However, this comes at the cost of indoor air quality, as pollutants become trapped inside. This points to the need for an energy efficient air ventilation system to keep the occupants healthy while lowering the residence's carbon footprint.

Partially vs. Fully Dedicated Systems

Mechanical ventilation systems are a great way to improve indoor air quality. These include forced air furnaces, Heat Recovery Ventilators (HRVs), range hoods, and more. HRVs are becoming increasingly prevalent in new home construction due to their low operating costs and high efficiencies. There are two types of systems that can be installed using an HRV; partially dedicated which consists of either just supply or just exhaust runs, and fully dedicated which is a combination of supply and exhaust runs.

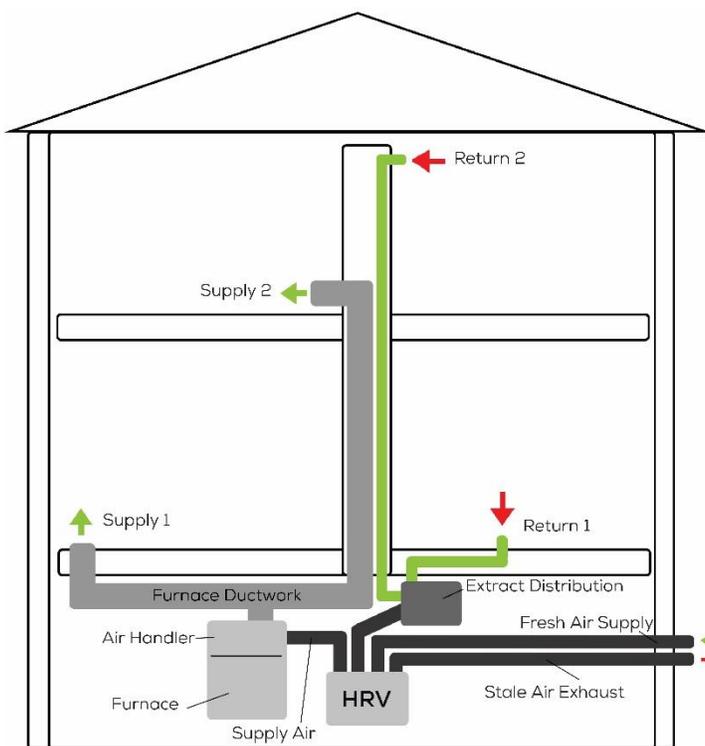


Figure 1: Diagram of a partially dedicated system

Partially dedicated exhaust systems are the most common in Canadian households as they provide an efficient method to increase IAQ while reducing installation costs. Typically, the air supply is interlocked with an existing furnace return duct, while the extract is ducted separately to each highly contaminated and humid room, such as bathrooms and kitchens. The supply air is distributed by the air handling unit of the conditioning appliance. While this system offers a lower installation cost, as it utilizes existing ducts for air supply, there are two major drawbacks compared to a fully dedicated system: depreciated air quality and greater electrical consumption.

Although using an existing ductwork system for the air supply seems like an appealing route, this is actually the contributing factor to both of the previously stated shortcomings. Simply put, furnaces serve a different purpose than HRVs, and are designed to reflect as such. The objective of a forced-air handling system is to provide a substantial amount of warm air throughout a building, whereas an HRV is designed to bring in fresh air and circulate it throughout the building. Ventilation and heating/cooling load needs for each room vary depending on factors including duration of time spent in the room and external wall exposure. For example, large open spaces such as living rooms are a considerable heating/cooling load due to their large exterior surface area but aren't inhabited for long periods of time. This can be easily juxtaposed to a bedroom, a space where more time is spent by inhabitants but has less area exposed to the outdoors and therefore less of a thermal load. Likewise, living rooms naturally receive ample air circulation as a direct result of the open floor layout, whereas bedrooms require further assistance in air movement as a direct result of their closed design and doors being shut most of the time.

In this instance, the ductwork from the furnace to the living room would be designed to handle the larger thermal load, resulting in a greater flow rate of air which is not required for its short occupancy periods. By contrast, the bedroom would inevitably receive less air supplied by the furnace ducts as a direct result of its lower heating and cooling needs despite the need for a larger ventilation rate from its longer occupancy periods. This demonstrates the contrasting nature of thermal versus ventilation demands throughout a building, validating that heating/cooling and air circulation should be implemented as separate systems to achieve an ideal indoor environment.

Air quality would also suffer if the HRV is connected to the air handling unit because of the size of the ductwork attached to the appliance. Furnaces are designed to move much higher amounts of air compared to a residential HRV. Typical flow rates for furnaces and HRVs are around 1500 cfm and 150 cfm, respectively, meaning that there is a tenfold difference in flow rates. Therefore, the ductwork connected to the furnace is much larger in diameter since it must be able to handle a far higher airflow capacity. While a larger diameter system is imperative for high flow rates due to pressure, for this same reason it should not be incorporated with an HRV, as the low pressure in the trunk will inhibit adequate air flow.

The fan on an HRV is considerably smaller than that of a furnace blower. This essentially means that the small amount of air supplied from the HRV does not have enough power to move throughout the oversized ductwork system. In this situation, only the closest vents to the HRV will supply air, while the furthest vents will not receive as much air, since there is not enough pressure. The only solution is the furnace fan must be on in addition to the HRV in order to allow air to flow throughout the supply ducts. The longer the fan is on, the better circulation is achieved, hence continuous fan operation would produce optimal air movement throughout the building if a partially dedicated system were used. However, continuous operation leads to excessive energy use that could be avoided if a fully dedicated system is implemented.

Fully dedicated systems are optimal to achieve sufficient airflow. This way the ventilation requirements are met and only the HRV needs to be on rather than the addition of a furnace fan. The most advantageous fully dedicated design is a radial system. In a radial system each run is distributed from the HRV directly to each room, rather than a trunk and branch layout. This eliminates oversized ductwork and prevents contamination between rooms.

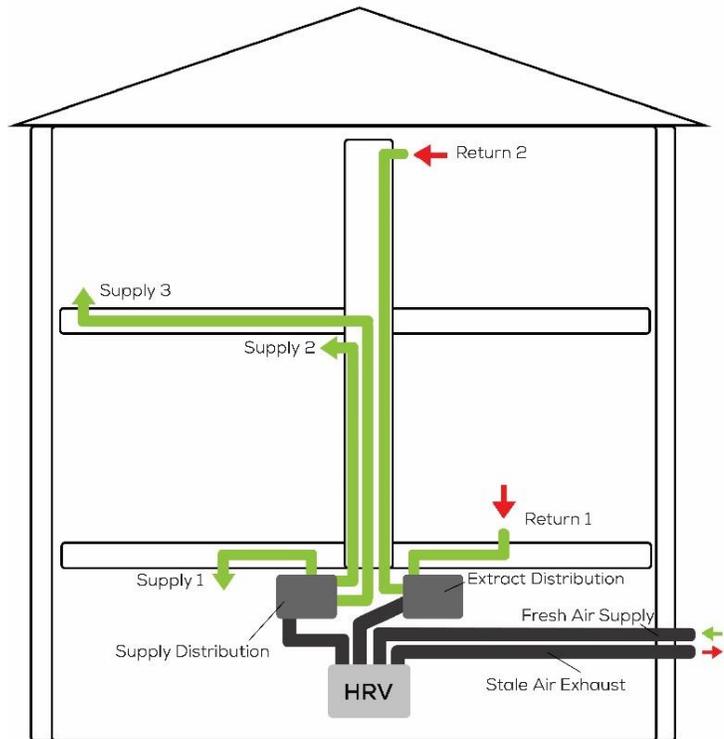


Figure 2: Diagram of a fully dedicated system

One HRV manufacturer, provides the following reasons for why an HRV should not connect to the furnace as a mode of distributing air:

