

# **Air-Source Heat Pump Retrofits in Mid Vancouver Island**

Backup Furnaces and Fuel Switching  
Billings Analysis  
Life Cycle Costs  
Electrical Demand  
Cooling Loads

By

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## Executive Summary

Air-source heat pumps are an ideal space heating technology for the mild climate of southern and coastal BC. Consuming a small amount of electricity, heat pumps move heat energy available in the outdoor air to indoors. Their operating efficiency has improved significantly over recent years and prices have dropped. Sales of residential air-source heat pumps are growing steadily for new and existing houses in BC; 1,600 units were sold in the year 2000, while in 2006 8,200 were sold. The findings of this study and recent field studies in Oregon provide ample evidence for the Province to help accelerate the sales of air-source heat pumps. The technology is expanding mostly on Vancouver Island where natural gas is priced higher and electric heating is traditional. It needs relatively more promotion in the Lower Mainland and Southern Interior.

370 houses in mid Vancouver Island were surveyed to determine if the original furnace was switched at the same time as the heat pump retrofit. Notably, electric heating was originally in 16% (60) of the houses; after the heat pump retrofits 52% (193) were using electric backup furnaces. Most of the original 159 oil furnaces were discarded and replaced with an electric furnace whereas most of the 124 natural gas furnaces were kept as the backup. The move from oil furnaces to electric was due to the high price of fuel, the liability of oil storage tanks and unavailability of natural gas.

By analyzing several years of energy bills from 10 houses that had recently installed a heat pump, the resulting energy savings, cost savings and GHG savings were determined. The average savings realized for space heating were 58% on energy, 57% on heating costs, and 79% on GHG emissions for the average case and 218% for the marginal case:

**Average Annual Savings for the 10 Study Houses**

<b>Heating Cost</b>	<b>Marginal GHG Emissions (tonnes)</b>	<b>Average GHG Emissions (tonnes)</b>
\$880	3.00	3.35
57%	218%	79%

Retrofitting heat pumps into all 229,115 detached houses and mobiles on Vancouver Island could reduce annual GHG emissions by approximately 660,000 tonnes - assuming three tonnes of GHG are saved per retrofit. Similarly, heat pumps retrofit into all 956,012 detached houses, row/town houses and mobiles in the Lower Mainland, on Vancouver Island and in the Southern Interior would save 2.8 million tonnes of GHG emissions per year<sup>1</sup>. BC's clean electricity could be leveraged by a factor of 2.5 – a heat pump's seasonal energy efficiency - to vastly reduce the GHG emissions from natural gas, oil and electric furnaces.

<sup>1</sup> This is an approximate estimate only. The 2006 End Use Study data could be used for a more accurate estimate.

Among the 16 houses that were considered for billings analysis, two had significant performance problems with the heat pump, likely caused by new thermostats. No consistent standard is practiced for designing, installing or commissioning air-source heat pumps, although the CSA standard C273.5-1980 provides one. It appears that the CSA's recommended sizing method, based on the cooling load, is not appropriate for the coastal BC climate. There is an opportunity and need for the industry to develop and follow better standards for heat pump sizing, installation and commissioning.

The Net Present Value (NPV) of the initial cost of a heat pump retrofit plus its operating cost savings over 15 years varied from -\$756 for a mid-efficient natural gas furnace to \$13,515 for a low-efficiency oil furnace. Notably, the NPV calculated for upgrading a mid-efficient gas furnace to a 92% AFUE furnace was -\$2,857 - worse than for the heat pump retrofit. The economics of retrofitting a natural gas furnace would be worse in the Lower Mainland where natural gas is cheaper; a more detailed LCC analysis should be carried out for this particular case. The NPV of switching from baseboard electric to a heat pump was estimated at -\$3,720. We suspect the NPV of any furnace to heat pump retrofit would be higher than upgrading windows or insulating a basement or crawl space.

A theoretical analysis of electrical demand showed heat pump retrofits generally increase the electrical peak demand, but decrease it for existing electric furnaces. Based on the theoretical estimates, the collective demand from 350 heating systems surveyed increased only 10%, while the peak demand increased by 117%. A variety of existing technology options along with best design practices discussed in the report can be used to mitigate peak demand. Increased peak demand is the only serious drawback of air-source heat pumps, yet it is also inevitable if clean electricity is to be used strategically to mitigate GHG emissions. Therefore, BC Hydro would need to be proactive in managing peak demand and freeing existing capacity for more heat pumps (and other electrical substitutes for fossil fuels) via more aggressive DSM.

The additional energy consumption for summertime space cooling is shown to be small for a heat pump used on Vancouver Island. Unlike Vancouver Island, there is a large market for central air conditioners in the Southern Interior. An opportunity therefore exists to transition this air conditioning market toward heat pumps and generate additional benefits.

The Province should consider the following additional research on air-source heat pumps:

- Develop a sizing method appropriate for BC.
- Assist in improving training and certification for the industry.
- A billings analysis or a more detailed theoretical economic model for retrofitting baseboard heated houses.
- A comparison of the LCC of heat pump retrofits to various building envelope upgrades.
- An LCC analysis for adding heat pumps to existing natural gas furnaces in other regions of BC.
- Economic modeling for retrofitting MURBs with split systems or ductless mini-split systems.

- Technology options such as Load Management Controls to reduce peak demand. Quantify more accurately the peak demand with various mitigating design and technology options for heat pumps.
- Field monitoring at several houses to measure the space heating energy consumption, electrical consumption of the heat pump, energy consumption of the backup furnace, and peak demand of the heat pump and backup furnace. This study should include some two-stage or dual compressor models.

## 1.0 Introduction

The popularity of air-source heat pumps for new houses and as retrofits is growing on Vancouver Island. One heating contractor estimates that approximately 5,000 heat pumps are being installed on the Island each year<sup>2</sup>. The growth is due to a number of factors: the increasing cost of conventional energy; a decrease in the installation cost; greater awareness of the technology; improved heating efficiency; the ability to cool; and concern for the environment.

Utilizing mostly renewable energy, heat pumps promise to reduce overall energy consumption and GHG emissions. Typical installations decrease the use of fossil fuel heating while increasing electricity consumption. Coastal BC's mild climate is one of the best suited in the world for air-source heat pumps, and they are even being used successfully in much colder locations like Prince George. Conceivably, air-source heat pumps will continue to be popular as conventional heating fuels become more expensive.

### Typical Advantages of Heat Pumps

- Pricing is now at a level where a retrofit is affordable to many homeowners
- Simple Payback Period is normally three to ten years
- Very high level of customer satisfaction
- Utilizes renewable energy contained in outdoor air, and is the most cost-effective form of renewable energy technology in Canada
- Reduces energy consumption for space heating (at the house) by approximately 50% to 75% compared to conventional fuels or electric resistance
- Reduces the cost of space heating up to 75%
- Reduces GHG and other emissions
- For a house currently heated with electricity, a heat pump is expected to reduce both load and peak electrical demand
- Efficiency of the technology continues to improve. The HOT2000 energy model calculates the seasonal energy efficiency of a heat pump plus backup furnace at 250%.

