HEAT RECOVERY VENTILATION STUDY

in Vancouver Single Family Homes

Brady Faught, E.I.T.
UBC Masters of Clean Energy Engineering Graduate
2016 (Summer) Greenest City Scholar Program

Supervisor: Chris Higgins
Prepared for: City of Vancouver Sustainability Dept.
7th Floor City Hall
Delivered: July 31st 2016

The Greenest City Scholar Program

My name is **Brady Faught** and I graduated from the **Masters of Clean Energy Engineering** program at the University of British Columbia in May 2016. During my program I developed a keen interest in the innovative world of green buildings, and I am excited to contribute to the City of Vancouver's Greenest City 2020 GHG emission reduction goals. I am very grateful to the GC Scholar program, the UBC and the City of Vancouver for allowing me this opportunity to be immersed in green building policy, and give me the chance to make a contribution to creating a more sustainable, livable city.

Please contact me at brady.faught@gmail.com if you have questions concerning the study.

The Greenest City Action Plan represents a road map for the City of Vancouver to become the greenest city in 2020. It supports a wide range of projects, contained within 10 main goals.

Goal 2 (of 10): Green Buildings looks to reduce energy use and GHG emissions in existing buildings by 20% from 2007 levels, and have all new buildings from 2020 onward be carbon-neutral

CITY OF VANCOUVER
GREENEST CITY 2020

Acknowledgements

Numerous stakeholders and those involved in the ventilation industry provided excellent feedback and suggestions for this report. I would like to thank the following for their time and insight:

The City of Vancouver: Chris Higgins (supervisor), Dhaniva Panday, Sean Pander, Lisa Brideau, Jacyln Jimenez, and everyone at the Sustainability Office.

Bram Cowan and Mike Mcdiarmid at City Inspections

Empower Me Program: Ken Hseuh (translator), Danielle Milln, Amy Hennessy (coordinators)

E3 Eco Group: Troy Glasner, James Hornett and Sherman Wai

Lanefab Homes: Bryn Davidson

Clay Construction: Larry Clay

Eneready: David Hill

Small Planet Supply: Albert Rooks

Zehnder: Aubrey Gewehr

BC Housing – Home Protection Office: Remi Charron

EcoLighten: Ryan Coleman

Executive Summary

This project represents a 3-month Greenest City Scholar study, completed from May to July, 2016. It is part of Goal 2 (Green Buildings) of the Greenest City Strategy, and was focused on determining how heat recovery ventilation (HRV) systems are being installed and operated in single family homes.

BACKGROUND

As new homes are built relatively airtight (i.e. less than 3.5 air changes per hour), mechanical ventilation is required. A heat recovery ventilator, a type of mechanical ventilation, not only exhausts stale air and brings in fresh air, but also captures upwards of 90% of heat leaving the home. HRV's have been required in the Vancouver Building Bylaw (VBBL) in Vancouver homes since 2009.

PROJECT OVERVIEW

The study included 18 single family homes across the City of Vancouver (of which 4 were laneway homes). Both empirical and quantitative data was collected: homeowners were asked about their HRV unit and if they were provided information on how to operate and maintain it, as well as if they found the HRV beneficial and effective. The unit was assessed on its proper installation, operation and cleanliness of filters. A representative from the consulting group E3 Eco Group provided technical assistance and measured grill supply and exhaust flow rates using a flow meter.

HOME OUTREACH

Several means of outreach were used including the City's Facebook and Twitter feeds, the Greenest City newsletter, requests to builders and architects to pass on the study to clients, and door-to-door visits with pamphlets. The door-to-door visiting proved most effective with 11 homes contacted via this method.

Executive Summary

RESULTS

In summary, all units were operable, accessible (however some more difficult than others), and were plugged in upon inspection. Unwanted noise was not an issue for most. Venmar units were found in 56% of the homes.