1. In this case, the air handling unit (AHU) must run continuously or be interlocked to operate with the HRV/ERV to avoid loss of balanced supply and exhaust airflows.
2. In multi-speed AHU's, balancing must be conducted on the most frequently used speed, but the HRV/ERV may not remain in balance at other speeds. The same is true if the AHU has multi-speed blowers.
3. In warm, humid seasons, continuous operation of the AHU causes evaporation from the cooling coil, resulting in a loss of humidity control. Failure to operate the AHU with the HRV/ERV may also result in condensation in the supply plenum and ducting."

Even an HRV manufacturer deters using their product with a furnace. Simply put, the air handling unit must be constantly running, it's difficult to properly balance both appliances since they each have multiple operating speeds, and condensation buildup occurs in warmer conditions, which lowers the indoor air quality (8). These arguments point to the need for a fully dedicated system to provide the best air quality while avoiding excessive air handling unit operation.

IAQ and Occupant Health

There are countless reasons as to why indoor air quality should be a priority for occupants with regards to their physical wellbeing. Nevertheless, proper air ventilation is usually an afterthought for many residents since the archaic method of simply opening a window achieves fresh airflow within the house. Even though this approach works, opening windows throughout a building unfolds its airtight envelope, allowing conditioned air to escape and consequently wasting energy. As previously discussed, it's imperative now more than ever to maximize building efficiency to subdue the building's environmental impact.

Apart from partially dedicated systems requiring more energy to operate, they also fail to provide optimal air circulation because they make use of the existing furnace ducts. This impedes achieving the best possible indoor airflow since furnace ducts are oversized compared to ventilation ducts, and heating demands of a room oppose its ventilation demands. In a partially dedicated system, the contractor only has control of valve placement in exhaust runs and must accept the location of the existing supply terminals from the air handling unit. Conversely, in a fully dedicated system the contractor has full autonomy over the placement of supply and exhaust terminals and can therefore create a strategic arrangement to get the most out of air mixing.

To consider the extent of the impact inadequate air distribution has on the health of its occupants requires looking through a broader scope.

Air pollutants including dust mites, mold, tobacco smoke, and particulate matter are commonly found within every building. These particular contaminants are considered "asthma triggers" by the EPA (9), meaning that exposure could induce an attack to those who suffer from asthma. However, an occupant can still experience adverse health effects when subjected to inadequate air quality even if they are not asthmatic. A common and well-studied example is "sick building syndrome" where occupants with no record of preexisting conditions express acute discomforts such as headaches, throat irritation, coughing, nausea, fatigue, and difficulty concentrating (10). While this is certainly not something anyone wants to experience within their living space, sick building syndrome can drastically hamper performance in academic and work settings. It's no wonder why asthma-related illness accounts for 10 million missed school days per year (11), making it one of the leading causes of absenteeism.

Improving indoor air quality is proven to increase productivity in a working environment as much as 5% -10%. In most businesses employee salary expense is far greater than energy costs of the office building, making it a worthwhile investment to increase productivity. In fact, only 1% increase in productivity is enough to offset annual ventilating costs for the office building. It's been shown that doubling the fresh air supply rate not only reduced absences from illnesses by 10%, but also increased work output by 1.5% (12), which is more than enough to cover ventilating costs.

The Covid-19 pandemic has transformed the definition of an office, allowing employees to work from anywhere, mostly within the comfort of their living spaces, which further

supports the need for proper indoor air quality in residential spaces. The pandemic has also lowered indoor air quality for other reasons including a surge in household cleaning products like aerosols and more time spent cooking rather than eating out. Constant air circulation can also decrease the risk of transmission up to 47% according to the World Health Organization (13).

Indoor air quality is so vital to combatting the spread of the Coronavirus, that the EPA has dedicated part of their website to this relationship. They state, "Although improvements to ventilation and air cleaning cannot on their own eliminate the risk of airborne transmission of the SARS-CoV-2 virus, EPA recommends precautions to reduce the potential for airborne transmission of the virus. These precautions include increasing ventilation with outdoor air and air filtration as part of a larger strategy..." They also cite using mechanical ventilation, such as an HRV, as a means to increase airflow (14).

In all, indoor air quality can positively benefit occupant well-being in terms of lung health, productivity, and decreased risk of transmission of Covid.

Energy Consumption

Partially dedicated systems must employ the furnace fan simultaneously with the HRV to achieve suitable air distribution due to the nature of the oversized air handler ducts. Many new furnaces have variable fan speeds, so the fan could be run on a continuous low speed. However, older models typically only have a single speed, resulting in excess energy use if continuously operated. Nonetheless, in both cases the furnace fan is still operating concurrently with the HRV, i.e., two appliances are running at the same time in a partially dedicated system when only one appliance is needed in a fully dedicated system. Consequently, more energy is used as opposed to solely running the HRV.

In order to quantify how much additional energy is consumed if both the furnace and HRV are running simultaneously, a baseline of annual furnace fan use needs to be established. The first step is to determine how often the furnace is running (how many hours a year) in a typical household, to reveal how frequently the fan blower is on. This is done by taking the heating loads of a residence into account to determine how much energy is required to heat the household over a year based on its location.

In a fully dedicated system, the HRV is not connected to the furnace, therefore the fan would only need to operate while the furnace is running. Determining the number of hours per year the furnace is running equates to the number of hours per year the fan would be operating in a fully dedicated system.

The excess electrical consumption in a partially dedicated system is attributed to running the fan when the furnace is not on. The number of additional hours of fan operation is governed by the fan speed, either single or variable. Essentially, energy savings from a fully dedicated system is the difference in the number of hours of additional fan operation.

i. Determining A Furnace Fan Operation Baseline

First, the number of hours a furnace operates in a one-year period to heat the average Canadian home needs to be established. This will be used as a baseline when comparing the number of hours the fan would be operating if implemented in a partially dedicated system.

