Life Cycle Cost Analysis of HVAC Systems Across British Columbia

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Architect Peter Treuheit's rendering of the proposed BC Housing building on Hightide Avenue

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Abstract

A detailed life cycle cost analysis of different HVAC systems was performed across British Columbia. Although the all gas system has a much lower utility cost in terms of NPV, it is not a very suitable business case because of high capital costs. It is also mandated by CleanBC standards that the gas emissions of the buildings be reduced by 50% by 2030 and thus using this system is not the best choice. The all-electric HVAC system has a lower present value cost over the 60 years due to lower capital costs.

In warmer areas of British Columbia, using heat pumps is more efficient in terms of cost compared to electric baseboard heaters. This is because the COP of the heat pump is not compromised and results in much lower utility costs, even though the baseboard heaters have much lower capital costs.

Then, a cold climate Mitsubishi heat pump was compared against a standard one for the northern region. The standard one performs slightly better in terms of cost. However, using just electric baseboard heaters is much more cost-effective in the northern region where there is an extreme temperature drop during the winter and thus the COP of the heat pumps would be compromised.

The possibility of using solar panels along with baseboard heaters or heat pumps was also considered. Combining solar panels with baseboards is not very cost-effective since using baseboard heaters alone and paying utility bills through BC Hydro would be more cost-effective. However, combining solar panels with heat pumps would decrease the present value of life cycle cost significantly and make it more cost-effective than using heat pumps and paying the bills through BC Hydro. Here is the summary of the results in the below table.

Cost Summary of the BC Housing Projects analysis

	All Gas (Hastings)	EBB+HP (Bowser)	HP+EBB (Fort St John)	HP+EBB with COP drop
NPV	$2,846,801.00	$391,208.16	$1,298,460.51	$1,413,283.49
NPV per square foot	$22.12	$21.70	$19.59	$21.33

Cost Summary of a Hypothetical Project with different electrical system

	Cold Climate HP in North	Standard HP in North	EBB in North	EBB in South	Standard HP in South	Solar panels with EBB	Solar Panels with HP
NPV	$21,557.08	$20,316.07	$10,409.62	$9,900.19	$9,067.13	$12,423.57	$8,224.14
NPV per square foot	$31.29	$29.49	$15.11	$14.37	$13.16	$18.03	$11.94

A sensitivity analysis was done with different scenarios to see how they affected the cost. Different rate hikes in electricity and gas were considered with different life cycles. These

scenarios did not change the results much. Nonetheless, as the useful life cycle of the building increases, the gas system becomes more cost-effective due to savings in utility costs.

However, because of the long payback period of the gas system, this system is very risky in terms of cost. On the other hand, electric baseboard heaters are the least risky, since they have a low capital cost. Moreover, heat pumps can provide cooling during summer which is another benefit of using heat pumps which need to be taken into consideration and we did not assign dollar values to.

In the end, some limitations of the analysis were discussed. It is recommended that a detailed investigation into these issues be conducted in separate studies to expand the scope of the study and form a strong conclusion. For example, increasing the electrical loads of some buildings, the insulation of the building envelope, materials used, etc are not considered.

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Introduction and Literature Review

A variety of factors affect the cost of the building over its life cycle. These include the type of material used, methods of construction, the architecture of the building, design, location, environmental considerations, labor, HVAC system used, building envelope, etc. [1]

These costs can affect the cost of ownership of the building throughout its lifetime which is also called the Life Cycle Cost (LCC). Cost of ownership can be affected through capital cost (investment cost), operations and maintenance cost, and demolition cost. For residential buildings, the capital cost could range between 45 to 60 percent, while for commercial buildings this number could range from 25 to 40 percent. Since most of the commercial buildings are operated at longer hours during the day, therefore it makes the operations and maintenance cost much higher. [2]

In this research, we want to focus on how the type of HVAC system used in a new construction affects the cost of ownership of the building. Depending on the type of construction and system, the total cost of the mechanical and electrical system could make up somewhere between 15 to 25 percent of the total cost of construction.[5] Based on available data from BC housing, we can get a rough estimate of the proportion of the capital cost of these systems to the total cost of construction. For example, in a project in Vancouver Island with 124 units, this fraction is around 17%. And in a similar project in Vancouver Island with 130 units, this fraction is around 20%. In both of these projects, a hybrid system is used in which electricity is used for space heating and gas is used for DHW (domestic hot water). The HVAC system could make up around 5% of the total cost of construction (Capital Cost).

