Greenhouse Gas Implications of HVAC Upgrades in Multi-Unit Residential Buildings

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BRITISH COLUMBIA

BC Housing

Homeowner Protection Office
Branch of BC Housing

INTRODUCTION

This Research Report explores best practices and approaches for reducing greenhouse gas (GHG) emissions through heating, ventilation, and air-conditioning (HVAC) upgrades in multi-unit residential buildings (MURBs) in British Columbia.

It presents the context as to why industry should be concerned with reducing greenhouse gas emissions, the importance of load reductions, and a checklist of strategies to consider when upgrading HVAC systems in MURBs.

The aim of this Research Report is to support industry in making informed HVAC upgrade decisions that can lead to greenhouse gas savings.

Commissioned by BC Housing and prepared by Perkins+Will, this report is based on:

- a review of industry best practices;
- research previously completed by Perkins+Will for BC Housing on greenhouse gas reduction strategies for MURBs through HVAC upgrades; and,
- data extracted from RDH Building Engineering Ltd.'s 2011 report *Energy Consumption and Conservation in Mid- and High-Rise Residential Buildings in British Columbia.*

GREENHOUSE GAS EMISSIONS OVERVIEW

Greenhouse gas emissions from new and existing buildings, contribute to climate change and pollution from energy consumption on both a local and global scale. GHGs also increasingly impact building operational costs due to energy fuel charges, including the carbon tax in the private sector and carbon offset costs in the public sector.

Provincial and municipal regulations have introduced specific energy and GHG related measures to limit the building sector footprint. This includes the introduction of the carbon tax placed on all fossil fuel purchases that largely impacts the operational costs of existing buildings. New building energy code requirements also impact the cost and performance of new buildings and major renovations.

A large portion of multi-family residential buildings in British Columbia were constructed in the 1960's, 70's and 80's and use large quantities of fossil fuels for heating the buildings and domestic hot water. Most of the heating and ventilation systems are outdated or reaching the end of their life. With this aging building stock there is a great opportunity to upgrade HVAC equipment and consider alternate strategies to reduce energy consumption, GHG emissions and long-term operational costs.

BC Provincial GHG Targets

The Province has set targets for GHG emission reductions over time. To reach these goals, reducing GHG emissions in the building sector is is important, as it is a large contributor of GHG emissions.

- By 2020, GHG emissions should be 33% lower than 2007 levels
- By 2050, GHG emissions should be 80% lower than 2007 levels

New Energy Code Requirements

The BC Building Code 2012 and the new Vancouver Building By-Law 2014 have adopted stricter energy efficiency requirements, which will help further reduce energy consumption and GHG emissions from buildings.

The code references NECB 2011 or ASHRAE 90.1-2010 for Part 3 buildings and have updated requirements based on the National Building Code for Part 9 buildings.

BC Provincial Carbon Costs

The BC carbon tax encourages the reduction of GHG emissions by putting a price on carbon.

The carbon tax and the carbon offset costs combined add an increased cost of $2.75/GJ, or a 34% increase, when applied to the cost of natural gas per delivered gigajoule (GJ) of energy.

- BC carbon tax is $30 per tonne of carbon (private sector)
- BC carbon offset cost is $25 per tonne of carbon (public sector)

SETTING PROJECT GOALS

When evaluating opportunities for HVAC upgrades, it is important to understand how equipment selection influences GHG emissions, energy consumption, and energy costs relative to invested capital over time. Setting specific project goals before starting the HVAC upgrade process will help in the decision making process as different goals could lead to different system selections.

The GHG emissions associated with natural gas consumption is approximately seven times higher per generated kWh than emissions from electricity generated through hydro power. On the other hand, at current utility rates, energy costs for electricity are now more than twice as expensive as natural gas on a per energy unit basis. These competing factors can influence upgrade decisions depending on the objective of the project. The impact of imported electricity on overall GHG emissions from BC buildings is not considered in this report.

To illustrate the energy cost, energy performance and GHG emissions for a typical MURB's energy needs, Figure 1 shows the difference between the three factors per building energy end-use category.