The burning operating hours (BOH) of a furnace is the number of hours the furnace is running during a year period. It's used to determine annual heating loads and is calculated based on the annual household heating consumption and the input capacity of a typical furnace. Equation 1 was provided by the Office of Building Technologies and Community Systems of the U.S. Department of Energy (15).

$$BOH \left(\text{hrs/yr} \right) = \frac{Q_{yr}}{Q_{in}}$$

Equation 1: Annual Burning Operating Hours (BOH) of a furnace

Where Q_{yr} is defined as “the annual fuel consumption for heating the house- from RECS97 (Btu/yr)” and Q_{in} is defined as the “input capacity of the existing furnace (Btu/hr)”.

ii. Annual Household Fuel Consumption

Q_{yr} is now determined based on the annual fuel consumption of a household. It is necessary to break down the annual fuel consumption usage by province, since the climate varies greatly throughout Canada depending on the region. Based on values published by Statistics Canada (16), the average household energy use by province is as follows:

Province	GJ/household
AB	130
BC	99
MB	98
NB	92
NL	111
NS	101
ON	107
PE	142
QC	95
SK	110

Table 1: Average household energy use in GJ broken down by province

Natural Resources Canada states “Approximately 60 percent of the energy required to run the average home is used for space heating” (17). Taking 60% of the energy use per household¹ from table 1, the annual energy fuel consumption to heat an average household (Q_{yr}) in GJ and BTU is shown in Table 2.

Province	Heat Energy (GJ/yr)	Q_{yr} (Btu/yr)
AB	78	7.39E+07
BC	59.4	5.63E+07
MB	58.8	5.57E+07
NB	55.2	5.23E+07
NL	66.6	6.31E+07
NS	60.6	5.74E+07
ON	64.2	6.08E+07
PE	85.2	8.08E+07
QC	57	5.40E+07
SK	66	6.26E+07

Table 2: Annual heat energy consumption per household in GJ and Btu based on the assumption that 60% of residential energy consumption is used towards heating the house.

iii. Furnace Input Energy

Next, to determine the BOH, the input capacity of the furnace, Q_{in} , needs to be established. Furnace specifications are used from The Federal Energy Management Program (FEMP), which “provides acquisition guidance for residential furnaces, a product category covered by ENERGY STAR”. For an ENERGY STAR furnace, FEMP provides the following specifications (18):

AFUE	95%
Output Capacity	70,000 Btu/hr

Table 3: AFUE rating of an ENERGY STAR furnace with a 70,000 Btu/hr output

Where AFUE or Annual Fuel Utilization Efficiency is defined as the “ratio of useful energy output to energy input as a percentage (%) over the entire heating season” by ENERGY STAR. Using the AFUE rating and output capacity, it is possible to determine the energy input of the furnace.

$$Q_{in} (Btu/hr) = Q_{out} / AFUE$$

Equation 2: Input energy of a furnace based on its AFUE ratings and output energy

Using Equation 2, the total energy input of the furnace is determined to be 73,684 Btu/hr².

$$Q_{in} = \frac{70,000 \text{ Btu/hr}}{0.95} = 73,684 \text{ Btu/hr}$$

iv. Annual Furnace Fan Operating Hours

Now the BOH of each province can be determined using their respective Q_{yr} and Q_{in} .

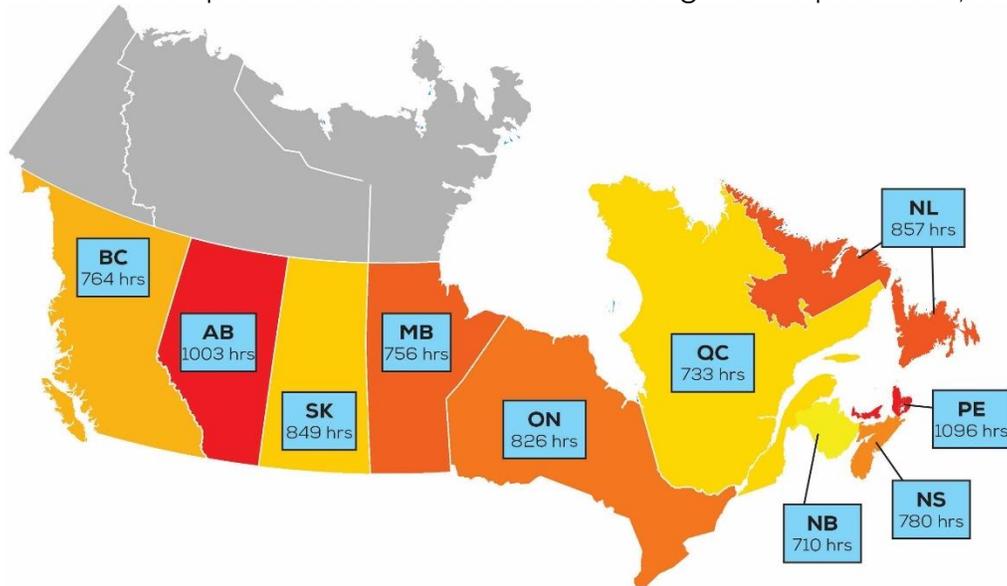


Figure 3: Burning Operating Hours (BOH) of each province calculated from equation 2

Assuming the blower is only operating while the furnace is running³, the BOH reflects the operating time of the blower fan. This can be used to determine the total electrical output of the furnace fan.

v. Annual Energy Consumption of a Single & Variable Speed Fan

Older furnaces utilize inefficient recirculation fan motors, ranging from 500 W to 800 W that operate on a single speed, while newer models can contain fans that use around 100 W with variable speeds (3). Table 5 below shows the total energy usage in kWh/year of a 500 W single speed fan⁴, and a more efficient 100 W variable speed fan⁵ if they are only operating during BOH.

Province	BOH	kWh/year	
		Single (100 W)	Variable (500 W)
AB	1003.3	501.7	100.3
BC	764.1	382.0	76.4
MB	756.4	378.2	75.6
NB	710.1	355.0	71.0
NL	856.7	428.3	85.7
NS	779.5	389.8	78.0
ON	825.8	412.9	82.6
PE	1095.9	548.0	109.6
QC	733.2	366.6	73.3
SK	849.0	424.5	84.9

Table 5: Annual energy usage for each province in kWh of a 500 W single speed fan and 100 W variable speed fan if operating during only BOH.

vi. Energy Consumption of a Single & Variable Fan in a Partially Dedicated System

As previously stated, if the HRV is connected to the forced-air handler ductwork, then the furnace blower should run either on a continuous⁶ low rate using a variable speed motor (100 W for 24hr/day), or intermittently on a 30 minute on and off cycle⁷ using a single speed motor (500 W). Equation 3 determines the energy consumption for both scenarios.

$$Energy\ (kWh/yr) = \frac{Power\ (W) * Time\ (hr/year)}{1000}$$

Equation 3: Annual energy consumption of a furnace fan in kWh

$$Energy_{single} = \frac{500\ W * 12 * 365\ (\frac{hr}{yr})}{1000} = 2190\ kWh/yr$$

$$Energy_{variable} = \frac{100\ W * 24 * 365\ (\frac{hr}{yr})}{1000} = 876\ kWh/yr$$

vii. Excess Energy Consumed by the Fan in a Partially Dedicated System

The annual consumption difference per province can be concluded by subtracting the values in Table 5 from their respective energy consumption from the calculated energy consumption if connected to the HRV and run for the suggested amount of time (Energy_{single} or Energy_{variable}). Table 6 quantifies this difference in energy consumption.