### Potential Disadvantages of Heat Pumps

- Adds both load and demand to the electrical grid, except in cases of houses previously heated with electricity where the opposite is expected.
- Adds a new summertime electrical load due to cooling, since many houses did not previously use cooling. The summer cooling load in Coastal BC is very small however.
- Creates noise outdoors, although outdoor sections are becoming quieter.

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<sup>2</sup> Northstar Heating and Cooling, Nanaimo

## 2.0 Survey of 370 Backup Furnaces

From a group of 564 EnerGuide for Houses “B” evaluations, 370 houses installed air-source heat pumps between January, 2004 and May, 2006. The original heating systems and the new backup furnaces for these heat pump retrofits are listed below.

The houses were located in the area bounded by Duncan/Lake Cowichan to the south, Campbell River to the north and Port Alberni to the east.

In summary:

- Electric heating was originally in 16% (60) of the 370 houses. After the heat pump retrofits, this had increased to 52% (193) with electric backup heating. 48% (177) of the 370 continue to use a non-electric backup furnace.
- 43% (133) of the houses heated with oil, natural gas, propane or wood switched to an electric backup furnace.
- Of the 165 new electric furnaces that were installed, 91 switched from oil, 21 switched from natural gas, 18 switched from wood, and three switched from propane. 21 switched from electric baseboards, and 10 were replacements of existing electric furnaces.
- Five of 124 natural gas furnaces were upgraded to a more efficient natural gas furnace. 98 natural gas furnaces were left unchanged.
- 10 of 159 oil furnaces were upgraded to a more efficient fossil fuel backup furnace. 58 oil furnaces were left unchanged.
- 147 or 40% of the 370 houses undertook building envelope energy efficiency upgrades. These efficiency upgrades included any of insulation, windows, doors and/or reduced air leakage.
- 60% (341) of 564 ‘B’ evaluated houses undertook envelope efficiency upgrades. The other 40% (223) only installed a new heating system.
- The average COP of the heat pumps installed was approximately 3.4. EnerGuide for houses data did not record HSPF or SEER values.

**Table 1: Heating Fuels - Original and New Backups**

	<i>Electric</i>	<i>Oil</i>	<i>Natural Gas</i>	<i>Propane</i>	<i>Wood</i>	<i>Total</i>
Original Qty	60	159	124	7	20	370
%	16%	43%	34%	2%	5%	
New Qty	193	63	108	5	1	370
%	52%	17%	29%	1.3%	0.3%	
% Change	+222%	-60%	-13%	-29%	-95%	

**Table 2: Type of Heating Systems - Original and New Backups**

	<i>Electric Furnace</i>	<i>Electric Baseboard</i>	<i>Electric Boiler</i>	<i>Oil Furnace</i>	<i>Gas Furnace</i>	<i>Propane Furnace</i>	<i>Wood Furnace or Stove</i>	<i>Total</i>
Original Qty	37	21	2	159	124	7	20	370
%	10%	6%	0.5%	43%	34%	2%	5%	
New Qty	192	0	1	63	108	5	1	370
%	52%	0%	0.3%	17%	29%	1%	0.3%	
% Change	419%	-100%	-50%	-60%	-13%	-29%	-95%	

**Table 3: Original Electric Heating and Switches**

Original		New Backup Furnace	
<i>Qty</i>	<i>Electric</i>	<i>Electric</i>	<i>No Change</i>
21	Baseboard	21	
37	Furnace	10	27
2	Boiler	1	1
60	TOTAL	32	28
	%	53%	47%

**Table 4: Original Natural Gas Furnaces and Switches**

Original		New Backup Furnace			
<i>Qty</i>	<i>Natural Gas</i>	<i>Electric</i>	<i>Nat Gas - Mid</i>	<i>Nat Gas - High</i>	<i>No Change</i>
14	Hi Efficiency	2			12
79	Mid Efficiency	9		3	67
31	Low Efficiency	10	1	1	19
124	TOTAL	21	1	4	98
	%	17%	1%	3%	79%

**Table 5: Original Oil Furnaces and Switches**

Original		New Backup Furnace						
Qty	Oil	Electric	Oil - Mid	Oil - High	Nat Gas - Mid	Nat Gas - Hi	Propane - Mid	No Change
1	Hi Efficiency							1
20	Mid Efficiency	4						16
138	Low Efficiency	87	2	2	4	1	1	41
159	TOTAL	91	2	2	4	1	1	58
	%	57%	1.3%	1.3%	2.5%	0.6%	0.6%	37%

**Table 6: Original Propane Furnaces and Switches**

Original		New Backup Furnace	
Qty	Propane	Electric	No Change
1	Hi Efficiency		1
1	Mid Efficiency	1	
5	Low Efficiency	2	3
7	TOTAL	3	4
	%	43%	57%

**Table 7: Original Wood Heating and Switches**

Original		New Backup Furnace		
Qty	Wood	Electric	Oil - Mid	No Change
2	Mid Efficiency	2		
18	Low Efficiency	16	1	1
20	TOTAL	18	1	1
	%	90%	5%	5%

**Table 8: Houses carrying out Envelope Upgrades - by Heating Fuel**

	Electric	Oil	Natural Gas	Propane	Wood	Total
Total Houses	60	159	124	7	20	370
No. with Envelope Upgrades	22	78	35	2	10	147
%	37%	49%	28%	29%	50%	40%

### 3.0 Pre/Post Heat Pump Energy Billings Analysis for 10 Houses

Billings analyses were carried out on three electrically heated, three natural gas heated, and four oil heated houses. Profiles of each house are found in Appendix B and the energy consumption figures copied from the bills are included in Appendix C.

The following factors for heating fuels are used throughout the report:

**Table 9: Energy Content, Price and GHG Emission Factors for Space Heating Fuels**

Fuel	Energy Content	Price	GHG Emission Factor (kg CO <sub>2</sub> e/GJ)	Source
Electricity - marginal	277.78 kWh/GJ	\$0.0633/kWh	100.00	MEMPR (360 tonne/GWh)
Electricity - average	277.78 kWh/GJ	\$0.0633/kWh	9.17	BC Hydro 2005 Annual Report (33 tonne/GWh)
Natural Gas	n/a	\$13.715/GJ	63.10	NRCan (RETScreen)
Oil (#2 Heating)	0.3875 GJ/Litre	\$0.95/Litre	74.72	NRCan (RETScreen)

Following are the results of the Billings Analysis.