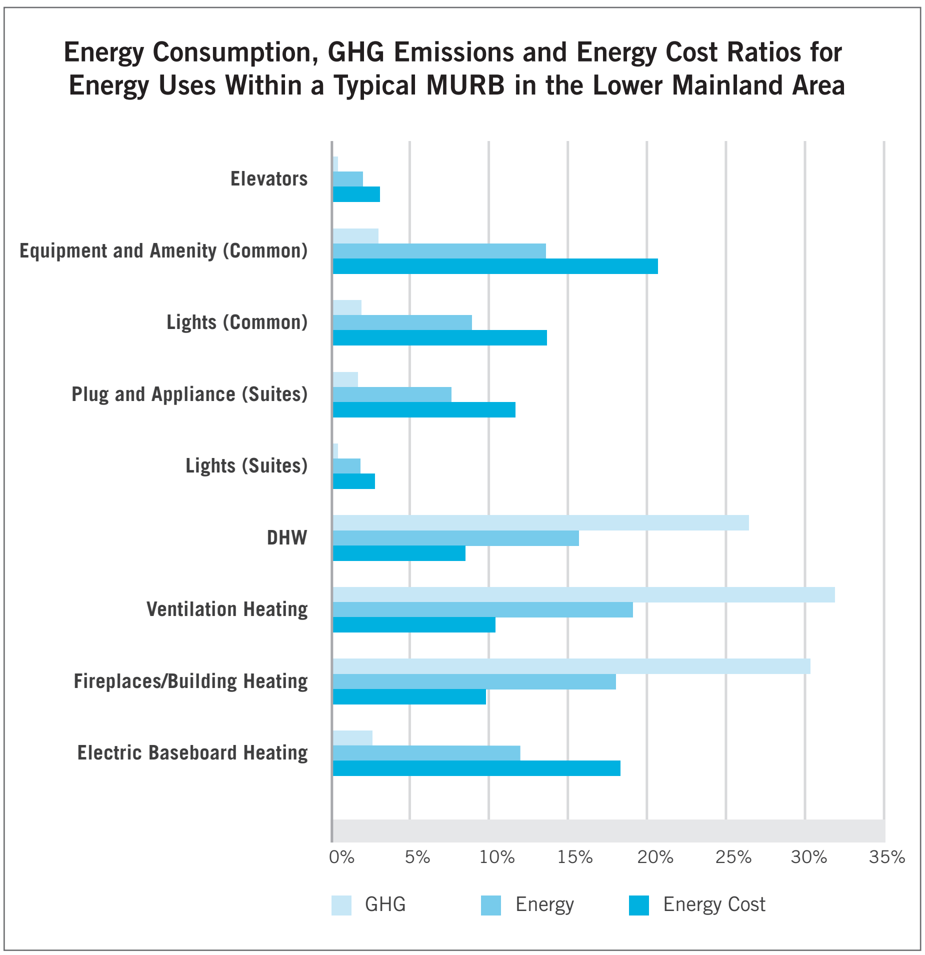

Figure 1: Energy consumption, GHG emissions and energy cost ratios for different energy end-uses in a typical MURB in the Lower Mainland area[1]

Emission Factors

- Electricity 23 tonnes CO_2/GWh (BC Hydro GHG intensities)
- Natural Gas 180 tonnes CO_2/GWh

[1] Data extracted from the 2011 HPO report: *Energy Consumption and Conservation in Mid- and High Rise Residential Buildings in British Columbia*, using emission rates from BC Hydro 2011 GHG intensities, GRI -EN16 reporting 2011, and assumed energy cost of $0.08/kWh for electricity and $7.89/GJ for natural gas

THE IMPORTANCE OF LOAD REDUCTION FOR GHG SAVINGS

To achieve energy and GHG savings, it is important to reduce the initial load in the building before spending additional capital on upgrading the HVAC system or installing renewable technologies. Figure 2 shows a general approach to an effective upgrade process.