A few common issues that were found during the home visits:

1. Homes were not achieving adequate air flow rates. This could be due to either undersized HRV units, significant air leakage within the house (leaky ducts due to gaps in connections), or both.

2. Homeowners were not provided sufficient information to maintain and/or operate their unit and therefore believed a home walkthrough from their builder would have been exceptionally useful.

3. Many exterior ducts were not insulated on visible locations, despite code requiring a minimum R 4.25 insulation on exterior connected ducts.

4. **Excessive bends and drops with flexible ducts.** The use of flexible ducts allows for sharp bends that significantly reduce air flow, and dips where condensation can collect. Only semi-rigid and rigid ducts should be permitted for use to mitigate these concerns.

Other issues were found on a home-by-home basis such as improperly insulation installed, difficult access to the unit, and outdoor vents installed too close together (less than 6’ apart). Problems in general appeared to be a mix of lack of knowledge and lack of care.

The results of this study will be used to form recommendations to create a more robust bylaw for HRV installation, which makes builders more accountable for proper sizing and installation, as well as adequate information handover to the homeowner.

Existing Vancouver Building Bylaw (VBBL) for Heat Recovery Ventilators (updated 2014)

Section 10.2.2.10 'Domestic Heat Recovery Ventilators' in the VBBL outlines the Vancouver-specific HRV requirements (which adds on to the BCBC / NBC requirements). The following summarizes the VBBL requirements:

- Single family dwellings require a heat recovery ventilator (not including laneway homes)
- The HRV shall have a minimum efficiency of 65%
- Installed by certified technicians from TECA or HRAI
- Shall not be connected to kitchen or bathroom exhaust fans
- Have exterior connected supply and exhaust ducts insulated to higher than R 4.25
- Have an effective vapour barrier to prevent condensation
- The HRV shall be located in a conditioned, accessible space
- Have balanced supply and exhaust air flows
- Have a label with tested supply and exhaust flows for high and low speeds (in CFM)
- The HRV contractor must provide a complete Mechanical Ventilation Checklist to the Chief Building Official

Recommended Revisions and Additions

- Third party certifier must commission the HRV system and complete the Mechanical Ventilation Checklist for HRV. This will be handed to the Chief Building Official. It will ensure:
    - proper balancing and adequate sizing of the HRV system
    - a home 'hand-off' to the homeowner is provided from the building representative to ensure owner is aware of proper maintenance and operation of HRV system
    - The HRV duct system must consist of either semi-rigid or rigid ducting (no flexible duct)
    - The HRV exterior supply and exhaust vents must be at least 6' apart and away from potential sources of pollution or contamination
- Clarify 'tested' flow rates must be in-home tested rates

1.1 Project Objectives

BEST PRACTICES

Determine optimal design, installation and maintenance of HRV's in single family homes. Contact manufacturers, inspectors, and home builders.

HOME OUTREACH

Conduct surveys and inspections of 20 homes in Vancouver with HRV installed and operated. Observe any issues such as unplugged units, improper installation, dirty filters, etc.

MAKE RECOMMENDATIONS

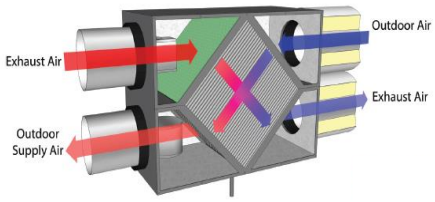
Use results to create recommendations for Vancouver Building Bylaw (VBBL) updates in Fall 2016 to promote effective installation and maintenance of HRV's in single family homes

1.2 What is a Heat Recovery Ventilator?

What is a Heat Recovery Ventilator (HRV)?

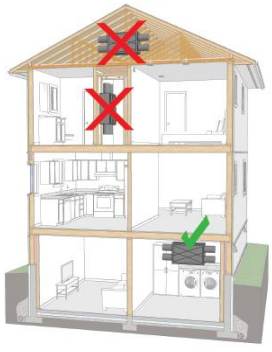
A Heat Recovery Ventilator is a device that provides mechanical ventilation in airtight homes (i.e. exhausts stale air and supplies fresh air). In addition, the unit captures heat from the exhaust stream before leaving by exchanging the exhaust with incoming supply air. Space heating can account for over 50% of annual energy consumption in houses, so the energy savings can be considerable.