**Table 10: Annual Savings after Installing an Air-Source Heat Pump**

Homeowner Name	Original Heating System	Heat Pump and Backup	Original Heating Energy (GJ/yr)	Space Heating Annual Savings <sup>1</sup>			
				Energy (GJ) <sup>2</sup>	Energy Cost (\$)	Marginal GHG (tonnes)	Average GHG (tonnes)
<b>Jim R.</b>	Electric - 20 kW furnace	3-ton / New 10 kW electric furnace	64	34	\$547	3.40	0.31
<i>% Savings</i>				<i>53%</i>	<i>53%</i>	<i>581%</i>	<i>53%</i>
<b>Pauline G.</b>	Electric - 20 kW boiler	5-ton / New 20 kW electric furnace	141	80	\$1,403	7.98	0.73
<i>% Savings</i>				<i>57%</i>	<i>57%</i>	<i>618%</i>	<i>57%</i>
<b>James E.</b>	Electric - 20 kW furnace	3-ton / Original furnace	61	25	\$442	2.52	0.23
<i>% Savings</i>				<i>64%</i>	<i>64%</i>	<i>695%</i>	<i>64%</i>
<b>Marcel P.</b>	Natural Gas - low efficient	2-ton / Original furnace with spark ignition	41	10	\$46	-0.26	1.97
<i>% Savings</i>				<i>25%</i>	<i>8%</i>	<i>-10%</i>	<i>77%</i>

**Table 10, continued**

Homeowner Name	Original Heating System	Heat Pump and Backup	Original Heating Energy (GJ/yr)	Space Heating Annual Savings <sup>1</sup>			
				Energy (GJ) <sup>2</sup>	Energy Cost (\$)	Marginal GHG (tonnes)	Average GHG (tonnes)
<b>James L.</b>	Natural Gas - mid efficient	2-½ ton / Original furnace	48	26	\$306	1.14	2.43
<i>% Savings</i>				<i>55%</i>	<i>46%</i>	<i>37%</i>	<i>80%</i>
<b>Helena S.</b>	Natural Gas - mid efficient	4-ton / New 15 kW electric furnace	118	67	\$729	2.38	6.99
<i>% Savings</i>				<i>57%</i>	<i>45%</i>	<i>32%</i>	<i>94%</i>
<b>John M.</b>	Oil Furnace - 67% efficient	2-½ ton / New 10kW electric furnace	51	67	\$1,809	4.58	6.21
<i>% Savings</i>				<i>79%</i>	<i>85%</i>	<i>72%</i>	<i>97%</i>
<b>Terry O.</b>	Oil Furnace - 68% efficient	2-½ ton / Original oil furnace	71	33	\$643	2.14	4.50
<i>% Savings</i>				<i>53%</i>	<i>64%</i>	<i>40%</i>	<i>85%</i>
<b>Norm N.</b>	Oil Furnace - 67% efficient	2-½ ton / Plug-in electric heaters	73	46	\$1,340	2.76	5.18
<i>% Savings</i>				<i>63%</i>	<i>74%</i>	<i>51%</i>	<i>95%</i>

**Table 10, continued**

Homeowner Name	Original Heating System	Heat Pump and Backup	Original Heating Energy (GJ/yr)	Space Heating Annual Savings <sup>1</sup>			
				Energy (GJ) <sup>2</sup>	Energy Cost (\$)	Marginal GHG (tonnes)	Average GHG (tonnes)
Terry H.	Oil Furnace - 80% efficient furnace	2-ton / Original oil furnace	79	56	\$1,532	3.35	4.90
<i>% Savings</i>				<i>71%</i>	<i>77%</i>	<i>61%</i>	<i>89%</i>
<b>Average of all 10 Houses</b>			75	45	\$ 880	3.00	3.55
<i>% Savings</i>				<i>58%</i>	<i>57%</i>	<i>218%</i>	<i>79%</i>

1. Savings figures incorporate both heating and cooling energy consumption of the heat pump and the backup furnace.
2. Adjusted for Heating Degree Days

### 3.1 Discussion

#### Energy Savings

Calculations were made to determine the non-heating season baseloads and space heating energy consumption adjusted for heating degree days. The savings figures listed account for both heat pump and backup energy consumption plus any new energy consumption for cooling. Only three houses reported using cooling to any extent in the summer and this was supported by the electricity bills.<sup>3</sup> A mobile home (*Marcel P.*) had the highest cooling load, approximately 8 GJ, which cancelled out a large portion of the energy savings for heating.

With the exception of *Marcel P.*, all heat pumps reduced GHG emissions for both the marginal and average case. The marginal GHG reductions in two gas heated houses, *James L.* and *Helena S.*, demonstrate that when Combined Cycle power is used the heat pump has a higher net energy efficiency compared to the original 80% efficient gas furnace.

Nine houses saved over 53% on their space heating energy consumption. These savings are lower than predicted by HOT2000 for an ideal heat pump: 18% lower for gas furnaces, 11% for oil and 5%

<sup>3</sup> Historically, Nanaimo has 77 cooling degree days; Vancouver has 44. Source: Environment Canada

for electric (see Table 11). The HOT2000 model used a house with a 60 GJ heating load and a 3-ton heat pump sized to match the design heat loss. It does not consider cooling energy.

**Table 11: Comparison of Savings Estimated by HOT2000 and from the Billings Analysis**

Backup Furnace	Operating Cost Savings - %		Space Heating Energy Savings - %	
	HOT2000	Billings Analysis	HOT2000	Billings Analysis
Gas - 80% Efficient	60%	33%	67%	45%
Gas - 80% Efficient not including the mobile home	60%	46%	67%	56%
Oil - 71% Efficient	80%	74%	73%	65%
Electric Furnace	61%	58%	61%	58%

The inferior energy savings determined from the billings analysis are likely due to under-sized heat pumps and some use of cooling during summer which is not considered in the HOT2000 model. In the case of the mobile home it due to the high use of cooling. As shown in Table 12, seven of 10 heat pumps were undersized with respect to the heat loss at 0 °C (a reasonable balance point to size the heat pump for) estimated by HOT2000. Under-sizing the heat pumps could have been caused by:

- The contractor’s inaccurate estimate of the design heat loss and balance point heat loss;
- The heat pump was sized mainly according to the practical airflow capacity of existing ductwork. Upgrading the ducts was deemed unfeasible;
- The contractor under-sized the heat pump to offer a lower price.

Various deficiencies or discrepancies could also reduce the predicted energy savings. For example air flow was designed too low or ducting was designed too small; the heating set-point temperature was increased by the occupants and; the original furnace’s operating AFUE was higher or lower than assumed.

**Table 12: Actual Size of Heat Pump Installed vs. the Ideal Size**

Name	Nominal Capacity of Heat Pump Installed (Tons)	Ideal Nominal Capacity for the Heat Loss at 0 °C <sup>2</sup> (Tons)	Under-sized?	House’s Design Heat Loss <sup>1</sup> (Btu/hr)	House’s Heat Loss at 0 °C (Btu/hr)	Installed Heat Pump’s Heating Capacity at 0 °C <sup>3</sup> (Btu/hr)	Heat Pump’s Capacity at 0 °C as a Percent of the House’s Heat Loss at 0 °C
Pauline G.	5.0	9.0	yes	112,700	85,494	47,726	56%
John M.	2.5	4.0	yes	49,100	37,247	23,863	64%
Norm. N	2.5	4.5	yes	57,300	43,468	23,863	55%
Terry O.	2.5	3.5	yes	44,000	33,378	23,863	71%
Terry H.	2.0	2.0		20,900	15,855	19,090	120%
Helena S.	4.0	4.5	yes	56,300	42,709	38,181	89%

Marcel P.	2.0	1.5		20,200	15,324	19,090	125%
James L.	2.5	3.5	yes	43,000	32,620	23,863	73%
Jim E.	3.0	3.0		35,700	27,082	28,635	106%
Jim R.	3.0	4.0	yes	48,100	36,489	28,635	78%

1. From the house's EnerGuide for Houses HOT2000 model; -7 °C outdoors, 22 °C indoors.
2. A heat pump produces approximately 80% of its nominal heating capacity at 0 °C outdoors.
3. 76% of the design heat loss occurs at 0 °C outdoors.