This study focuses on two HVAC systems used for air conditioning in the buildings. These systems are all gas (boiler + hydronic heating), all-electric (heat pumps, electric baseboards, solar panels). Given the low price of gas, the majority of buildings in BC use gas as a primary source of heating and air conditioning. Moreover, it is usually the case that passive strategies have been implemented to aid the air conditioning of the buildings, especially for cooling.

According to BC Housing guidelines, it is mandated by CleanBC standards that the green-house gas emission be reduced by 50% in the owned and leased buildings by 2030 with reference to the 2010 baseline [3]. Therefore, with this sustainability requirement in place, it is crucial now more than ever to study the cost of ownership of the HVAC system used in buildings to better understand the cost it takes to fully convert to total electric systems or solar panels for air conditioning in buildings.

We also want to consider the future possibilities of converting to these systems depending on the specific region in British Columbia. It is usually believed that the price of gas is low enough for the gas HVAC systems to be cost-efficient in the province compared to electrical systems. The price of gas is currently 3.2 cents per kwh including carbon taxes and other charges but excluding the basic daily charge (FortisBC). The price of electricity is around 11 cents per kwh (BCHydro). However, with more environmental regulations in place and carbon taxes going up in the future, it is beneficial to estimate the gas price in the future to see when and if it will be more cost-efficient to convert to electrical systems in the future. The carbon tax has increased from $35 to $40 per ton of CO2 in 2019 (Gov of BC). Moreover, the price of solar panels has been decreasing throughout the years. While it might not be cost-efficient to install solar panels now, it might be in the future. And we want to evaluate when and if that might be the case.

While gas is the cheaper option now, the electric system is the more viable and reasonable solution in the long run to meet the mentioned sustainability standards (50% reduction by 2030). Moreover, usually, the capital cost for electric systems is lower than the gas option [5]. Therefore, we will also consider different HVAC systems that could be used in buildings like centralized and decentralized HVAC systems.

There are various methods to evaluate a project. We can use IRR (Internal Rate of Return), NPV (Net Present Value), Payback Period, etc. For the purpose of this study, the best method would be NPV. Because there are several flaws associated with IRR and we are dealing with negative values which are costs, the NPV method would be more relevant in this context.

The way we plan to do the project is to look at similar projects with different HVAC systems used, and then analyze the cost data. Then the project with the lower NPV of the cost would be the more cost-effective one if we assume positive numbers for the cost.

All Gas System

To analyze the costs associated with this system we look at a project located at Hastings Street in Vancouver. This is a multipurpose building that consists of residential, medical, and restaurant sections. It has 11 storeys and 111 residential units. The cost breakdown of the building is available in BC Housing Files. From the Data available and some reasonable estimates, we can calculate the present value cost of ownership of the HVAC system.

The HVAC system in this building consists of Water Hydronic Baseboard and Fan Coils for space heating and a Local HRV unit for Ventilation. All of these are connected to a central gas heated condensing boiler. The domestic hot water is also supplied by this system.

Table 1: Mechanical System Used in Hastings Project

4. Mechanical Systems	
Heating/Cooling	Residential: - 4-pipe Fan Coils Connected to Central Condensing Boiler 96% & Air-cooled Chiller (EER 10.5) Medical / Dental/Healing: - 4-pipe Fan Coils Connected to Central Condensing Boiler 96% & Air-cooled Chiller (EER 10.5) Restaurant (Dining): - 4-pipe Fan Coils Connected to Central Condensing Boiler 96% & Air-cooled Chiller (EER 10.5) Residential Corridors: - Makeup Air Unit with Hydronic Heating from Central Boiler 96% (LAT 65 °F) Medical / Dental / Healing Centre Corridors: - Makeup Air Unit with Hydronic Heating / Cooling Connected to Central Boiler 96% & Air-cooled Chiller (EER 10.5)