	Annual Excess Energy (kWh/yr)	
Province	Single	Variable
AB	1688	776
BC	1808	800
MB	1812	800
NB	1835	805
NL	1762	790
NS	1800	798
ON	1777	793
PE	1642	766
QC	1823	803
SK	1766	791

Table 6: Difference in energy consumption shown in kWh/yr if the furnace fan is running only at BOH versus if it is in a partially dedicated system and operating for the suggested amount of time based on the fan speed (12 hrs/day if single and 24 hrs/day if variable).

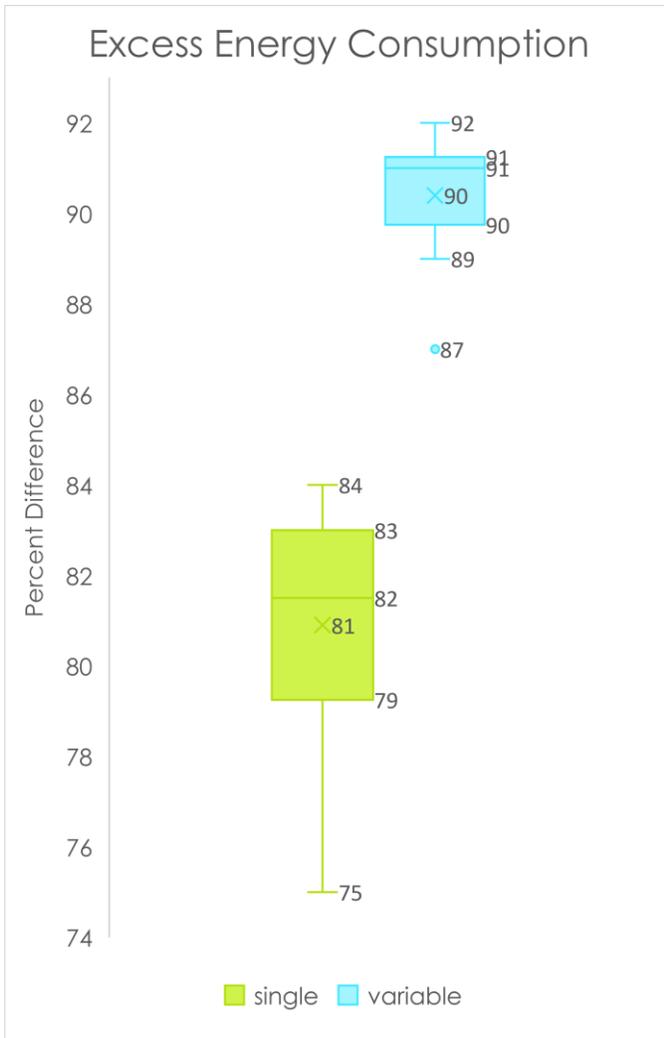


Figure 4: Additional percentage of energy used by a single and variable speed fan based on values from Table 6

The data in Table 6 reveals the electrical savings potential in a fully dedicated system. In other words, this is the additional amount of energy that would be consumed in a partially dedicated system. To put this into perspective, Figure 4 displays the percent difference from the energy savings in Table 6.

A residence can save anywhere between 75%-92% on their furnace electrical consumption while improving air quality if a fully dedicated system is employed instead of a partially dedicated system. Although the amount of electricity consumed by a single speed fan is higher than a variable speed fan based on the values in Table 6, proportionally the highest savings are attributed to switching from a variable speed fan as seen in Figure 4. The difference for a single speed fan ranges from 75% to 84%, while the difference for a variable speed fan ranges from 87% to 92%.

Looking at the bigger picture, energy savings can be translated into savings on a residence's electricity bill, as well as lowering a residence's carbon footprint.

Sustainability

As the number of Canadian households continues to grow, the need for energy efficiency improvements in the residential sector becomes critical. Between 1990 and 2017 the total increase in Canadian residential energy use was only 5.8% despite a 46% increase in the number of households. Additionally, the households erected during this time also had an average of 20% more floor space, meaning more energy was required to heat these newer homes. This disparity between increasing energy demand and declining energy use is attributed to improvements in energy efficiency. Without gains in efficiency, the Canadian residential energy use would have increased by 57.5%, ten times more than it actually did (19).

Change in Canadian Residential Energy Use Between 1990-2017

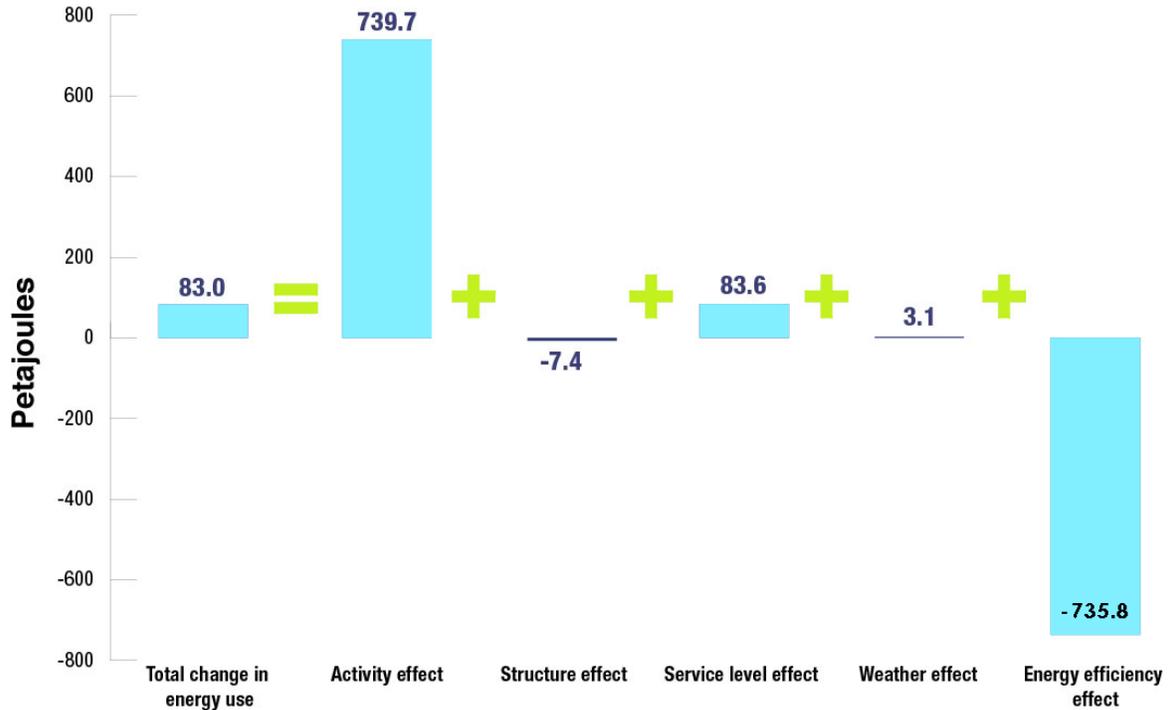


Figure 5: Impact of activity, structure, service level, weather, and energy efficiency on the change in residential energy use, 1990-2017. Source: Natural Resources Canada

Figure 5 illustrates that the clear contributors to energy use and energy savings are the activity and efficiency effects, respectively. The 740 PJ of energy used by the activity effect, which is the growth of the residential sector and consequently its demand for energy, emitted 30.4 Megatons of greenhouse gases. Fortunately, this was virtually counterbalanced by the 736 PJ saved from energy efficiency improvements within the residential sector, preventing an additional 30.2 Megatons of greenhouse gases from being emitted.