### Mobile Homes

We have observed many heat pumps retrofit in newer mobile houses for the cooling benefit. Generally, these houses can overheat easily. They are relatively small and well insulated, often fully exposed to direct sunlight with no local shading from other buildings or trees. Windows are the conventional type with very short overhangs that provide little or no solar shading. These factors plus internal heat gains from a regular set of appliances and electronics can cause the houses to overheat rapidly in summer.

Also, many new mobile houses are occupied by seniors who are much more sensitive to overheating. The body's ability for "thermoregulation" decreases with age so seniors are less tolerant of too warm or too cool.

### Baseboard Heated Houses

The analysis does not include the case of a heat pump retrofit into a baseboard heated house, although the cohort includes 21 of them. It would be valuable to study the real energy savings for this case. We expect the savings would be significantly lower than with electric furnaces since duct work has to be installed in an unconditioned crawl space, thereby increasing overall heating energy consumption. Further, the benefit of room-by-room zoning with the baseboards is eliminated. Similarly there may be relatively little reduction in peak demand.

### Data and Calculations

Selecting appropriate candidates was highly constrained by the preference for:

- At least one full year of the heat pump in operation
- No envelope upgrades
- No domestic hot water upgrade
- No extensive use of secondary heating such as a gas or wood fireplace
- Energy Star rated heat pump
- Achieving a representative cross section of house sizes and fuel types
- Homeowner's interest in participating

Two of the houses had "equalized" electricity bills. Their annual energy consumptions could be compared to determine overall energy savings, but baseloads could not be calculated reliably, nor could cooling loads be detected.

## **Six Houses were rejected for Study**

Bills for six additional houses were collected and viewed, but were rejected for various reasons:

- Two gas heated houses achieved almost no reduction in natural gas consumption and showed little increase in electricity consumption. Based on our research, the problem is likely caused by two conflicting thermostats and a “fossil fuel kit” controller. The heat pump never comes on. This exemplifies the problems with installation and commissioning that have been reported by other researchers and need to be addressed by the industry in British Columbia.
- An electrically heated house added an HRV.
- An electric furnace heated house added extensive ductwork and heating registers.
- An oil heated house had similar savings to the four that were included.
- An oil heated house used significant wood heating but still had similar savings to the other oil heated houses included.

## 4.0 Statistics for Detached and Mobile Houses, and Heat Pump Sales

**Table 13: Estimated Residential Split System Heat Pump Installations**

Vancouver Island Data and Estimates for 2006	No.	Source of Data
SFD Housing Starts	2,968	BC Government
No. heat pumps installed in new houses - 15% share	445	Karen Gorecki's Master's Thesis <sup>1</sup>
No. of split system heat pumps installed in BC	8,268	HRAI
No. split system heat pumps installed on Vancouver Island	5,456	Arbitrary estimate of 66% of 8,268
No. of retrofit heat pumps installed	5,010	Line 4 – Line 2
No. of existing detached and mobile houses	229,115	Powersmart Residential End Use Study page 6
No. of homeowners considering or going to install a heat pump within 12 months – 4% of respondents	8,663	Taylor Marketing Group, Nanaimo <sup>2</sup>

1. *The Social Cost of New Construction Residential Space Heating in British Columbia*. Karen Gorecki, M.Sc., 2006. Our 15% estimate was extrapolated from the 10% heat pump share estimated for the period 2000-2005.
2. Northstar Heating and Cooling of Nanaimo hired Taylor Marketing Group in 2006 to determine the market potential for heat pump retrofits. 4% of the 2,000 Nanaimo homeowners surveyed indicated they were “going to install or considering installing” a heat pump within 12 months. Of note, Northstar is monitoring three air-source heat pumps in Prince George. They claim that a 3-ton system installed in a 2,200 sq. ft. house can maintain an indoor temperature of 21°C without backup heat, at an outdoor temperature of -17°C.

Based on the statistics and assumptions above, the large majority of heat pump installations on Vancouver Island are for existing houses.

The 2006 Residential End Use Study shows no breakout of electric furnaces for Vancouver Island detached and mobile houses (see tables 5-4 and 5-5 in the End Use Study). Heat pumps were 5% of the Main Heating Systems used in all housing types on Vancouver Island, while baseboard electric was 39% in all housing types. The following useful data was also gleaned from the Study:

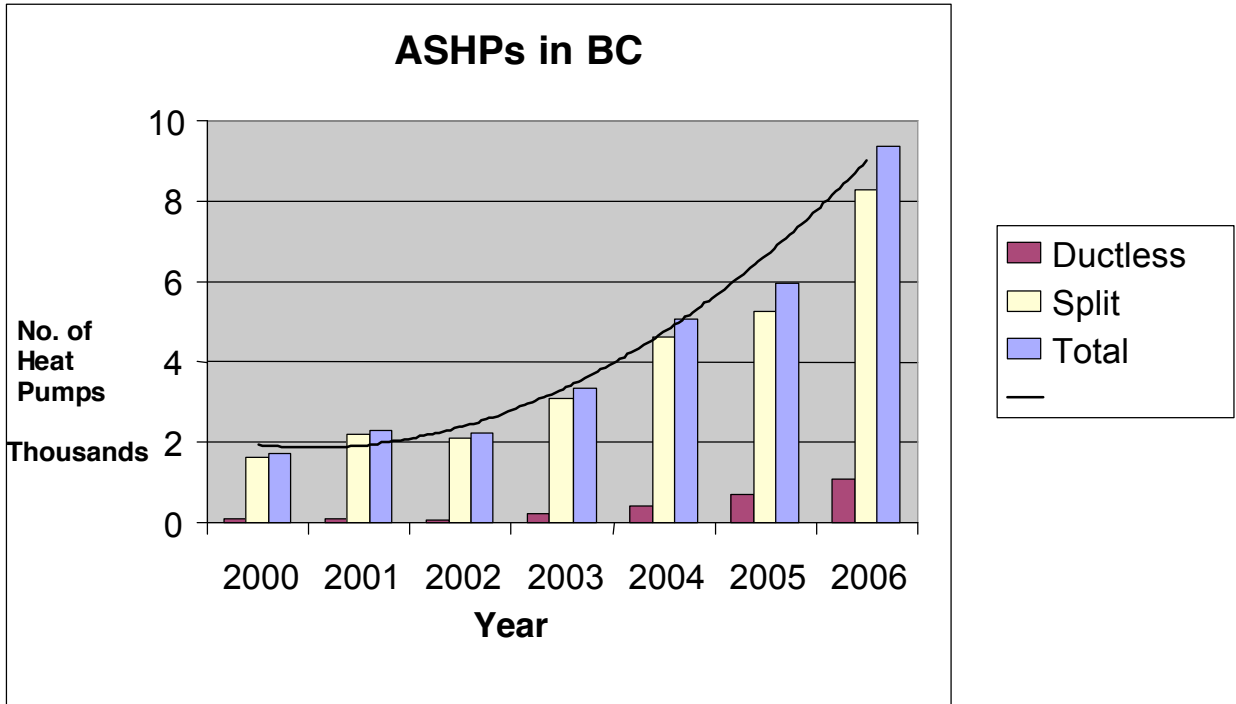
**Table 13: Main Heating Fuel Used by Housing Type: Vancouver Island**