Not only do they save energy, they also make for a healthier space by regulating moisture and reducing concentrations of home contaminants using filters in the unit.

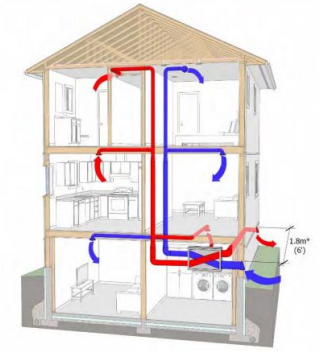


An HRV must be:

- Super-insulated
- Airtight
- Thermal Bridge-free
- Energy efficient
- Compact
- Quiet
- Accessible for maintenance



Good and bad HRV locations. No unconditioned spaces or close to bedrooms to avoid noise issues. (source: HPO)



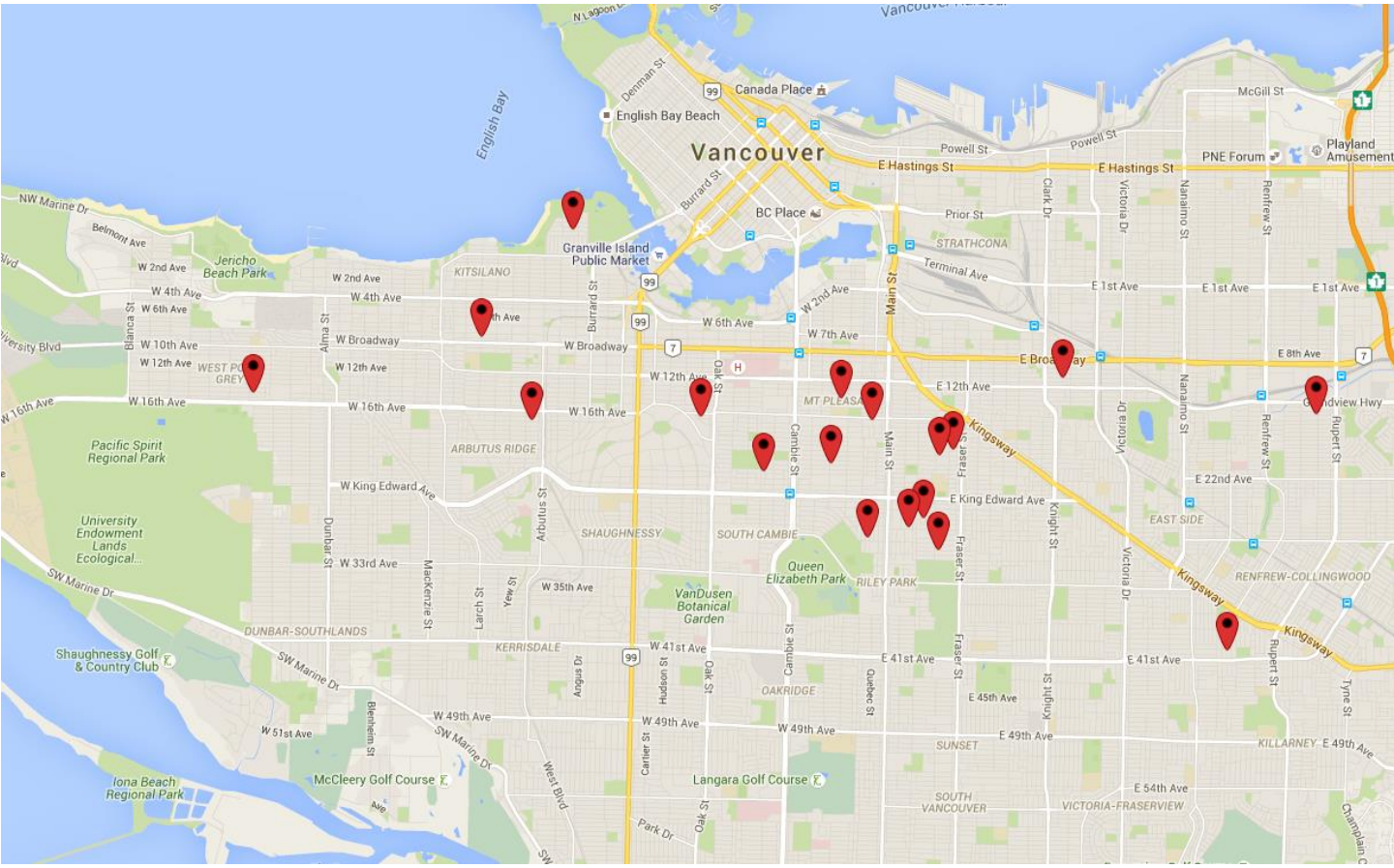
General good practice for supply and exhaust. Exterior vents at least 6 feet apart (source: HPO)