The largest use of residential energy is dedicated to space heating, which accounted for 62% of the total energy use (19). As a result, many efficiency improvements are aimed at reducing the heating load by sealing the building envelope, ultimately hindering indoor air quality. As this trend of enhancing airtightness combines with the growth of the residential sector and its consequent demand for energy, it's evident that decreasing energy consumption and improving IAQ is a vital solution to minimize carbon emissions while ensuring occupant health.

Implementing a fully dedicated ventilation system drastically reduces electrical consumption compared to a partially dedicated system, subsequently lowering the household's environmental impact. To determine the equivalent carbon footprint offset, each province's mode of electricity production i.e., renewable sources vs. fossil fuels, must be considered.

i. Amount of CO₂ Emitted from Electricity Production

Electricity can be generated through sustainable methods such as hydropower, wind turbines, and solar panels, or conversely using fossil fuels which contribute to greenhouse gas (GHG) emissions. Each province employs a different combination of energy generation methods. Thus, the carbon footprint contributed by electricity production varies by province based on how heavily they rely on fossil fuels versus renewable energy sources.

The greenhouse gas emission expressed in grams of CO₂ per kWh of electricity produced for each province is determined by equation 4.

$$CO_2(g)/kWh = \frac{CO_{2eq} \text{ emitted (kt)}}{Electricity Produced (TWh)} * \frac{1 (TWh)}{1.0E + 9 (kWh)} * \frac{1.0E + 9 (g)}{1 (kt)}$$

Equation 4: Grams of equivalent CO₂ emitted per kWh

Where kt of CO₂eq is the equivalent amount of CO₂ (combination of greenhouse gases CO₂, CH₄, and N₂O) emitted from public electricity production for each province sourced by the 2020 Canadian National Inventory Report (20). Electricity produced is the total amount of TWh of electricity produced for each province reported by the Canada Energy Regulator⁸(21). Table 7 provides the data used to calculate the equivalent amount of CO₂ in grams produced for each kWh of electricity generated by each province.

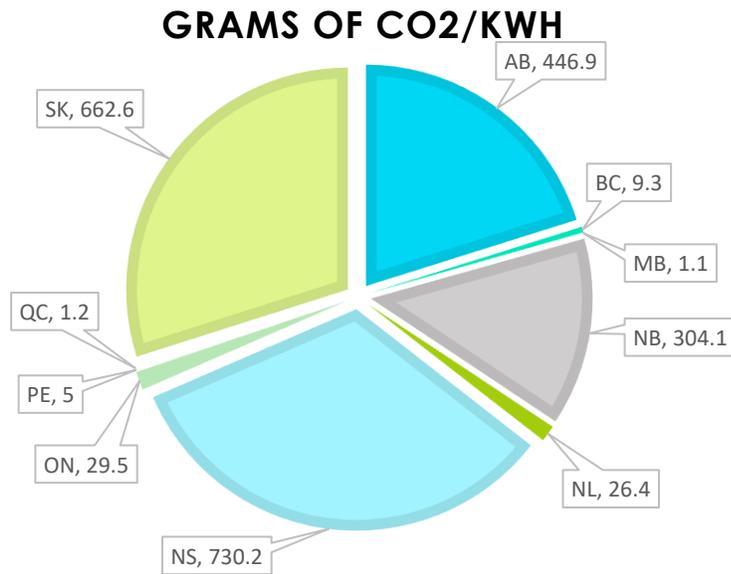
Province	Electricity (TWh)	GHG (kt CO ₂ eq)
AB	81	36200
BC	74.2	689
MB	36.9	41
NB	12.2	3710
NL	42.8	1130
NS	9.6	7010
ON	151	4450
PE	0.6	3
QC	213.7	255
SK	24.3	16100
YT	0.5	33

Table 7: Electricity generated by each province and their respective CO₂ emissions from production.

The Canada Energy Regulator states (21):

“B.C., Manitoba, Quebec, Newfoundland and Labrador, and Yukon each generate over 80% of their electricity from hydroelectricity. Ontario, New Brunswick, and NWT rely on various combinations of nuclear, hydro, wind, biomass, coal, natural gas, and petroleum.... Alberta, Saskatchewan, Nova Scotia, and Nunavut generate the majority of their electricity from fossil fuels such as coal, natural gas, or petroleum.”

Taking this into context of the data in Table 7 explains the drastic difference between the greenhouse gas emissions of AB, SK, and NS compared to the other provinces.



The equivalent amount of CO₂ in grams produced for each kWh of electricity generated by each province is calculated from the values in Table 7 with Equation 4.

Figure 6 illustrates the influence various methods of electricity production each province employs has on the environment.

For some provinces such as AB, NB, NS, and SK, reducing energy consumption by even a small amount can still play a major role in mitigating carbon emissions.

Figure 6: Equivalent amount of CO₂ in grams produced from each kWh of electricity generation for each province.

ii. Carbon Footprint of a Partially Dedicated System

Using the difference in additional electricity consumption in kWh/yr between a fully dedicated system and partially dedicated system calculated in Table 6, the total amount of additional CO₂ produced from a partially dedicated system for each province can be concluded. The results are shown in Figure 7 below.

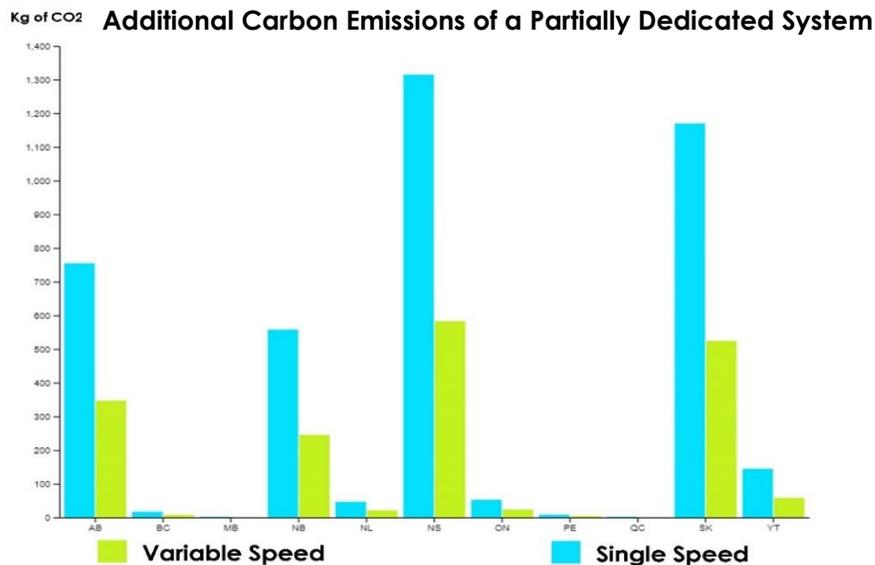


Figure 7: Annual carbon emissions (kg) from a single and variable speed fan in a partially dedicated system for each province.

iii. Number of Trees Needed to Offset a Partially Dedicated System

The above results show the positive impact of using a fully dedicated system compared to a partially dedicated system from an environmental standpoint. However, kg of CO₂ is a difficult unit of measurement to comprehend since it is essentially the weight of a gas. This can be converted into a more tangible unit that's easier to grasp, such as number of trees needed to offset this carbon footprint.