A cost engineering study has been conducted on this project. From the available file, we use the cost study done by this corporation to obtain the cost of the HVAC system. We can see from the file that the total cost of the mechanical system in the building is $5,524,053 with the HVAC system consisting $2,151,019 of this cost as below (16.72 per sqft):

Table 2: Cost Breakdown of the mechanical system in Hasting Project

15000	MECHANICAL						
	15200	Plumbing & Drainage	$	2,182,875	$	16.96	4.72%
	15300	Fire Protection	$	680,979	$	5.29	1.47%
	15500	HVAC	$	2,151,019	$	16.72	4.65%
	15950	Controls	$	426,363	$	3.31	0.92%
	02450	Site Mechanical	$	82,818	$	0.64	0.18%
	MECHANICAL TOTAL		$	5,524,053	$	42.93	11.93%

As explained in the file, this does not include the design and consulting costs associated with it. By looking at similar projects, we see that the design cost is somewhere between 0.5% and 2% of the total cost of the HVAC system. In this project, we take it to be 1% of the HVAC system cost. We take the capital cost to be design cost plus the HVAC system cost shown above.

From the energy modelling done, we can calculate the approximate utility cost. The gross construction area of the house is 128,673 ft^2 which is approximately equivalent to 11,954 m^2. The thermal energy demand intensity is 26.2 KWH per square meter in one year.

Table 3: Thermal and Total Energy Demand Intensity of the Hastings project

Compliance Results			BCBS
Metric	Requirement (1) (VBBL & BCH-DGCS)	Proposed Design	Result
Thermal Energy Demand Intensity (TEDI) [kWh/y/m^2]	26.2	25.9	Complies + 1%
Total Energy Use Intensity (TEUI) [kWh/y/m^2]	121.0	121.0	Complies + 0%

Notes:
1. Area-averaged based on the following:
   – Residential Occupancy (MFA Residential: 7,192 m^2): TEDI: 30, TEUI: 120
   – Medical Occupancy (MFA Medical: 4,052 m^2): TEDI: 20, TEUI: 120
   – Restaurant Occupancy (MFA Restaurant: 289 m^2): No TEDI/TEUI Requirements. TEDI/TEUI obtained from NECB 2015 reference building as per CoV-EMG. $TEDI_{Reference}$: 17, $TEUI_{Reference}$: 159

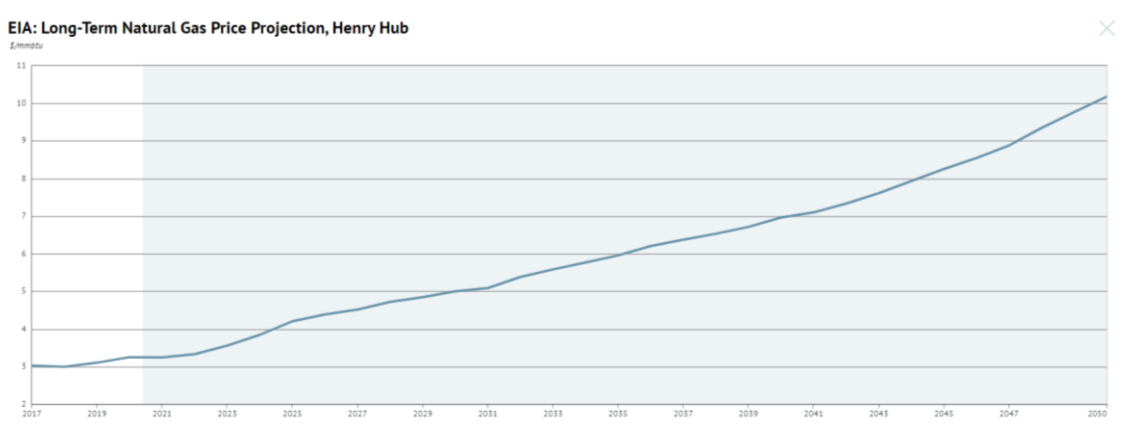
We can get the natural gas rates in British Columbia from FortisBC. The table below is derived from fortisbc.com. There is also a Federal tax rate of 5% and a Provincial tax rate of 7% charged for a total of 12% on top of that. There is an additional ICE (Innovative Clean Energy) levy of 0.4% on top of the carbon tax which we also take into consideration. The carbon tax is $1.99 per GJ (FortisBC)