1.3 Home Visits - Summary

- All homes in study had HRV's (the majority being Venmar units)
- All laneway homes in study had an HRV
- All homes were owned by the occupants (no home renters)
- All homes used in-floor radiant heating
- All units were plugged in

Home #	Outreach	Type of Home	Year Built	Sq. ft.	# occupants	Location of HRV
1	Empower Me	Single Family + Secondary Suite	2013	2600	7	Attic
2	Builder Newsletter	Laneway	2014	1080	2	Mechanical Room
3	Facebook / Twitter	Single Family + Secondary Suite	2009	2009	3	Mechanical Room
4	Builder Newsletter	Laneway	2013	1170	4	Closet
5	Door to door	Single Family	2014	1750	4	Crawlspace
6	Facebook / Twitter	Duplex	2014	1550	4	Crawlspace
7	Door to door	Single Family	2011	4700	5	Laundry Room
8	Empower Me	Single Family	2013	2600	4	Laundry Room
9	Door to door	Duplex	2015	2140	7	Basement Closet
10	Door to door	Single Family + Secondary Suite	2012	1940	2	Basement Closet
11	Door to door	Laneway	2014	740	2	Mechanical Room
12	Door to door	Single Family + Secondary Suite	2014	1140	2	Conditioned Attic
13	Door to door	Laneway	2014	2900	5	Laundry closet
14	Door to door	Single Family	2014	2900	4	Laundry closet
15	Door to door	Duplex	2015	1950	3	Crawlspace
16	Facebook / Twitter	Single Family	2015	3000	4	Laundry room - closet
17	Door to door	Single Family +Secondary Suite	2015	3200	4	Laundry closet
18	Door to door	Single Family	2012	2800	3	Mechanical room

1.4 Map of Visited Homes



1.5 Results and Observations

The following summarizes the overall observations and common themes from the 18 home visits:

1. HRV Operation

- All units were functioning and plugged in.
- All units were fully-ducted (independent) HRV's
- No units had a label with commissioned (tested) flow rates for supply and exhaust, as required by code
- 50% of homes did not have adequately balanced systems.
- 33% of homes did not meet minimum performance air flowrates (by ASHRAE standards)

2. Occupant Satisfaction

- Almost no occupants had issues with unpleasant noise from the unit
- The majority of occupants were unsatisfied with the level of information provided to properly operate and maintain their HRV

- Picture shows adequate installation
- Unit is accessible
- Insulated exterior ducts
- Located in laundry room, far away from bedrooms
- Properly sized for size of home

3. HRV Sizing and Location

- Several undersized units not capable of meeting minimum airflows
- Over and under-ventilation with respect to Code requirements.
- All homes except one had the HRV in an accessible, conditioned space (one home had the HRV in an unconditioned attic)

4. Duct Installation

- The vast majority of homes used flexible ducting. Inherent issues such as excessive bends, inadequate attachment to unit, leakage due to no mastic or taping on seams.
- Greater than 30% air leakage found in some homes.
- Reduced flow rates with increased distance from the unit.