According to Kohl et al. 2017 (22), one mature tree can store up to 48 lbs, or 22 kg of carbon annually. Figure 6 illustrates the number of trees needed to offset the additional carbon emissions from a partially dedicated system with a single speed fan for an average household in each province.

Number of Trees Required to Offset Carbon Emissions of a Partially Dedicated System with a Single Speed Fan for One Year



Figure 8: Number of trees needed to offset additional CO₂ emissions from a partially dedicated system with a single speed fan for each province found by dividing the values in Table 8 by 22 kg.

It should be noted that a carbon offset of 22 kg is only true for adult trees, which can take approximately forty years to reach maturity (23), meaning that even if a residence planted the suggested number of trees, there wouldn't even be a noticeable positive effect until decades after. Converting carbon emissions into a more demonstrable instance unveils just how paramount reducing electrical consumption really is and the larger impact it can have on the environment.

Electricity Savings

In addition to lowering carbon emissions from requiring less energy, a fully dedicated system also lowers the homeowner's electricity bill. Savings vary based on how much more frequently the fan would be operating in a partially dedicated system, which is dictated by the building's thermal load (see excess energy use in table 6). The strongest appeal of a partially dedicated exhaust system is lower installation costs since the system utilizes existing ductwork. However, this cost would be offset by the electricity savings. The funds saved in operating costs can be used to invest in other sustainable and efficient home solutions and can eventually pay off the installation difference.

i. Annual Electricity cost of a Fully and Partially Dedicated System

The annual cost of electricity for a fully and partially dedicated system for both a single and variable speed fan in each province is determined by multiplying the costs/kWh of electricity (24) by the annual kWh consumed for each fan type under their respective fully and partially dedicated operating hours.

Province	Price/kWh	Price/year (fully)		Price/year (partial)	
		single	variable	single	variable
AB	\$ 0.166	\$ 83.28	\$ 16.66	\$ 363.54	\$ 145.42
BC	\$ 0.126	\$ 48.14	\$ 9.63	\$ 275.94	\$ 110.38
MB	\$ 0.099	\$ 37.44	\$ 7.49	\$ 216.81	\$ 86.72
NB	\$ 0.127	\$ 45.09	\$ 9.02	\$ 278.13	\$ 111.25
NL	\$ 0.138	\$ 59.11	\$ 11.82	\$ 302.22	\$ 120.89
NS	\$ 0.171	\$ 66.65	\$ 13.33	\$ 374.49	\$ 149.80
ON	\$ 0.130	\$ 53.68	\$ 10.74	\$ 284.70	\$ 113.88
PE	\$ 0.174	\$ 95.35	\$ 19.07	\$ 381.06	\$ 152.42
QC	\$ 0.073	\$ 26.76	\$ 5.35	\$ 159.87	\$ 63.95
SK	\$ 0.181	\$ 76.83	\$ 15.37	\$ 396.39	\$ 158.56

Table 8: Annual cost of electricity for each province if a single and variable furnace fan were run in a fully dedicated system (during BOH) versus a partially dedicated system (operating during their suggested amount of time based on the fan speed, 12 hrs/day if single and 24 hrs/day if variable).

Table 8 displays the annual cost of electricity to operate a furnace blower under various conditions. The Price/year (fully) column exhibits the annual electrical cost to run a fully dedicated system (blower on only when the furnace is running for both a single speed 500 W and variable speed 100 W fan). These costs are relatively low compared to the Price/year (partial) column, which presents the annual price of electricity for a single speed and variable speed fan in a partially dedicated system running under their respective airflow assumptions used in the previous calculations (12 hours/day for single speed and 24 hours a day for variable speed).

ii. Fully Dedicated Electricity Savings Over a One, Three, and Five Year Period

This difference becomes even more apparent when looking through a larger timeframe and taking inflation into account. Savings are calculated using equation 5:

$$Savings (\$) = Cost_{partial} - Cost_{fully} * n * 1.02^{n-1}$$

Equation 5: Annual electricity savings if the furnace fans are running during BOH versus if they are operating during their suggested amount of time based on the fan speed, with 2% inflation.

Where $Cost_{partial}$ is the annual electrical cost of either the single or variable speed fan when used under its respective operating frequency assumptions, $Cost_{fully}$ is the annual electrical cost of either the single or variable speed fan when running only while the furnace is running (BOH), and n is the number of years after installation. Equation 5 also considers a 2% inflation rate⁹. This formula was used to calculate the potential electricity savings of a fully dedicated system for one, three, and five years seen in Table 9 below.

Province	Yearly price difference		3-year savings		5-year savings	
	single	variable	single	variable	single	variable
AB	\$ 280.26	\$ 128.76	\$ 874.76	\$ 401.89	\$ 1,516.83	\$ 696.87
BC	\$ 227.80	\$ 100.75	\$ 711.02	\$ 314.46	\$ 1,232.91	\$ 545.27
MB	\$ 179.37	\$ 79.24	\$ 559.85	\$ 247.31	\$ 970.78	\$ 428.84
NB	\$ 233.04	\$ 102.23	\$ 727.37	\$ 319.09	\$ 1,261.26	\$ 553.31
NL	\$ 243.11	\$ 109.07	\$ 758.79	\$ 340.42	\$ 1,315.74	\$ 590.28
NS	\$ 307.84	\$ 136.47	\$ 960.84	\$ 425.94	\$ 1,666.09	\$ 738.58
ON	\$ 231.02	\$ 103.14	\$ 721.07	\$ 321.93	\$ 1,250.33	\$ 558.23
PE	\$ 285.71	\$ 133.35	\$ 891.77	\$ 416.23	\$ 1,546.32	\$ 721.74
QC	\$ 133.11	\$ 58.60	\$ 415.46	\$ 182.89	\$ 720.40	\$ 317.13
SK	\$ 319.56	\$ 143.19	\$ 997.40	\$ 446.92	\$ 1,729.50	\$ 774.97

Table 9: Electrical price difference between a single and variable speed furnace fan operation during only BOH versus within a partially dedicated system shown over a period of 1, 3, & 5 years for each province.