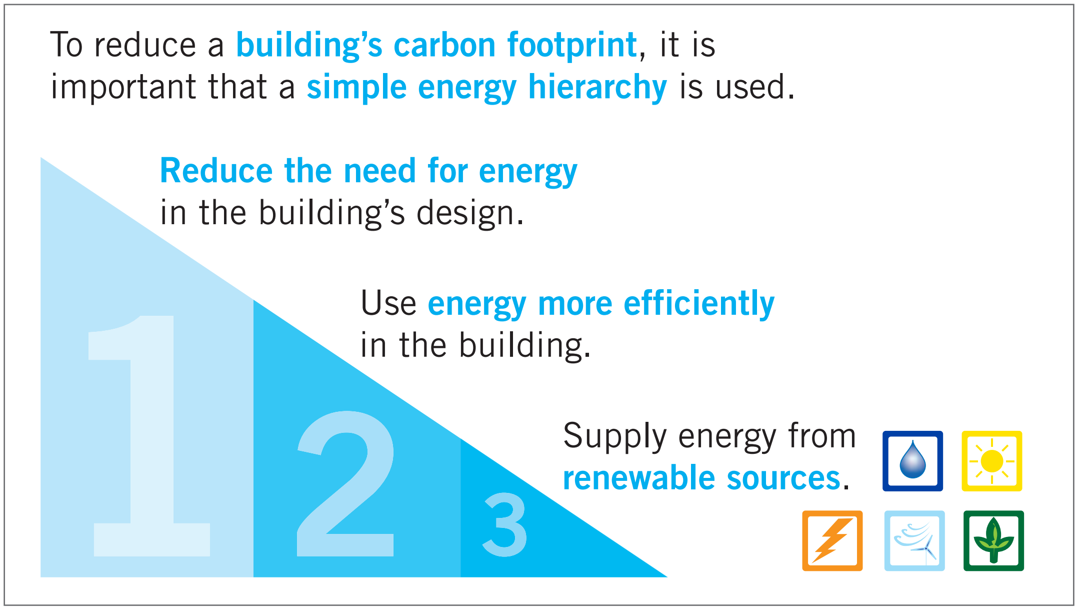

Figure 2: To achieve energy and GHG savings, it is important to reduce the initial load in the building before spending additional capital on upgrading the HVAC system or installing renewable technologies.

As heating energy accounts for approximately 65% of the total energy consumption in a MURB in BC, this provides a large opportunity for reductions. The heating demand can further be divided into three primary building heating needs:

1. **Envelope heating** represents approximately 40% of total heating energy load. Heat used to offset envelope heat loss through walls, roofs and windows is usually provided by hydronic or electric baseboard heating. Envelope upgrades are not discussed in this report but cannot be considered in isolation as they impact the effectiveness of the HVAC system. If the envelope is well insulated, airtight and has a good glazing and framing system, heat loss is reduced. As a result, the load on the central heating system is significantly reduced and the HVAC system can be re-sized to work more effectively.
2. **Ventilation air heating** represents approximately 30% of total heating energy load. Ventilation for a multi-floor MURB is typically provided by roof make-up air units (MAU) through a corridor pressurization distribution system. The MAU is typically natural gas heated by a hot water coil or gas furnace, or not heated at all, and sometimes cooled. Corridor pressurization ventilation is, in many cases, ineffective and does not result in adequate ventilation into the suites due to pressure imbalances, tight door undercuts or shortcuts in the corridor supply air system where the air travels into elevator shafts and similar openings instead of into the suites. This has implications on the air balance (pressure levels) in the building, occupant comfort and energy consumption for envelope heating as this may lead to windows being open in the winter to provide fresh air.
3. **Domestic hot water heating** represents approximately 30% of total heating energy load. Domestic hot water is typically heated by dedicated gas fired tanks. Another common alternative is to heat the DHW with the same boilers as those used for the building heating system.

GHG EMISSIONS FOR TYPICAL MURBS IN BC

The GHG profile of a MURB includes emissions from electricity consumption for lighting, appliances, fans, pumps and baseboard heating, and emissions from natural gas consumption used for building heating needs. The GHG profile depends on how large the ratio between electricity and natural gas consumption is and varies depending on building type. Figure 3 presents an overview of which building components contribute to the major greenhouse gas emissions from a typical MURB with fireplace in the Lower Mainland area. Addressing building heating needs is the major area of focus to achieve large GHG reductions.