- 8 homes were observed to have non-insulated ducts leading to the exterior (some were not visible for inspection)
- Some homes simply had improperly insulated ducts
- Overly complicated bends and elbows

- Duct tape used for sealing
- HRV located in unconditioned attic
- Large amount of leakage observed

- Sharp bends and elbows
- Insufficient sealing where ducts meet HRV, visible air leakage

- Nearly all homes used flexible ducting
- Unnecessarily long flex ducts – condensation pooling and pressure losses

- Two homes had exhaust and supply vents that were not 6’ apart as per ASHRAE standards
- This can cause short-circuiting, reducing HRV effectiveness
- Some vents were under decks (inaccessible) or close to combustion gas outlets
- Some roof vents were not 18” above the snow line. This could lead to water ingression in to the HRV

- Grills too close to corners or in inaccessible location
- Makes testing and balancing difficult or not possible
- Keep a 10” radius of flat wall or ceiling around grill

5. Homeowner Maintenance

- Supply (left) and exhaust (right) filters after 1+ years use
- Lack of owner awareness for filter cleaning – dirty, clogged filters
- 56% of homes had dirty filters, cores and/or fresh air intakes

- Several condensate drain lines were missing p-trap style loop to prevent gases from travelling back in to HRV
- Connection of drain line to unit should use clamps, as some fell off when the access door was removed

- All units were accessible, but some were difficult to remove filters or core.
- Picture shows an access door unable to open fully due to hot water tank below

6. Homeowner Knowledge and Occupant Handover

- Many occupants were simply supplied a manual, but few read it or found the information user friendly
- Three homes had a lack of remote controls in living areas
- Lack of knowledge of operation and maintenance from homeowner

- Homeowners are typically not sure how to operate their unit, or what setting to use
- There is a large variety of control panels, from humidistat control to min/max control. Homeowners generally do not understand the use of their controls.

Limitations of Study

An inherent bias existed in the study, as those most likely to participate were typically interested or concerned with their ventilation system. The language barrier also added challenge, as all outreach media was in English. And finally, many homes were strata units or had secondary suites which we were not able to access during our visit, which limited the results.

1.6 Recommendations / Best Practices

1. Design and Location

"Appropriate airflow capacity and high-rated heat recovery efficiency are two of the most important HRV selection criteria. " -HPO Builder's Guide

- **Designed for easy operation and maintenance**
  - Controls in a convenient, central location
  - Filters easily accessible for changing, access door can fully open
- **Choose a third-party certified unit** (such as PH, Energy Star)
- **Size the unit so it operates at 70% of fan speed**
  - or oversize the unit by 40% over code requirements
- **Choose the HRV location during the design phase.** This allows for:
  - synergy with other equipment
  - minimizing of duct runs required
  - Dedicated space for accessible placement of unit

2. Installation and Ducting

- **Prohibit the use of flexible ducting**, as to completely avoid mold, cracking, condensation buildup and excess bends in duct runs, all of which is synonymous with flexible duct installation.
- **Semi-flexible HDPE tube ducting** is ideal to minimize bends and air leakage while keeping costs within reason
  - Duct runs should be straight, minimized in length, no dips (to prevent condensation), and seams taped or sealed.
- **Plug holes of tubing**, diffusers and the HRV unit while installing to prevent dust collection inside
- **Seal all duct joints** and seams with liquid sealant or mastic
- **Require a manufacturer P-trap** (no homemade p-traps)
- **Ensure grills and external vents are accessible** to allow for proper commissioning and balancing