	Electric	Natural Gas	Oil	Wood	Propane	?
Single Detached Houses	51%	19%	16%	12%	1%	1%
Mobile Houses	35%	19%	31%	9%	3%	3%

Source: 2006 Residential End Use Study Table 5-3

Over the seven year period 2000 to 2006, growth in sales of air-source heat pumps has been exponential. 8,268 units were sold in 2006:

**Figure 1: BC's Heat Pump Sales, 2000 to 2006**



Source: HRAI

## 5.0 Economics and Life Cycle Costs

Typical high and low retrofit costs were provided by three contractors – Northstar Heating and Cooling, Pope & Sons, and The Comfort Group. The reported cost ranges from three companies were averaged:

**Table 14: Typical Capital Costs for Retrofit Heat Pumps**

Case	Low	Hi	Average
1. Add a heat pump on to an existing furnace	\$5,367	\$7,100	\$6,233
2. Add a heat pump plus a new electric furnace	\$7,433	\$10,133	\$8,783
3. Upgrade the electric service to 200 Amps	\$2,333	\$2,700	\$2,517
4. Modify duct work	\$833	\$2,000	\$1,417

Table 15 shows a heat pump's operating cost savings, energy savings and GHG emission reductions as modeled by HOT2000, for five different heating systems. These figures were used in the LCC calculations shown in Table 16.

**Table 15: Operating Cost Savings and Energy Savings as modeled with HOT2000**

Backup Furnace	Original Space Heating Cost <sup>1</sup>	Operating Cost Savings <sup>2</sup>	Energy Savings	GHG Emission Reduction - Marginal (kg CO <sub>2</sub> e)	GHG Emission Reduction - Average (kg CO <sub>2</sub> e)
Gas – 80% Efficient	\$995	\$492	67%	2,350	4,150
Oil - 71% Efficient	\$2,278	\$1,776	73%	4,500	6,380
Oil - 83% Efficient	\$1,924	\$1,439	69%	3,500	5,370
Electric Furnace	\$1,064	\$605	61%	3,720	340
Electric Baseboard	\$1,064	\$605	61%	3,720	340

1. Annual space heating load of approximately 60 GJ using the BCH archetype house
2. Include \$50 for annual heat pump service. Contractors typically service the heat pump and backup furnace for \$50 more than a furnace alone.

The life cycle cost of heat pump retrofits are expressed below as the Net Present Value of the initial cost of the retrofit plus the operating cost savings over a 15 year lifetime, when compared to continuing to heat with the original furnace.

**Table 16: Life Cycle Cost of Heat Pump Retrofits – Initial Cost plus Operating Cost Savings**

Original/Backup Furnace	Initial Cost of the Add-On Heat Pump	Net Present Value <sup>1</sup>	Alternate Upgrade	Initial Cost	Net Present Value <sup>1</sup>
Gas - 80% Efficient	\$6,223	-\$756	92% AFUE Gas Furnace	\$4,300	-\$2,857
Oil - 71% Efficient	\$6,223	\$13,515	Heat Pump and a new Electric Furnace	\$8,783	\$8,488
Oil - 83% Efficient	\$6,223	\$9,774	Heat Pump and a new Electric Furnace	\$8,783	\$4,707
Electric Furnace	\$6,223	\$1,047			
Electric Baseboard	\$11,000	-\$3,720			

1. Discount rate 6.5%, inflation 2.5%, lifetime 15 years, 60 GJ space heating load. Possible intermittent maintenance costs are not included in the analysis. Possible credits for avoiding/deferring the replacement of the original furnace are no included. NPVs would increase with larger heating loads. GHG emission reduction credits are not included.

## Discussion

The NPV of retrofitting a gas furnace is the least economical. However, valuing its additional benefits such as GHG reductions, reduced local air pollution, and occupant comfort could move it into the positive. As simply a GHG emission reduction investment at a cost of \$12.60 to \$16.50 per avoided tonne (assuming 3 to 4 tonnes avoided per year), it is compelling.

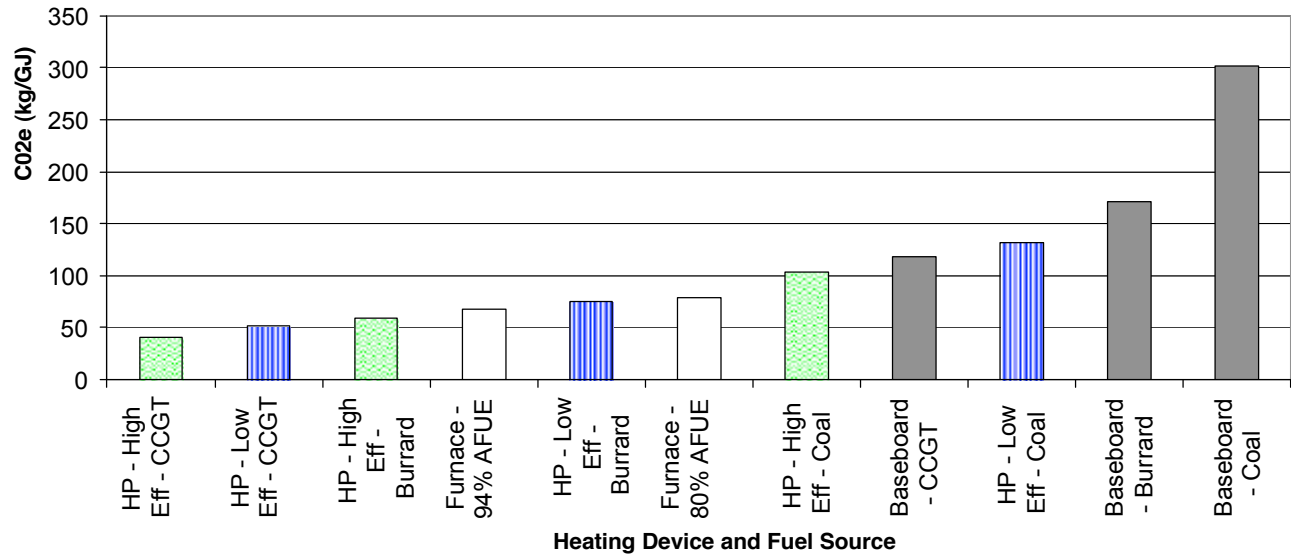
Many homeowners needed to replace an oil furnace because it was too expensive to operate, defunct, or the oil tank was an insurance liability. These issues plus the compelling economics of a heat pump explain why proportionally so many low efficiency oil furnaces were replaced with heat pumps and new electric backup furnaces.

Renovating a baseboard heated house with a heat pump is unlikely to be strictly economical. A more detailed analysis of this would be useful.