Table 4: FortisBC natural gas charge rates, Jan 2020

(Effective January 1, 2020)	
Basic charge per day	$0.4085
Delivery charge per GJ	$4.596
Storage and transport charge per GJ	$1.019
Cost of gas per GJ	$1.549

With these data, we can easily calculate the utility bills approximately for the project, However, the challenge is how these rates change in future years. There are multiple forecasts available for the price of natural gas in different institutions like the World Bank, IMF, EIA, NEB, etc. We use the forecast predicted by EIA (Energy Information Administration) which is available at knoema.com

Figure 1: Natural Gas price prediction in the future (Source: EIA)



With this figure, we could expect an average natural gas price increase of 3.88% in the long run. We also assume that the other charges will increase with an average inflation rate for the last 20 years. We take the average inflation to be 1.82% in Canada (Bank of Canada).

We expect that some parts of the mechanical HVAC system need replacement after 15 to 25 years. We take it to be 20 years. Most likely the boiler needs replacement. Moreover, some pumps and other mechanical elements might need replacement after this time. Since we do not have the exact cost of the boiler system, we are forced to make some estimates.

Based on some estimates we can calculate the BTU requirements for heating of the house (supplyhouse.com). We can also take the square footage and multiply it by 30 for moderate climates (homeadvisor.com) Based on the climate data and the area of the house, the approximate BTU requirement is 3,538,508 BTU/h for this project. We can make some estimates on boiler prices from some sellers. We choose the ecomfort.com website to get some estimates on boiler prices. Considering the purchase and installation cost of the boiler, we estimate around $90,000 for boiler replacement.

However, since some makeup air units or pumps might need replacement, we have to multiply it by a factor to account for that costs. The ventilation requirement is included in the energy report which is 15cfm/person for the residential units. Again, we can estimate the cost for ventilators (makeup air units) to be around $60,000. However, we are uncertain whether these need replacement after that time. Therefore, we multiply the boiler cost by 2.5 factor to account for all the other costs including maintenance costs. This factor is arbitrary but estimates the real replacement projects good enough [5]. The real replacement costs somewhere between $50k for smaller projects to $200k for larger projects. Maintenance might cost up to 500 dollars each year, but since we multiplied the replacement cost by the mentioned factor, we neglect it.

Table 5: Ventilation Requirements

Ventilation	Residential: - Direct Ventilation by Local HRV 78% SRE (15 [cfm/Person]) Medical/Dental/Healing: - Direct Ventilation by Local HRV 78% SRE (ASHRAE 62 Ventilation Requirements) Restaurant: - Dining Area: Direct Ventilation Supply (ASHRAE 62), Transfer to Kitchen for Exhaust (400 cfm) - Kitchen Area: Transfer from Dining (400 cfm) + Direct Makeup Air Supply (160 cfm) Pre-Heated to 65 °F Corridors/Lobbies: - ASHRAE 62 Parkade: - Supply and Exhaust at 0.75 [cfm/ft^2]

We assume the useful life cycle of the building to be 60 years. We assume that the replacement cost and the cost of mechanical elements increase with the average rate of inflation throughout the years which is 1.82%. With these assumptions, we can easily calculate the cash flows throughout the life cycle of the building.

To get a reasonable discount factor, we use the capital asset pricing model (CAPM) model to calculate the required rate of return in similar industries and projects. We use the formula below to get the discount rate [9]:

real discount rate = real risk-free rate + (market risk premium × beta)

Where beta is the industry correlation with the market and is a proxy for risk. We consider the average beta for the general utility market in the above formula. We take the risk-free rate to be the average Treasury Bond returns in the last ten years and the market risk premium to be the difference between the stock market and bond market returns in the last 10 years.

The average beta for the general utility sector is 0.28 [10]. The risk-free rate is 2.5% and the market risk premium is 5.5% (statista.com). Then, the real discount factor is about 4% from the above formula.