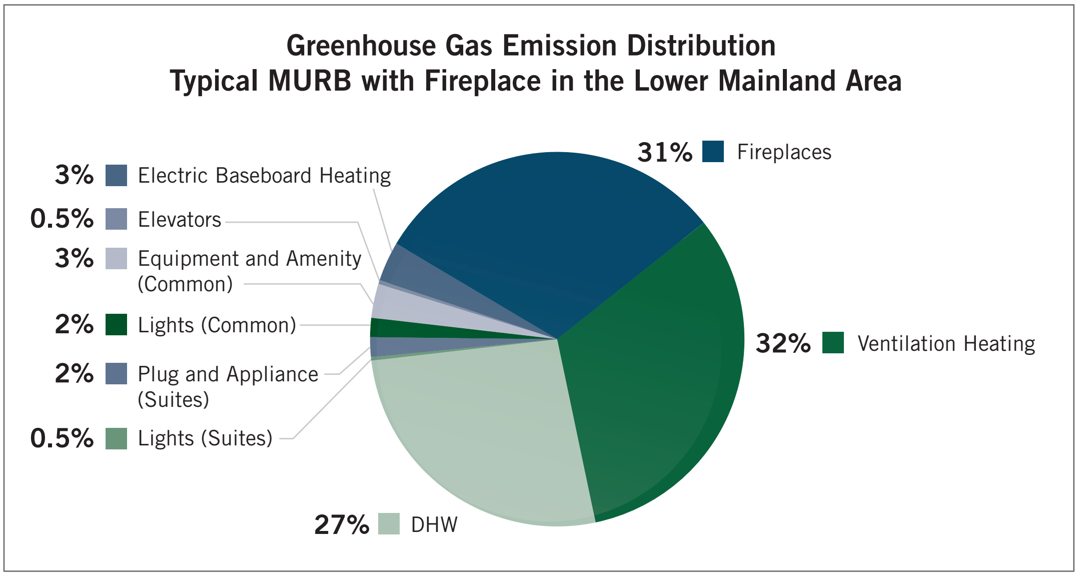

Figure 3: Greenhouse gas emission distribution in a typical MURB with fireplace in the Lower Mainland area[1].

GHG REDUCTION OPPORTUNITIES AND BUILDING HVAC SYSTEM

The most effective strategy for an upgrade largely depends on the existing building context, building size, age, envelope, HVAC system type, and previous upgrades completed in the building. However, the main focus to achieve large GHG reductions through the HVAC system upgrade is to improve heating energy efficiency within the three main identified areas.

1. **Building heating** – including in-suite heating system, controls and central building heating system. Opportunities exist to upgrade the boiler system, thermostat set-points, baseboard efficiencies, combustion efficiencies and use of control strategies for optimized part-load performance.
2. **Ventilation heating** – including make-up air ventilation heating and ventilation effectiveness. Opportunities exist to look at alternative ways to preheat the ventilation air or using heat recovery systems. Improving ventilation effectiveness into the suites through continuous operation of bathroom exhaust fans might be suitable and would assist with the potential for heat recovery for lower buildings. This would also help avoid the issue of open windows in winter for ventilation. In addition, updated ventilation code requirements for projects seeking LEED certification require ventilation to be supplied directly into the residential suites that could impact HVAC system selection for new buildings and major upgrades.
3. **Domestic hot water heating** – opportunities exist to look at reducing the hot water load by using more efficient fixtures and appliances, insulating the tank and pipes, selecting higher efficiency heating equipment and using preheat from building hot water return, heat pump or a solar hot water heater.

[1] Data extracted from the 2011 HPO report: *Energy Consumption and Conservation in Mid- and High Rise Residential Buildings in British Columbia*, using emission rates from BC Hydro 2011 GHG intensities, GRI -EN16 reporting 2011.

The following checklist gives an overview of strategies that could be considered for improved HVAC system performance when doing an upgrade.