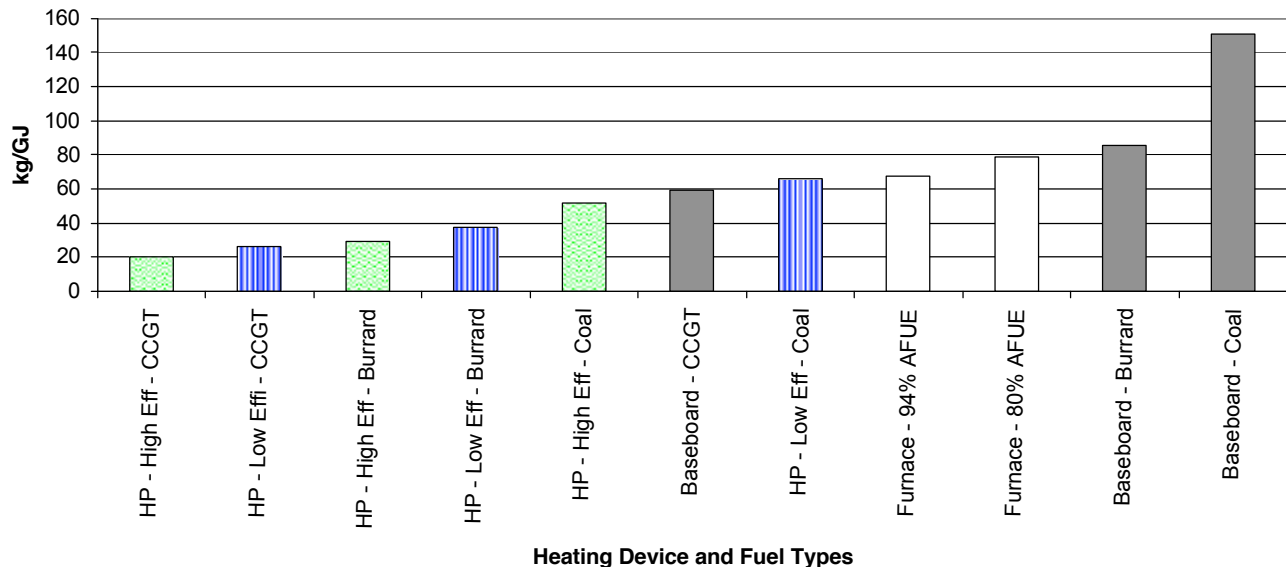
## 5.1 GHG Emission Reductions

The following two graphs are from Karen Gorecki's Master's thesis and are included with her permission<sup>4</sup>. The results of our billings analysis support the trends of these theoretical GHG emission estimates for heat pumps, natural gas furnaces, and electric heating.

**Figure 2: GHG Emissions from Heat Pumps, Natural Gas Furnaces, and Electric Heating Assuming 100% CCGT Marginal Electricity Generation**



**Figure 3: GHG Emissions from Heat Pumps, Natural Gas Furnaces, and Electric Heating Assuming 50% BC Clean, 50% CCGT Marginal Electricity Generation**



<sup>4</sup> *The Social Cost of New Construction Residential Space Heating in British Columbia* Karen Gorecki, M.Sc., 2006

## 6.0 Electrical Demand Analysis

The following section offers a technical primer and discusses ways to mitigate electrical demand and consumption from heat pump retrofits. This is followed by a theoretical demand analysis and then an estimate of how much extra demand was created by 350 of the surveyed houses.

### 6.1 Factors Affecting Electrical Demand and Energy Optimization

#### Low Temperature “Cut-Off” Strategies

Since a heat pump cannot satisfy the entire heating load during cold weather, the backup furnace must be signaled to activate. There are four ways to control when the heat pump stops heating (cuts off) and the backup furnace switches on. These are listed in order of the most optimal to the least optimal use of the heat pump.

1. Unrestricted Cut-off– the heat pump is allowed to work at any cold outdoor temperature, and can heat simultaneously with the backup furnace when necessary. The “A” coil must be installed in the return air plenum, upstream of the warmer furnace output to allow both the heat pump and backup to operate simultaneously (see below for additional discussion).

A refinement of this approach uses a backup electric furnace which stages on 5 kW at a time, to satisfy the indoor temperature set-point. Staged backup optimizes the use of the heat pump, and further reduces electrical demand. It is available only with new matching furnaces and cannot be done with existing electric furnaces.

2. Manual Cut-off – the backup furnace is only used when switched on by the occupant. Some customers ask for this manual switch in order to optimize the energy savings. This is rare and unlikely to be practical for most homeowners.
3. Balance Point Cut-off - a two-stage thermostat determines when the heat pump cannot maintain the indoor temperature, and switches from the heat pump to full backup heat.
4. Restricted Cut-off – the heat pump switches off at a pre-selected and fixed outdoor temperature, and the full backup is activated. An outdoor temperature sensor provides the signal.

#### Location of the refrigerant “A” Coil

The unrestricted cut-off is the most energy efficient since it allows the heat pump to contribute heat even during the coldest weather. This requires that the A coil be installed in the return-air plenum, upstream of the backup furnace. However, with natural gas or oil backup furnaces the standard and commonly recommended practice is to install the A coil in the supply-air plenum. In these cases, the

*balance point* or *restricted* temperature cut-off strategy is used. This design is contentious: one contractor insists that the A coil can usually be placed in the return-air, provided the gas or oil furnace blower is also upgraded to ensure proper air flow. This allows him to use an unrestricted temperature cut-off and maximize the contribution of the heat pump.

### **Oversized Existing Electric Furnaces**

The building code requires a heating system that can meet the design heat loss; but most furnaces are over sized. All the electric furnaces we encounter in the field are 20 kW (68,000 Btu/hr), which is up to double the necessary capacity. Savvy heat pump contractors will disable two 5 kW elements, knowing that 10 kW plus the heat pump will satisfy the design heat loss. This should be encouraged as standard practice.

BCH might consider a program to downsize all 20 kW furnaces by 5 or 10 kW, verifying the design heat loss for each house with HOT2000. This could free up significant grid capacity and reduce peak demand. Further, homes with e-plus could be offered special incentives to install air-source heat pumps now, rather than continue to use electric furnaces.

In new construction we are seeing package backup furnaces in the 8 kW to 12 kW range. However we know that oversized 20 kW ones are still being installed in houses with and without heat pumps.

### **Variable Speed Drive Blower Motors**

Very few existing blower motors are replaced with variable speed motors during a heat pump retrofit. Doing so would increase the overall efficiency of heating, reduce electrical demand, and decrease any summer cooling load. We have lobbied ecoEnergy to add a \$200 grant for upgrading any existing furnace with a VSD blower.

### **Accurate Heat Pump Sizing**

Ideally a heat loss analysis including an air leakage test should be performed to correctly size the heat pump, and to demonstrate the opportunity to mitigate heat loss through upgrades to the building envelope.

An under-sized heat pump with an electric backup furnace imposes greater electrical demand and consumption than a properly sized one.

### **Defrost cycle**

Defrost cycles are controlled by a frost sensor on the outdoor unit and typically run for 2 to 3 minutes. Heat is absorbed from warm air inside the house (and/or from the backup furnace) and transferred to the outdoor coil. The backup furnace is automatically switched on during the defrost cycle to make sure cool air is not being blown out of the heating registers.

The building code does not require the backup furnace to operate during the defrost cycle. Rather, it is a standard practice to avoid cooling down the house. Removing this feature would reduce electrical consumption, but it might diminish occupant comfort.