Then we calculate the present value of the cost of ownership with these numbers. We get $2,846,801 in present value for the total cost of ownership. If we divide this number by the square footage, we get the NPV per square foot which is $22.12 per square foot which is $238.15 per square meter. The NPV of the utility cost of this project is $3.13 per square foot. You can see parts of the calculation done in the following table:

Table 6: Cash Flows and Present Value Calculation of Cost for the Hastings Project

	A	B	C	D	E	F	G	H	J	L	N	Q
16												
17	Years	Capital Co	Maintenar	Utility Cost	Total Operati	Cash Flows	NPV	NPV per sqft	NPV per sqm	Utility Cost NPV	Utility Cost NPV per m2	Utility Cost NPV per sqf
18	0	2,172,529	0		$0.00	$2,172,529.19	$2,846,801.00	$22.12	$238.15	$402,680.22	$33.69	$3.13
19	1	0	0	$10,917.52	$10,917.52	$10,917.52						
20	2	0	0	$11,158.20	$11,158.20	$11,158.20						
21	3	0	0	$11,404.90	$11,404.90	$11,404.90						
22	4	0	0	$11,657.77	$11,657.77	$11,657.77						
23	5	0	0	$11,917.01	$11,917.01	$11,917.01						
24	6	0	0	$12,182.79	$12,182.79	$12,182.79						
25	7	0	0	$12,455.30	$12,455.30	$12,455.30						
26	8	0	0	$12,734.75	$12,734.75	$12,734.75						
27	9	0	0	$13,021.32	$13,021.32	$13,021.32						
28	10	0	0	$13,315.24	$13,315.24	$13,315.24						
29	11	0	0	$13,616.72	$13,616.72	$13,616.72						
30	12	0	0	$13,925.97	$13,925.97	$13,925.97						
31	13	0	0	$14,243.24	$14,243.24	$14,243.24						
32	14	0	0	$14,568.76	$14,568.76	$14,568.76						
33	15	0	0	$14,902.77	$14,902.77	$14,902.77						
34	16	0	0	$15,245.53	$15,245.53	$15,245.53						
35	17	0	0	$15,597.31	$15,597.31	$15,597.31						
36	18	0	0	$15,958.37	$15,958.37	$15,958.37						
37	19	0	0	$16,329.00	$16,329.00	$16,329.00						
38	20	0	357889.4	$16,709.48	$374,598.89	$374,598.89						
39	21	0	0	$17,100.12	$17,100.12	$17,100.12						
40	22	0	0	$17,501.22	$17,501.22	$17,501.22						
41	23	0	0	$17,913.11	$17,913.11	$17,913.11						
42	24	0	0	$18,336.12	$18,336.12	$18,336.12						
43	25	0	0	$18,770.59	$18,770.59	$18,770.59						
44	26	0	0	$19,216.87	$19,216.87	$19,216.87						

All Electric System

In this section, we mainly want to compare 2 types of electric HVAC systems, namely heat pumps and electric baseboard heaters used for space-heating. In colder climates, we could use a system that incorporates both a heat pump as the main source and electric baseboards as a backup for space heating.

We also want to answer the question “is an HP with higher efficiency more cost-effective?”. In the remainder of this part, We are going to give a brief review of heat pumps and the available ones used in British Columbia and Canada.

Broadly heat pumps can be categorized as air source heat pumps, cold climate heat pumps (advanced air source), and geothermal heat pumps.

Air Source Heat Pumps are the most common ones. They should rely on a secondary heat source in freezing weather as the COP of the heat pump drops and they become less effective in freezing weather. This type is very competitive with many good brands. There are multiple HP units available in from Lennox, Bryant/Carrier, Rheem, Mitsubishi Electric, Fujitsu as well as many other major brands. These brands are usually very quiet. Usually, the less famous brands do not have a good support system in Canada.