3. Operation and Maintenance (Occupant Hand-over)

Mandatory 'information transfer mechanisms' should be in place to ensure the building representative provides the homeowner with enough information and knowledge required to effectively operate and maintain their HRV

- **The building representative should ensure the owner is made aware of proper operation and maintenance of the HRV**
  - Provide a hands-on demonstration and equipment manual
  - Provide a schematic of the home's ducting system

- **A sticker on the unit** should provide contact information for maintenance services, balanced airflow rates, a contact for replacement filters

- **The unit's control panel should be located in a central location** in the home, and ideally near other controls such as the thermostat

- **Units should be commissioned upon operation**, and retro-commissioning should occur a few years after use

4. Public Policy, Code Changes (VBBL) and Inspections

- **Floor Space Relaxations (FSR):** can be provided to allow designated space in the home (such as in the laundry room) for the HRV to be installed at no penalty to the builder or architect

- **Commissioning:** Should be required as a part of the final inspection checklist. Require a commissioning report from a certified third-party. This report should include the tester's information, time of adjustment, ventilation manufacturer and type, volume flow rates, and balance for supply and exhaust air

- **Mechanical HRV inspection:** should be required in the pre-drywall inspection checklist

- **Effective Communication:** create an exchange between TECA and inspections to ensure that inspectors are aware of what is required in a proper HRV installation. Properly educate inspectors on what they need to look for in an installed HRV system.

5. Recommendations to HRV Manufacturers

- **Incentives for commissioning.** In Europe, the 2.5 year warranty is increased to 5 years if unit commissioning is completed

- **Include a change filter light / maintenance required light**, or email reminder service for maintenance

1.6 Vancouver Building Bylaw

(Recommended revisions and additions in red.)

Existing 2014 Vancouver Building Bylaw (VBBL) for HRV's

Section 10.2.2.10 'Domestic Heat Recovery Ventilators' in the VBBL outlines the Vancouver-specific HRV requirements. (This bylaw adds on to the BCBC and NBC mechanical ventilation requirements in sections 9.32 / 9.33 / 9.36)

10.2.2.10. Domestic Heat Recovery Ventilators

1) This Article does not apply to *laneway houses*.

2) There shall be one heat recovery ventilator in:

a) each *one-family dwelling*,

b) each *one-family dwelling with secondary suite* or *lock-off unit*,

c) each *dwelling unit* in a *two-family dwelling*, and

d) each *dwelling unit* in a *two-family dwelling with secondary suite* or *lock-off unit*

3) Components of mechanical ventilation systems not specifically described in this Subsection shall be designed, constructed and installed in accordance with good engineering practice and as described in the ASHRAE Handbooks and Standards, HRAI Digest, TECA Ventilation Guideline, Hydronics Institute Manuals or the SMACNA manuals.

4) ~~A heat recovery ventilator (HRV) shall:~~ A certified third-party shall commission the HRV system, and provide a completed Mechanical Ventilation Checklist to the *Chief Building Official.* This shall ensure the heat recovery ventilator (HRV):

a) ~~have~~ has a 65 per cent sensible heat recovery efficiency (65 per cent Minimum SRE at 0°C) and be designed and tested in conformance with CSA 22.2 No. 113M-1984,

b) be designed and tested to meet the CSA International Standard CAN/CSA-F326 M91 ("Residential Mechanical Ventilation Systems"),

c) be installed by persons trained by the Thermal Environmental Comfort Association (TECA) or the Heating, Refrigeration and Air Conditioning Institute of Canada (HRAI) or equivalent,

d) supply outdoor air directly to the principal living area, to each bedroom, and to any floor without a bedroom, directly or indirectly, through a central recirculation system with a continuously operating fan,

e) be designed to run continuously to meet or exceed Table 9.32.3.3.A of Division B,

f) not be connected to kitchen and bathroom exhaust fans,

g) have exterior connected supply-air ducts and exhaust ducts insulated to not less than RSI 0.75 (R 4.25) and shall have an effective vapour barrier,

h) have balanced HRV supply and exhaust air flows within plus or minus 10 per cent of the actual normal operating exhaust capacity,

i) be labelled with in-home tested supply and exhaust air flows for high and low settings, measured in CFM and

j) be located within conditioned space in the *dwelling unit* for access, in a space that allows for complete access to the HRV unit