### **Two-Stage or Dual Compressors**

A two-stage compressor in the outdoor unit can operate at a low or high capacity. The heat pump can be sized to operate mainly using the first stage. This offers several advantages:

- a. better matches the heat generated to the heating load
- b. reduces heat pump cycling in mild heating weather
- c. allows the second stage to be over-sized. The second stage can provide more efficient cold weather heating and so reduce demand from the backup. The design air flow must be sufficient for the capacity of the second stage.
- d. reduces noise from the outdoor unit since the first stage is quieter

### **Improving the Quality of Installations**

The most recent field studies in the Pacific Northwest indicate heat pumps are operating close to the rated heating performance<sup>5</sup>. Our observation on Vancouver Island is contractors are learning by trial and error but some installers are not as well trained as they need to be. Clearly there are still design and operating problems as we discovered looking at the billings for 16 houses. Likely few if any contractors in the mid Vancouver Island carry out complete commissioning tests for duct air flow or refrigerant charge. Some contractors have effectively told us that due to a tight market they must cut corners to compete.

### **CSA Standard 273.5, Standardized Design, Installation and Commissioning**

Industry associations need to encourage heat pump contractors to follow the requirements of CSA 237.5 (or similar), as well as a standard commissioning protocol, and greater consistency in system design. CSA Standard 273.5 includes a commissioning form. This standard was written in 1980 and reaffirmed in 2002.

We reviewed CSA Standard 273.5 and think that it would benefit from a revision. It recommends sizing a heat pump to match the cooling load; this is not appropriate for coastal BC where cooling is barely used. The same sizing method is recommended by NRCAN however we expect it was developed for climates with much larger cooling loads and longer cooling seasons where heat pump cycling would be a concern. This method is expected to generally undersize heat pumps for heating loads in coastal BC. Table 17 demonstrates that if the design cooling load were used, 7 of 10 heat pumps studied would be undersized with respect to a balance point of 0 °C.

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<sup>5</sup>*High Efficiency Heat Pump Monitoring Project*, January, 2006 by Howard Reichmuth, David Robison, Stellar Processes and Bob Davis, Ecotope Inc. for Oregon Department of Energy and Northwest Power and Conservation Council.

*Analysis of Heat Pump Installation Practices and Performance*, October, 2005 by Ecotope Inc. and Stellar Processes

Instead we recommend they be sized to match the heat loss (i.e. the balance point) at 0 °C to -2 °C outdoors. Selecting a nominal heat pump capacity that equals the design heat loss (at -7 °C) would be a very reasonable approximation.

**Table 17: Effect of using the Design Cooling Load to Size the Heat Pump**

Name	Design Cooling Load <sup>1</sup> (Btu/hr)	House's Heat Loss at 0 °C (Btu/hr)	Design Cooling Load as a Percent of the House's Heat Loss at 0 °C	Size of Heat Pump would be
Pauline G.	102,400	85,494	120%	
John M.	33,600	37,247	90%	Undersized
Norm. N	32,400	43,468	75%	Undersized
Terry O.	29,700	33,378	89%	Undersized
Terry H.	15,700	15,855	99%	
Helena S.	46,200	42,709	108%	
Marcel P.	13,600	15,324	89%	Undersized
James L.	19,800	32,620	61%	Undersized
Jim E.	12,100	27,082	45%	Undersized
Jim R.	25,200	36,489	69%	Undersized

1. Estimated by HOT2000 for the EnerGuide evaluation.

The Thermal Environmental Comfort Association (TECA) offers a 3-day course for forced air heating system design. It includes a small component on air-source heat pumps, however according to some contractors a far more in depth course would be worthwhile<sup>6</sup>. We suggest that a dedicated heat pump course should be offered and required for heat pump contractors.

The building code requires a heat loss calculation be performed before sizing a replacement heating system. This however is not being practiced. Contractors use rules of thumb based on square footage and also limit the size based on the flow capacity of the existing ductwork.

## 6.2 Backup Furnaces and their Impact on Electrical Demand

In the following analysis we assume that a 3-ton heat pump draws 3.0 kW, that the defrost cycle (operating for 3 minutes) does not increase demand, and there is no call for quick recovery back up heating due to a nighttime temperature setback.

<sup>6</sup> Personal communication with TECA

**Table 18: Nominal Electrical Demand of New Backup Furnaces and Heat Pumps**

New Back-Up Furnace	Heat Pump Temperature Cut-Off	Original Demand and Peak Demand (kW)	New Demand <sup>7</sup> (kW)	New Peak Demand <sup>8</sup> (kW)	Change in Peak Demand	Notes
<b>Originally Gas</b>						
Original Gas	restricted	0.25	3.38	0.38	small increase	1,2,3
Original Gas	unrestricted	0.25	3.38	3.38	medium increase	1,2,4
New Electric	unrestricted	0.25	3.38	10.00	large increase	1,4
<b>Originally Oil</b>						
Original Oil	restricted	0.25	3.38	0.38	small increase	1,2,3
Original Oil	unrestricted	0.25	3.38	3.38	medium increase	1,2,4
New Electric	unrestricted	0.25	3.38	10.00	large increase	1,4
<b>Originally Electric Furnace</b>						
Original 20 kW furnace	restricted	20.38	3.38	20.38	no change	3
Original with 10 kW removed	unrestricted	20.38	3.38	10.38	large decrease	5
New 10 kW Electric furnace	unrestricted	20.38	3.38	10.38	large decrease	5
New 10 kW Electric furnace with staged backup	unrestricted	20.38	3.38	10.38	large decrease	5
<b>Originally Baseboards</b>						
New 10 kW Electric furnace	unrestricted	10.00	3.38	10.38	?	6

**Notes and Assumptions**

1. A 3-ton heat pump draws 3.0 kW (13.4 Amps at 220 Volt)
2. The blower motor is upgraded from 1/3 h.p. to 1/2 h.p, an increase of 125 watts
3. Heat pump is not operating during the Peak Demand
4. Heat pump is operating during the Peak Demand; the "A" coil is installed in the return air plenum
5. Most existing electric furnaces are 20 kW (68, 300 Btu/hr) and are oversized.
6. Changes in demand would probably be quite variable. These cases often require additional heating in a crawl space, plus zoned room-by-room heating would be eliminated.  
At outdoor air temperatures above -2 °C. The Balance Point for an oil or gas backup is assumed at
7. -2 °C.
8. The Peak Demand occurs at an outdoor temperature below -2 °C, when backup heating is required.
9. A 3-ton heat pump operates at a COP of 2.5 at -7 °C
10. Adding a VSD blower to any of the scenarios in Table 16 would reduce electrical demand

**Discussion**

Notice that for oil and gas backups with a heat pump that fully shuts off between 0 °C and -2 °C (restricted cut-off), the peak demand is 3 kW lower than using an unrestricted cut-off. This theory holds if the extreme peak occurs below an outdoor temperature of -2 °C.

To mitigate peak demand when the backup is gas or oil, the heat pump could be deliberately and automatically shut off based on a signal such as the outdoor temperature, or the electrical frequency<sup>7,8</sup>. Firm electrical supply for space heating would therefore not be necessary. Retaining the existing oil and gas backup furnaces, or choosing oil or gas instead of electric backups, would reduce peak demand. A reduction in peak demand of 3 kW in 5,000 houses on Vancouver Island would equal 15 MW avoided per year.

Replacing electric baseboards with a heat pump and backup furnace would not likely reduce peak demand unless the baseboard capacity was over-sized. Further study of this case and additional billings analysis would be useful.