The nominal COP of Air Source Heat-Pumps range from 3.2 to 4.5. When used for heating a building with an outside temperature of, for example, 10 °C, a typical air-source heat pump

(ASHP) has a COP of 3 to 4, whereas an electrical resistance heater has a COP of 1.0. That is, to produce one joule of useful heat, a resistance heater needs one joule of electrical energy, while a heat pump under conditions where its COP is 3 or 4 would require only a 0.33 or 0.25 joules of electrical energy, the difference is taken from the cooler place. Note the diminishing returns: increasing the COP from 1 to 2 halves the required energy (50% saving), then increasing it from 2 to 3 saves only a (1/2 - 1/3) =1/6 (17%) more, going from 3 to 4 saves 8% more, etc. Improving COP to high numbers comes at a price that is quickly not worth it. [12]

Also, note that an air source heat pump is more efficient in hotter climates than cooler ones, so when the weather is much warmer the unit will perform with a higher COP (as it has a smaller temperature gap to bridge). When there is a wide temperature differential between the hot and cold reservoirs, the COP is lower (worse). In extremely cold weather the COP will go down to 1.0.

The COP reaches a theoretical limit of 1.0 at −273 °C. In practice, a COP of 1.0 will typically be reached at an outdoor temperature around −18 °C (0 °F) for air source heat pumps.

Cold Climate Heat Pumps (Advanced Air Source) which absorb heat from ambient air down to approximately -30C. These units can be sized with or without back up heat in British Columbia and surrounding areas winter design temperatures. These units utilize inverter technology and DC fans which are all very quiet. The Japanese equipment Mitsubishi Zuba Central and Zuba Multi are reliable options for colder temperatures as they were designed for Canada and the Mitsubishi P series units. Fujitsu also makes very efficient cold climate units. Bryant/Carrier GreenSpeed has a full output to -8C and is another good North American manufacturer.

Geothermal Heat Pumps absorb heat from the ground or a body of water via a loop or a series of deep drilled holes. They have the potential to be the most efficient to operate. An engineered geothermal Heat Pump has the highest efficiency potential when engineered and installed correctly. Due to the complex engineering and installation cost, these systems tend to be for very large homes, commercial, and district heating. Beware: These systems are often not designed or installed correctly. It is extremely difficult to change the design afterward. It is recommended that these systems be designed only by a professional mechanical engineer. The VRF indoor units from Mitsubishi Electric Heat Pumps paired with a geothermal Loop are available in British Columbia. These units can easily do domestic hot water as well. Nordic Heat Pumps are a good Canadian-made option as well. [16]

A well designed ground-source heat pump (GSHP) systems benefit from the moderate temperature underground, as the ground acts naturally as a store of thermal energy. Their year-round COP is therefore normally in the range of 3.2 to 5.0. According to the United States Environmental Protection Agency (EPA), geothermal heat pumps can reduce energy consumption by up to 44% compared with air-source heat pumps and up to 72% compared with electric resistance heating.

Electric Baseboards System (Heat Pump for Common Areas)

For this part, we look at a project located at Island Highway, which is located in Bowser city on Vancouver Island. This project uses baseboard heaters for individual units and central roof-top heat pumps for common areas. Therefore, in this project, we have a hybrid system of electric baseboards and heat pumps. As you can see in the following table, the COP of the heat pumps is between 3 and 4. The Domestic water heater is also electric. Therefore, this building uses mainly Electric Baseboard heaters for space heating. This project is approximately 1675 m^2 (18030 ft^2) consisting of residential units, corridors, office space, commercial kitchen, laundry, and washrooms, etc. The residential units area of the building is about 12,954 square feet or 1,203 square meters and the common area is about 472 square meters.

We can see the HVAC specifications used in this building from the BC Housing Available files.

Table 7: The HVAC system specification of the Bowers building (second column)

HVAC Systems	Suites with individual baseboard heaters; Central RTU HPs serving common areas ($COP_{HEATING}$=4.1, $COP_{COOLING}$=4.1)	Suites with individual baseboard heaters and HRVs @ 75% recovery efficiency; Central RTU HPs serving common areas ($COP_{HEATING}$=3.5, $COP_{COOLING}$=3.34)
DHW Heater	Individual electric storage water heaters in suites. Dedicated electric storage water heaters in mechanical rooms serving kitchen and laundry rooms.	
Fans	HRV fan @ 0.34 W/CFM, 70% efficiency RTU fans @ 0.25 W/CFM, 70% efficiency	

A cost study has been conducted by a third party. From this cost study, we can get an estimate of the HVAC capital cost. As we can see, the capital cost of the HVAC system is $228,100. Again, we take the design cost to be 1% of the capital cost of the system.