Based on the costs above, it's evident that the highest potential electrical savings come from implementing a fully dedicated system rather than a partially dedicated system with a single speed furnace blower. These savings could even be deemed a conservative estimate, considering that they are based on the assumption the single speed fan is only running for 12 hours of the day, rather than the recommended continuous 24 hours, which would provide better air circulation.

iii. Payback Period of a Fully Dedicated System

After only a couple of years, the savings from employing a fully dedicated system over a partially dedicated system would cover the installation and materials cost and continue saving the residence money on their energy bill while providing optimal air circulation. A reasonable installation cost for the supply side of a dedicated ventilation system is around \$1200¹⁰.

This can be used to determine the payback period of a fully dedicated system by dividing the assumed installation cost of \$1200 by the annual electricity savings.

Payback Period of a Fully Dedicated System

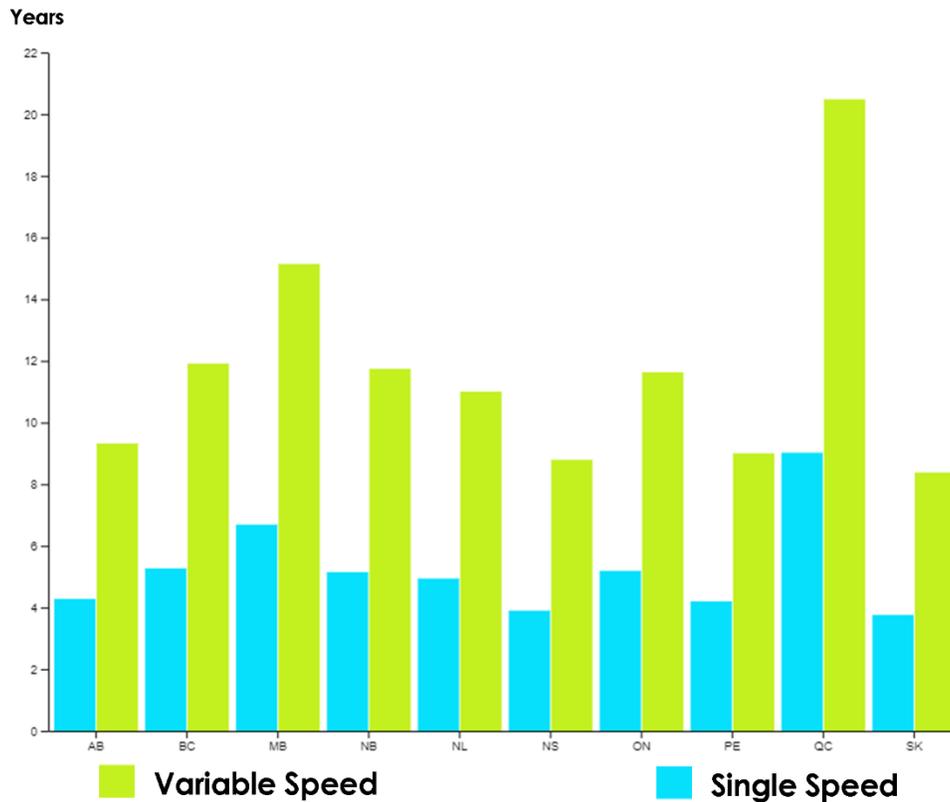


Figure 9: Payback period of a fully dedicated system with a single and variable speed fan for each province based on an estimated installation cost of \$1200.

Figure 9 illustrates the difference in payback period between a single speed and variable speed fully dedicated system. It would only take between four to six years to pay off the installation costs of a fully dedicated system if the homeowner had a single speed fan. The payback period is longer for a variable speed furnace and would realistically take between eight to twelve years to cover the installation costs. Once the installation cost is paid off, the homeowner will continue to save money every year thereafter, making a fully dedicated system a worthwhile investment.

Discussion

The average person spends most of their time at home and tries to stay healthy, so keeping living spaces and lungs in good shape should receive the same amount of emphasis. Extending past living spaces, it's crucial now more than ever to make sure the environment is healthy as well. For these reasons, capitalizing on proper ventilation produces a wide range of returns, reaching occupant health, electrical bills, carbon footprint, and even transmission of diseases.

Partially dedicated ventilation systems are abundant throughout Canada, as they are presumably the better option based on installation costs while still offering dedicated extracts. Yet looking below the surface reveals that these systems require excess electrical consumption and only provide enough air circulation if properly installed. Still, the volume and assignment of air flow doesn't compare in quality to a fully dedicated system and redundant electricity use has lasting environmental impacts.

For the assumed average household, making the switch from a partially to a fully dedicated system will result in electrical savings and lower carbon emissions, but these results vary greatly depending on the location of the residence or building. For example, a homeowner in Alberta could save 14 times the number of trees compared to a homeowner in Ontario, even though an electricity bill in Alberta would only be 20% greater than that of Ontario. Moreover, a dedicated system in Alberta would be paid back within a matter of only four years if they had a single speed furnace, which is the most common type in Canadian homes.

As ventilation requirements become more stringent throughout Canada and HRV mandates are even imposed in some jurisdictions (3), choosing the proper ventilation system is crucial in new construction. Fully dedicated systems undeniably offer optimal air circulation and reduce a home's environmental impact by lowering electrical consumption, consequently saving the homeowner on their electricity bills, and eventually covering the cost of installation as an added benefit. In other words, an investment in a fully dedicated ventilation system is an investment in health, savings, and the environment.

Appendix A: Assumptions

The calculations in this paper are based on assumed values and datasets.

1. All the 60% of energy used for space heating in the average home provided by the natural Resources Canada is used by only the furnace. This results in a conservative energy savings estimate, since assuming all 60% of heat energy is used by the furnace raises the Q_{yr} , and therefore increases the baseline of furnace operation (BOH).
2. The furnace has an energy star rating and an AFUE of 95%. Not all Canadian homes have a high efficiency furnace, meaning the Q_{in} would be larger in that case. This results in a conservative energy savings estimate, since assuming a high efficiency furnace lowers the Q_{in} , therefore increasing the baseline of furnace operation (BOH).
3. The blower only operates while the furnace is running and not more. Although it's not uncommon to run the fan outside of when the furnace is not on to increase air mixing, if the household has a fully dedicated system there is no need to run the fan additionally, since the system is designed to maximize airflow.
4. The single speed furnace fan uses 500 W. This results in a conservative energy savings estimate since the furnace fan could use up to 800 W, which would consume 60% more electricity and emit more greenhouse gases and cost the homeowner more to operate.
5. The variable speed furnace fan uses 100 W. This is a realistic energy savings estimate; however, some newer high efficiency fans can use as little as 75 W, which would result in lower greenhouse gas emissions and operating costs.
6. The variable speed fan operates continuously when integrated in a partially dedicated system, which is recommended by the HRV manufacturer.
7. The single speed fan operates on a 30 minute on and off cycle, or 12 hours per day. This is a conservative estimate considering a recommended continuous operation to achieve optimal air quality.
8. The equivalent amount of CO₂ emitted from electricity generation for each province assumes that a household receives power only from the electricity generated by the province it is located in, and no other sources.
9. A 2.00% inflation rate is used to determine the savings of a fully dedicated system over time. This is a slightly conservative estimate, considering the average inflation rate is approximately 2.27% compared to the previous year.
10. The installation cost of the supply runs in a dedicated system is \$1200. The installation costs can differ greatly based on variables such as building size, ventilation requirements, contractor, location, and more.