~~**5)** The HRV system contractor or installer shall provide a completed Mechanical Ventilation Checklist to the *Chief Building Official.*~~

k) ensure the HRV contractor, third-party certifier or building representative provided home 'hand-off'; detailed instruction (either in person and documented) to home-owner to properly operate and maintain the HRV unit.

4) A *contractor* trained in the installation of Energy Recovery Ventilators (ERV) may install an ERV in lieu of a Heat Recovery Ventilator.>

1.7 Mechanical Ventilation Checklist

According to the VBBL, the HRV contractor must provide a complete Mechanical Ventilation Checklist to the Chief Building Official.

The following is a draft of the HRV portion of the Mechanical Ventilation Checklist, based primarily off of an existing checklist created by the Homeowners Protection Office. This checklist must be completed by a certified third party and will be required by the city building inspector.

HRV/ERV Mechanical Ventilation Checklist	
HRV/ERV unit manufacturer & model:	
HRV/ERV Rated performance at 0°C (32°F) and -25C (-13F), per CAN/CSA C439:	
Net air flow, L/S (CFM):	
Power consumed (Watts):	
Cross-Flow or Counter Flow	
Sensible Heat Recovery Efficiency (SRE)/ Total Recovery Efficiency (TRE):	
HRV Capacity, L/S at 100 pa (CFM at 0.4 ESP per TECA guideline)	
Design airflow, continuous mode, L/S (CFM)	
Design airflow, boost mode, L/S (CFM)	
Design meets required airflow in home, based on 9.32 requirements	Y/N
Unit location is specified on plans	Y/N
Unit has been installed by certified TECA or HRAI technician (or equivalent)	Y/N
Unit is located inside thermal envelope	Y/N
HRV panel, internal filters and core are fully accessible	Y/N
Condensate line goes to drain, is clamped to unit, and has vertical p-trap loop	Y/N
Outdoor supply and exhaust vents are marked on plans	Y/N
Min 1.8 m (6') between outdoor supply and exhaust	Y/N
Potential pollutant sources at least 6 ft. from HRV supply	Y/N
Min 25cm (10") radius of flat wall or ceiling around grills (to allow for balancing)	Y/N
Semi rigid or rigid ducts (no flexible ducting)	Y/N
Dedicated low-volume ductwork (or) forced-air heating ducts?	
Plans specify all ductwork inside thermal envelope	Y/N
Exterior connected supply-air ducts and exhaust ducts are insulated to not less than RSI 0.75 (R 4.25) and have an effective vapour barrier	Y/N
Plans show outdoor air supply to all bedrooms and primary living areas	Y/N
Exhaust from all bathrooms, kitchens and laundry areas	Y/N
Boost mode controller is provided in each bathroom	Y/N
If not, secondary exhaust fan is provided in each bathroom	Y/N
Building representative or third-party certifier provided adequate instruction to homeowner for proper maintenance and operation of HRV unit	Y/N

Homeowner HRV Maintenance Checklist

Similar to changing the oil in a car, it is primarily in the hands of the homeowner to ensure periodic maintenance of their ventilation system. However, unlike the oil change light in your car's dashboard, some HRV control panels do not feature a 'Change Filter' indicator.