Checklist for HVAC Upgrade Opportunities		
Checked	**Item**	**General Comments**
A. Load Reduction Strategies		
❑	**Building envelope and HVAC performance**	Review building load reduction strategies, especially HVAC system selection, in combination with building envelope performance.
B. Building Heating System		
❑	**In-suite heating**	Review performance of baseboards and in-suite heating system to optimize output. Consider initiating building-wide fireplace pilot light shut-off program in summer, and installation of fireplace timers.
❑	**Boiler upgrades**	Review opportunities to upgrade boiler with higher efficiency equipment.
❑	**Achieving high combustion efficiencies**	Review opportunities for achieving high combustion efficiencies through optimized supply and return temperatures, outdoor reset, and effective boiler modularity for part-load performance.
❑	**Effective heat pump applications**	Review opportunities for heat pump applications for single unit heating, or for central ventilation and hot water preheat.
C. Domestic Hot Water System		
❑	**Low-flow fixtures**	Review opportunities for installing low-flow fixtures to reduce hot water load.
❑	**Drain heat recovery**	Review opportunities for using drain heat recovery to reduce hot water load.
❑	**Combustion efficiencies**	Review tank heat source and efficiency ratings.
❑	**Preheat by building hot water return water**	Review opportunities for domestic hot water preheat from the building return hot water.
❑	**Preheat by air-source heat pumps (ASHP) or by solar hot water heater**	Review opportunities for domestic hot water preheat by air-source heat pump or solar hot water heating.
D. Building Ventilation System		
❑	**Minimum ventilation performance**	Review performance of in-suite ventilation to meet minimum ventilation requirements and optimize flow.
❑	**Ventilation air heat recovery**	Review opportunities for ventilation heat recovery and review performance to maximize effectiveness.
❑	**Ventilation air preheat**	Review opportunities for preheat of ventilation air by air-source heat pump or by building return hot water.

THINGS TO CONSIDER

Some of the upgrade opportunities are better suited for certain buildings compared to others depending on the existing conditions. Before deciding on an approach, a few items to consider are whether:

- **An envelope upgrade has been done.** If not, the heat loss through the envelope will be the same and the improved performance of the upgraded heating system might not outweigh the less efficient envelope. Consider investing in an upgraded envelope first as part of a load reduction strategy, including reviewing exterior insulation, airtightness and improved glazing and frame systems. This will largely impact baseboard performance. If baseboard upgrades are necessary, determine the most effective hot water temperatures and the impact on boiler sizing. If a condensing boiler is selected based on higher efficiency rating and the envelope is inefficient, it will be challenging to achieve the lower return water temperatures required for the boiler to operate effectively, and there is a risk that the condensing system will not perform as intended.
- **The ventilation rates are meeting code.** If not, the suite ventilation supply efficiency should be reviewed, or the volumes upgraded for improved indoor air quality and the ventilation heating system carefully reviewed. If the building has exhausts to the roof, there might be an opportunity to upgrade with a central heat recovery ventilator and continuous exhaust. If the exhausts are local through the wall, heat recovery is more challenging and improving the heating system in the make-up air unit by looking at preheat options from air-source heat pump or building return water is probably more efficient.
- **The building water faucets and fixtures have been upgraded.** If not, consider replacing old inefficient fixtures with high efficiency low-flow fixtures. This is a cost effective way to reduce the domestic hot water load. Secondly, look at using preheat and upgrading the DHW heating equipment for increased efficiencies.

CASE STUDY EXAMPLE

To get a sense of relative performance on energy, GHG and cost for a "standard" hydronic heated high-rise apartment building compared to an HVAC retrofitted building, the following case study is presented. HVAC upgrade components are isolated and upgrade options on building envelope, plumbing fixtures and appliances that would further help reduce the energy load are not taken into consideration. The example includes a full upgrade on the baseboard system which might not have been required if window and envelope upgrades had been completed. Costs are estimates and can vary greatly from one project to another.

Assumptions for High-Rise Apartment Building Baseline and Retrofit Case

High-Rise (8-24 Storeys)	Baseline High-Rise	Retrofit High-Rise
Area (m^2) (units+corridors)	14,000	14,000
Units	200	200
Central Heating	Conventional old boiler 70% efficiency*	Condensing boiler 92% efficiency* (95% nominal)
In-suite Heating	Old hydronic baseboards	Baseboards type SlantFin for condensing temp, 4"fins
Ventilation MAU	Existing MAU on roof, approx 20,000 cfm	Upgraded MAU on roof, 20,000 with ASHP for ventilation preheat
	Assuming 100 cfm supply per suite	100 cfm/suite (exhaust and supply)
	Assuming 15 HP fan motor (11.2 kW)	Assuming 15 HP fan motor (11.2 kW)
	Heating MAU: HW heating coil	Continuous fan operation
	Continuous fan operation	ASHP, air-to-air, DX system, for preheat
Exhaust Fan	30-50 cfm exhaust/suite (toilet)	30-50 cfm exhaust/suite (toilet)
	Intermittent manual operation, 0.2 kW/fan, assumed 2 hrs per day	Continuous exhaust, minimum speed, low noise
		Occupancy sensors for in-suite exhaust for high speed operation during occupancy
DHW	Conventional old boiler, 70% efficiency*	ASHP for preheat + 85% mid-efficiency boiler for booster