Downsizing 20 kW electric furnaces to 10 kW (by disabling two 5kW elements) and retrofitting with a heat pump would reduce demand and peak demand. (The 2006 End Use Study does not report the share of electric furnaces on Vancouver Island.)

While increasing the peak demand is a serious concern, it can be mitigated as discussed above. Even if the additional peak demand were met with CCGT generation, an air-source heat pump would cause fewer emissions than any other heating system (Figure 2). Since installations are bound to continue growing, it would be prudent for BC Hydro or the Province to engage with the industry and actively promote a best practices policy for the technology.

The clean electricity available in BC offers a critical opportunity to substitute and displace existing fossil fuel consumption. By destroying demand elsewhere through policies and incentive programs, existing capacity could be freed in order to displace fossil fuel consumption and reduce GHG emissions. Where they can be shown to replace electric resistance heating, heat pumps could be counted as part of BC Hydro's new renewable or green energy generation requirement since they use mostly renewable energy from solar heated air.

### **6.3 Extra Demand created by 350 Heat Pump Retrofits**

The following two tables show the demand from 350<sup>9</sup> of our surveyed heat pump retrofits. These tables use the nominal demand estimates from Table 18. For the sample of 350 houses, the average electrical demand of space heating increased by only 10% from 3.1 kW to 3.4 kW. Note this is demand due to space heating only, not from all the house's loads. The average peak demand however increased by 117% from 3.1 kW to 6.7 kW. Table 20 lists the data in expanded detail.

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<sup>7</sup> Northstar Heating and Cooling reported that some E-plus furnaces were equipped with a peak demand limiting device to shut down the furnace during electrical peaking. Northstar is working with Amana to offer such a device for their heat pumps.

<sup>8</sup> Load controllers can shed demand from low priority loads during peak times, and save customers who have time-of-use billing.

<sup>9</sup> 20 wood heated houses were not included

**Table 19: Summary of Space Heating Demand Estimated for 350 Retrofit Houses**

Original Fuel and No. of Houses	Before / After the Heat Pump	Demand (kW)	Peak Demand (kW)
<b>Gas</b> 113 houses	Before HP	33	33
	After HP	442	230
	% Change	1,250%	602%
<b>Oil</b> 159 houses	Before HP	40	40
	After HP	537	1,209
	% Change	1,252%	2,943%
<b>Electric</b> 39 houses	Before HP	795	795
	After HP	132	685
	% Change	-83%	-14%
<b>Baseboard</b> 21 houses	Before HP	210	210
	After HP	71	218
	% Change	-66%	4%
<b>Sum of All 350 Houses</b>	Before HP	1,077	1,077
	After HP	1,182	2,342
	% Change	10%	117%

**Table 20: Space Heating Demand Estimated for 350 Retrofit Houses**

		No. of Houses	Demand per House (kW)	Total Demand (kW)	Peak Demand per House (kW)	Total Peak Demand (kW)
<b>Original Furnace</b>	<b>Gas</b>	131	0.25	33	0.25	33
<b>New Backup Furnace</b>	Same Gas	113	3.38	381	0.38	43
<b>New Backup Furnace</b>	New 10 kW Electric	18	3.38	61	10.38	187
<b>Original Furnace</b>	<b>Oil</b>	159	0.25	40	0.25	40
<b>New Backup Furnace</b>	Same Oil	63	3.38	213	3.38	213
<b>New Backup Furnace</b>	New 10 kW Electric	96	3.38	324	10.38	996
<b>Original Furnace</b>	<b>Electric</b>	39	20.38	795	20.38	795
<b>New Backup Furnace</b>	Same Electric	28	3.38	95	20.38	571
<b>New Backup Furnace</b>	New 10 kW Electric	11	3.38	37	10.38	114
<b>Original Heating</b>	<b>Baseboard</b>	21	10.00	210	10.00	210
<b>New Backup Furnace</b>	New 10 kW Electric	21	3.38	71	10.38	218

## 7.0 Cooling Loads of Heat Pumps, Central a/c, Unitary Air Conditioners, and Circulating Fans

Only 9% of Vancouver Island residents use a central air conditioner or a portable or room air conditioner<sup>10</sup>. 81% of respondents used a ceiling fan or portable fan. Heat pumps were not surveyed but we expect they would be captured under “central air conditioning” – reported in 4% of Vancouver Island “households”.

The 2006 End Use Study reports the hours per day air conditioning is used by region, but reports the months in use only for the entire Province. We have assumed cooling is used 7 hours a day for 20 days based on 77 degree days above 18 °C for Nanaimo<sup>11</sup> and a cooling set point of 22 °C. Estimates of typical demand and consumption for the different cooling systems are shown below.

**Table 21: Cooling Equipment - Electrical Demand and Consumption**

Cooling Equipment	Brand	Cooling Capacity (BTU/hr)	Demand (kW) <sup>1</sup>	COP	Energy Consumption for 140 hours (kWh)	Typical Equipment Cost <sup>2</sup>	Estimated Installed Cost
Portable Air Conditioner	Haier	12,000	1.25	2.8	175	\$649	\$649
Window Mounted Air Conditioner	Haier	8,000	0.78	3.0	109	\$269	\$469
	Haier	29,000	3.45	2.5	483	\$1,125	\$1,325
Through-the-Wall Air Conditioner	Haier	8,000	0.78	3.0	109	\$449	\$949
	Haier	24,000	2.88	2.4	403	\$750	\$1,250
Central A/C - Retrofit 14 SEER	Any	36,000	2.57	3.7	360		\$5,600
Heat Pump – Retrofit 14 SEER	Any	36,000	2.57	3.7	360		\$6,300
1 Ceiling Fan <sup>3</sup>	Any		0.04		5.4	varies	varies
2 Ceiling Fans <sup>3</sup>	Any		0.07		10.8	varies	varies

1. source: Haier or the Energy Star web site

2. source: Home Depot

3. with the lights off

<sup>10</sup> 2006 Residential End Use Study

<sup>11</sup> Environment Canada

## Discussion

Based on typical operating data, both heat pumps and central air conditioners demand less power than the largest available window-mounted and through-the-wall air conditioners. This is due to their significantly better cooling efficiency.

10,000 split system central air conditioners were installed in BC in 2006<sup>12</sup> which is greater than the number of split system heat pumps (8,216). Central air conditioners typically cost 10% less to install than a heat pump<sup>13</sup>; however contractors in the mid-Island do not generally offer central a/c for cooling since it is outmoded. Therefore we deduce that most central a/c in BC is being installed in the Southern Interior where 33% of households already use it<sup>14</sup>. Clearly, there is a significant opportunity to transition the central a/c market to heat pumps and increase benefits to homeowners and society.

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<sup>12</sup> HRAI data

<sup>13</sup> Personal communication - Martell Refrigeration, Nanaimo and Northstar Heating and Cooling, Nanaimo

<sup>14</sup> 2006 End Use Study table 6-1

# LIST of APPENDICES

## Appendix A

List of 370 Heat Pump Retrofits in order of New Backup Furnace Type

## Appendix B

Billings Analysis House Profiles

## Appendix C

Energy Consumption Figures from the Billings Analysis

## Appendix D

Text prepared by EnergyWise Technologies for Morningstar Enterprises Inc. for the MEMP Air-source Heat Pump Brochure

## Appendix E

Assumptions and Calculations