Sources:

1. Brown, Ann. "How Many Breaths Do You Take Each Day?" *The EPA Blog*, EPA, 28 Apr. 2014, blog.epa.gov/2014/04/28/how-many-breaths-do-you-take-each-day.
2. Abouleish, M. Y. Z. "Indoor Air Quality and Covid-19." *Royal Society for Public Health*, vol. 191, 2020, pp. 1–2. *ScienceDirect*, doi:10.1016/j.puhe.2020.04.047.
3. Health Canada. "Ventilation and the Indoor Environment - Canada.Ca." *Government of Canada*, 19 Apr. 2018, www.canada.ca/en/health-canada/services/publications/healthy-living/ventilation-indoor-environment.html.
4. Snider, Joe. "Could Indoor Air Quality Become Part of the Post Coronavirus Playbook? | Greenbiz." *Could Indoor Air Quality Become Part of the Post Coronavirus Playbook?*, GreenBiz, 15 May 2020, www.greenbiz.com/article/could-indoor-air-quality-become-part-post-coronavirus-playbook.
5. National Institutes of Health. "New Coronavirus Stable for Hours on Surfaces." *National Institutes of Health (NIH)*, 17 Mar. 2020, www.nih.gov/news-events/news-releases/new-coronavirus-stable-hours-surfaces.
6. Leong, Xi Wen, and Emmanuel A. Essah. "Bridging the Gap between Energy Consumption and the Indoor Environmental Quality of a 1960s Educational Building." *Energy Procedia*, vol. 132, 2017, pp. 87–92. *Crossref*, doi:10.1016/j.egypro.2017.09.643.
7. Environmental Protection Agency. "Health, Energy Efficiency and Climate Change." *US EPA*, 19 Aug. 2020, www.epa.gov/indoor-air-quality-iaq/health-energy-efficiency-and-climate-change.
8. American ALDES Ventilation Corporation. (2019). Heat & Energy Recovery Ventilators: Operations & Maintenance Manual. Retrieved from https://aldes.us/wp-content/uploads/2019/02/residential-hrv-erv_iom.REV0219.pdf
9. United States Environmental Protection Agency. "Indoor Air Quality." *US EPA*, 16 July 2018, www.epa.gov/report-environment/indoor-air-quality#:~:text=or%20air%20conditioning,-.Effects%20on%20Human%20Health,%2C%20heart%20disease%2C%20and%20cancer.
10. United States Environmental Protection Agency. "Indoor Air Facts No. 4 (Revised) Sick Building Syndrome." *Air and Radiation Research and Development (MD-56)*, 1991, pp. 1–4, www.epa.gov/sites/production/files/2014-08/documents/sick_building_factsheet.pdf.
11. Hsu, Joy et al. "Asthma-Related School Absenteeism, Morbidity, and Modifiable Factors." *American journal of preventive medicine* vol. 51,1 (2016): 23-32. doi:10.1016/j.amepre.2015.12.012
12. Wargocki, Pawel. "Indoor Climate and Productivity in Offices How to Integrate Productivity in Life-Cycle Cost Analysis of Building Services." *REHVA*, vol. 6, 2007, pp. 3–82. *Federation of European Heating and Air-Conditioning Associations*, biblioteka.ktu.edu/wp-content/uploads/sites/38/2017/06/06_Productivity_2ed_protected.pdf.

13. "COVID-19 Brings Indoor Air Quality Monitoring Upfront." *World Green Building Council*, 2020, www.worldgbc.org/news-media/covid-19-brings-indoor-air-quality-monitoring-upfront.
14. "Indoor Air and Coronavirus (COVID-19)." *US EPA*, 16 Dec. 2020, www.epa.gov/coronavirus/indoor-air-and-coronavirus-covid-19.
15. Lutz, James, Dunham-Whitehead, Camilla, Lekov, Alex, and McMahon, James. *Modeling energy consumption of residential furnaces and boilers in U.S. homes*. United States: N. p., 2004. Web. doi:10.2172/829987.
16. Environment Accounts and Statistics Division. "Households and the Environment: Energy Use: Table 4-2 — Average Household Energy Use, by Household and Dwelling Characteristics, 2011 — Size of Heated Area." *Statistics Canada*, 27 Nov. 2015, www150.statcan.gc.ca/n1/pub/11-526-s/2013002/t006-eng.htm.
17. Office of Energy Efficiency. "Heating With Gas." *Natural Resources Canada*, Oct. 2012, pp. 1–60.
18. Federal Energy Management Program. "Purchasing Energy-Efficient Residential Furnaces." *Office of Energy Efficiency & Renewable Energy*, U.S. Department of Energy, 2018, www.energy.gov/eere/femp/purchasing-energy-efficient-residential-furnaces.
19. Natural Resources Canada. "Energy Use in Canada: Trends Publications | Natural Resources Canada." *Energy Use in the Residential Sector*, Government of Canada, 2017, oee.nrcan.gc.ca/publications/statistics/trends/2017/residential.cfm#L2.
20. Minister of Environment and Climate Change, 2020. "National Inventory Report 1990–2018: Greenhouse Gas Sources and Sinks in Canada." *United Nations Framework Convention on Climate Change*, 2020, pp. 1–82. *Pollutant Inventories and Reporting Division*, publications.gc.ca/collections/collection_2020/eccc/En81-4-2018-3-eng.pdf.
21. Government of Canada. "Provincial and Territorial Energy Profiles." *Canada Energy Regulator*, 29 Jan. 2021, www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/#:~:text=Provincial%20and%20Territorial%20Energy%20Profiles%20explores%20these%20systems%20by%20providing,discussions%20about%20energy%20in%20Canada.
22. Köhl, Michael et al. "The impact of tree age on biomass growth and carbon accumulation capacity: A retrospective analysis using tree ring data of three tropical tree species grown in natural forests of Suriname." *PloS one* vol. 12,8 e0181187. 16 Aug. 2017, doi:10.1371/journal.pone.0181187
23. CO2 Meter. "Could Global CO2 Levels Be Reduced by Planting Trees?" *CO2 Meter*, 21 Sept. 2020, www.co2meter.com/blogs/news/could-global-co2-levels-be-reduced-by-planting-trees#:~:text=While%20a%20typical%20hardwood%20tree,into%20the%20air%20each%20year.
24. Urban, Ryan. "Electricity Prices in Canada (Updated 2021)." *Energyhub.Org*, Energy Hub, 11 Mar. 2021, www.energyhub.org/electricity-prices/#:~:text=The%20average%20residential%20price%20of,if%20you%20exclude%20the%20territories