Table 8: Cost Breakdown of the Mechanical system in Bowers Project

C1	MECHANICAL		18,025	ft²	44.80	1,675	m²	482.20		807,500	12.1%
C11	Plumbing and Drainage	1.00	18,025	ft²	25.01	1,675	m²	269.26	450,900		
C12	Fire Protection	1.00	18,025	ft²	4.77	1,675	m²	51.36	86,000		
C13	HVAC	1.00	18,025	ft²	12.65	1,675	m²	136.21	228,100		
C14	Controls	1.00	18,025	ft²	2.36	1,675	m²	25.38	42,500		

To estimate the utility cost, we can look at the energy modelling report of the building. We can see that the Thermal Energy Demand Intensity is 27.4 kwh per square meter per year. However, for the sake of comparison, we take the thermal energy demand intensity to be 26.2, the same value as the project in the last section. And according to BC Housing energy standards, the heating demand should not exceed 30 kwh per square meter in buildings, and therefore the difference is not significant. However, we can change it to the real value to get the real total cost of ownership later. But in this way, we can compare it to the All-Gas System and make better-informed decisions.

To calculate the utility cost of the HVAC system, we use the residential electricity rates of BC Hydro. There are 2 steps for electricity charge as described in the table below. We assume that 75% of the time we use the first step rate and 25% of the time we use the step 2 rate. Therefore, the weighted average electricity price is 11 cents per kwh. There is also a 21 cents charge per day for electricity use.

Furthermore, we take into account the 5% federal tax rate on electricity and 6 cents per day levy by Transit to calculate the electricity bill incurred by the HVAC system. Note that the electricity bills are exempt from provincial taxes.

Table 9: BC Hydro Electricity rates

Energy Charge	**Step 1** $0.0935 per kWh for first 1,350 in an average two month billing period (22.1918 kWh per day). **Step 2** $0.1403 per kWh over the 1,350 Step 1 threshold.
Minimum Charge	$0.2069 per day. Equal to the Basic Charge.

The life expectancy of an air source heat pump is around 20 years [15]. We estimate the BTU requirement of the house to be 508,482 BTU/h using the method of the previous section. The price of a typical heat pump with 11,700 BTU and a COP of 3.5 is around 1300 dollars (www.globalindustrial.ca). Therefore, we estimate the replacement cost to be around 17,800 dollars. We multiply this cost by a factor of 1.7 to account for any other possible costs like maintenance.

The life expectancy of Electric Baseboard Heaters is around 30 years which is a little longer than other gas and electric systems. A typical 5200 BTU/h electric heater costs around 200 dollars. Therefore, we estimate the replacement cost to be around 10,500 dollars. We multiply it by a factor of 1.3 to account for any other possible costs like maintenance. Moreover, note that the maintenance cost of electrical systems is usually much lower than Gas systems.

The price of electricity has increased dramatically in the last 10 years from 2010 to 2020 but we can expect a much lower increase in electricity prices in the coming years [14]. There are a lot of estimates for electricity prices. By looking at these estimates [14], I take the electricity price increase to be around 1.24% on average per year.

Now we have all the cost data and information to need to calculate the present value of the cost of this system. Using the discount rate of 4% again, we get the NPV of the cost to be $391,208 or $21.7 per square feet or $232.56 per square meter. You can see the cash flow calculations in Excel in Table 10.

Note that the cost of this system is a little lower than the All-Gas system, however it is in the margin of error which is between 5%-10%. The main reason for the cost-efficiency of the electric systems is the lower capital cost compared to natural gas systems. The capital cost in this project is $136 per square meter, whereas in the last part it was $180 per square meter. The NPV of the utility cost of this project is $6.44 per square foot which is a lot higher than the gas system.