If no indicator is included, the next best option is to provide a sheet or sticker in a visible place on the unit. This 'Owner Maintenance Checklist' could be similar the following, which contains the seven steps recommended by HPO 'Maintenance Matters' Guide:

HRV Homeowner Maintenance Checklist					
Maintenance Task	**Recommended Frequency**	**Date Maintenance was Performed**			
Clean and check exterior intake hood	3 months				
Check condition of exterior exhaust hood (ensure no nesting birds, rodent intrusion, etc.)	3 months				
Clean or replace internal HRV/ERV filters	3 months				
Replace external HRV/ERV filters if filter box is used	3 months				
Inspect HRV drain tube	3 months				
Clean fan blades	6 months				
Clean HRV/ERV drain pan	6 months				
Clean exhaust and supply grilles	12 months				
Lubricate fans if required	12 months				

Note that HRV and ERV maintenance is essentially the same. Find the full, detailed maintenance guide from HPO at:
'https://hpo.bc.ca/sites/default/files/download/MMR/MM16.pdf

2.4 Best Practices - Resources

Summary of Resources		
Name	Website	Comments
Manufacturers		
Zehnder	http://zehnderamerica.com/	Passive House Certified units
Venmar	http://www.venmar.ca/	
Certifiers and Standards		
HRAI (Heating Refrigeration Air Conditioning Institute of Canada	www.hrai.com	Offers HRV installation training
TECA (Thermal Environmental Comfort Association)	www.teca.ca	Offers HRV installation certification training
HVI (Home Ventilating Institute)	http://www.hvi.org/index.cfm	List of HVI certified products (including HRV's)
Previous Ventilation Studies		
CMHC study	https://www.cmhc-schl.gc.ca/publications/en/rh-pr/tech/96215.htm	60 homes in Canada
WSU study	http://neea.org/docs/default-source/reports/pacific-northwest-residential-ventilation-effectiveness-study.pdf?sfvrsn=6	29 homes in Washington
Inuit study	http://www.naho.ca/documents/it/2012_Kovesi_Indoor_air_quality_lrti.pdf	49 homes in northern communities
Best Practices Information		
HPO	www.hpo.bc.ca	Contains multiple HRV guides for design, maintenance, installation and operation
NRCAN (Natural Resources Canada)	http://www.nrcan.gc.ca/home	Energy Star certified HRV's
PHI (Passive House Institute)		Passive House Certified HRV's
CMHC	http://www.cmhc-schl.gc.ca/en/inpr/su/sufepr/sufepr_006.cfm	General information and best practices

References and Sources

- **Homeowners Protection Office (HPO)** – Technical Bulletins
  - Maintenance Matters https://hpo.bc.ca/sites/default/files/download/MMR/MM16.pdf
  - Builder Insight Bulletin https://hpo.bc.ca/sites/default/files/download/BuilderInsight/BI14_HeatRecoveryVentilation.pdf
  - Guide for Houses https://hpo.bc.ca/sites/www.hpo.bc.ca/files/download/Publications/HRV_Guide_for_Houses.pdf
- **2014 Vancouver Building Bylaw VBBL** (accessed June 2016)
- **Canadian Mortgage and Housing Corporation (CMHC)** – Field Survey of Heat Recovery Systems (1999) https://www.cmhc-schl.gc.ca/publications/en/rh-pr/tech/96215.htm
- **Pacific Northwest Residential Ventilation Effectiveness Study** (WSU), 2015https://neea.org/docs/default-source/reports/pacific-northwest-residential-ventilation-effectiveness-study.pdf?sfvrsn=6
- **One House Green**. Accessed June 2016: http://onehousegreen.com/heat-recovery-ventilator/
- **Paulsen, M. Red Door Design Passive House Design Course** (2016)
- **Dr. Kovesi, et al., 2007. Indoor Air Quality Study** – Risk of Respiratory Infection in Inuit Children, Accessed June 2016:http://www.naho.ca/documents/it/2012_Kovesi_Indoor_air_quality_lrti.pdf
- **Lennox HVAC Systems**. Accessed June 2016: http://www.lennox.com/products/indoor-air-quality/ventilation/hrv
- **City of Kelowna**, Updated BCBC Building Code, (presentation)http://apps.kelowna.ca/CityPage/Docs/PDFs/Inspection%20Services/2014%20ventilation%20changes.pdf