* denotes seasonal efficiency

Energy and GHG Performance Estimates – High-Rise

Energy End-Use	Baseline	Retrofit with ASHP Preheat	Retrofit no ASHP Preheat
DHW (natural gas, ekWh/m^2)	56	20	43
Ventilation (natural gas, ekWh/m^2)	56	15	43
Envelope Heating (natural gas, ekWh/m^2)	75	57	57
Total Electricity (kWh/m^2)	67	84	67
TOTAL ekWh/m^2	256	177	210
Energy Consumption Summary (eMWh/yr)	3,578	2,473	2,942
Energy Cost Summary ($/yr)	150,231	131,123	131,884
Total GHG Emissions Summary (tCO_2/yr)	499	261	385
Financial Estimate Summary			
Capital Investment ($)	-	220,000	140,000
Carbon Tax Savings ($/yr)	-	7,127	3,426
Simple Payback (years)	-	6	4
Equity Payback (years)	-	7	5
Summary of Savings			
Energy Savings		31%	18%
Energy Cost Savings (including carbon tax)		17%	14%
GHG Emissions Savings		48%	23%

By switching to a condensing boiler as the main heating source, using an ASHP for preheat, and a mid-efficiency boiler as DHW booster, approximately 48% GHG emissions savings, 31% energy savings and 17% energy cost savings could be achieved with an equity payback of 7 years.

This example shows that the energy cost savings on a yearly basis are fairly similar with or without the ASHP providing preheat. This is due to the difference in utility price between electricity and natural gas that partly offsets the benefit of the heat pump efficiency. However, it can be worth investing in the more expensive ASHP system when looking at the performance of energy cost over time and to achieve more than double the GHG reductions. Possible future increases to rates on the carbon tax would further improve the energy cost performance over time. Another benefit with the ASHP approach is that it could provide cooling on hot summer days for the ventilation.

KEY POINTS

- BC provincial and municipal regulations have started to mandate higher performing buildings and building systems in an effort to reduce energy consumption and curb GHG emissions. New energy codes came into effect on December 20th, 2013 as a step in this direction.
- The provincial carbon tax and carbon offset cost provides a financial incentive to invest in upgrading to higher efficiency HVAC systems in aging building stock.
- In BC, heating accounts for 65% of a typical MURB's energy use. A majority of this heating is provided with natural gas, which has a seven times higher carbon footprint than electricity, but currently costs less than half on a per unit energy basis in BC. This largely impacts the selection of optimal HVAC system from an energy, energy cost and greenhouse gas reduction perspective.
- To achieve large GHG reductions in a MURB, focus on improving energy efficiency for heating the building, fresh air and domestic hot water.
- To reduce a building's greenhouse gas emissions through HVAC upgrades, a simple energy reduction hierarchy should be considered for efficient capital investment. First, reduce the building load with an improved envelope and efficient fixtures and appliances. Secondly, select a high efficiency HVAC system, and finally, consider supplying energy from renewable energy systems.

For More Information

1. *British Columbia: Climate Action for the 21st Century.* Government of British Columbia. Available at http://www2.gov.bc.ca/
2. *Energy Use in Mid to High-Rise Residential Buildings.* Homeowner Protection Office, 2013. Available at www.bchousing.org/
3. *Energy Consumption and Conservation in Mid-and High Rise Residential Buildings in British Columbia.* RDH, 2011. Available at www.bchousing.org/
4. *Towards Carbon Neutral Buildings in BC: Framework for High-Rise Residential Buildings.* Light House Sustainable Building Centre and Intep LL, 2012. Available at www.sustainablebuildingcentre.com.
5. *City of Vancouver-Passive Design Toolkit-For Homes.* Light House Sustainable Building Centre and Dr. Guido Wimmers, 2009. Available at www.vancouver.ca.

Homeowner Protection Office
Branch of BC Housing

HPO Technical Research & Education

1701- 4555 Kingsway
Burnaby, BC V5H 4V8

Phone: 778 452 6454
Toll-free: 1 866 465 6873

www.hpo.bc.ca
www.bchousing.org
Email: hpo@hpo.bc.ca