Table 10: Cash flows and present value calculation for the Bowsers project

	Years	Capital Co	Maintenar	Utility Cost	Total Opera	Cash Flows	NPV	NPV per sqft	NPV per sqm	Utility Cost NPV	Utility Cost NPV per m2	Utility Cost NPV per sqf
18	0	230,381	0		$0.00	$230,381.00	$391,208.16	$21.70	$233.56	$116,126.44	$69.33	$6.44
19	1	0	0	$4,023.73	$4,023.73	$4,023.73						
20	2	0	0	$4,074.19	$4,074.19	$4,074.19						
21	3	0	0	$4,125.28	$4,125.28	$4,125.28						
22	4	0	0	$4,177.02	$4,177.02	$4,177.02						
23	5	0	0	$4,229.41	$4,229.41	$4,229.41						
24	6	0	0	$4,282.46	$4,282.46	$4,282.46						
25	7	0	0	$4,336.18	$4,336.18	$4,336.18						
26	8	0	0	$4,390.58	$4,390.58	$4,390.58						
27	9	0	0	$4,445.66	$4,445.66	$4,445.66						
28	10	0	0	$4,501.44	$4,501.44	$4,501.44						
29	11	0	0	$4,557.93	$4,557.93	$4,557.93						
30	12	0	0	$4,615.12	$4,615.12	$4,615.12						
31	13	0	0	$4,673.04	$4,673.04	$4,673.04						
32	14	0	0	$4,731.69	$4,731.69	$4,731.69						
33	15	0	0	$4,791.08	$4,791.08	$4,791.08						
34	16	0	0	$4,851.22	$4,851.22	$4,851.22						
35	17	0	0	$4,912.11	$4,912.11	$4,912.11						
36	18	0	0	$4,973.78	$4,973.78	$4,973.78						
37	19	0	0	$5,036.23	$5,036.23	$5,036.23						
38	20	0	45351.84	$5,099.46	$50,451.30	$50,451.30						
39	21	0	0	$5,163.49	$5,163.49	$5,163.49						
40	22	0	0	$5,228.34	$5,228.34	$5,228.34						
41	23	0	0	$5,294.00	$5,294.00	$5,294.00						
42	24	0	0	$5,360.49	$5,360.49	$5,360.49						
43	25	0	0	$5,427.82	$5,427.82	$5,427.82						
44	26	0	0	$5,496.00	$5,496.00	$5,496.00						

Also, note that the main reason that deters us from using electrical systems is because of high utility bills and consequently higher operating costs. However, since the electricity bills are exempt from provincial taxes this also plays a role in reducing these costs. Furthermore, we assumed that the COP of the heat pump is 3.5 which reduces the electricity consumption and consequently the costs associated with it.

The assumption of COP of 3.5 might be compromised in colder temperatures as the COP decreases when the temperature difference goes up. However, in Vancouver Island, we do not need to worry about these extreme weather conditions as the temperature mostly stays warmer than -5C.

If we change the Thermal Energy Demand intensity to the real value of 27.4 kwh we would get the NPV of 21.99 dollars per square foot. We can see this does not make much of a difference.

Heat Pump System (Electric Baseboards for Backup)

For this part, we look at a project in Northern British Columbia, in Fort St John. This project uses a VRF heat pump as the main source of heating. Electric baseboard heaters are also used for backup in case the temperature drops too much and the heat pump is not sufficient for heating. This is a 6-storey tall building with 50 residential units with a gross construction area of 6,157 square meters (66,273 square feet).

By looking at the cost data we can get the capital cost of the HVAC system which in this case is $853,900. (Table below)

Table 11: Cost Breakdown of the mechanical system in Fort St John Project

C1 MECHANICAL					2,212,000		359.30	14.1
C11 Plumbing & Drainage	1.000	6,157 m2	175.00	1,075,900		174.70		
C12 Fire Protection	1.000	6,157 m2	26.00	162,200		26.30		
C13 HVAC	1.000	6,157 m2	139.00	853,900		138.70		
C14 Controls	1.000	6,157 m2	19.00	120,000		19.50		

This building is classified as a passive house. A passive house is a voluntary standard for energy efficiency in a building, which reduces the building's ecological footprint. It results in ultra-low energy buildings that require little energy for space heating or cooling. The COP of the heat pump is 3.5

Table12: Energy modelling of the St Fort John Project

Specific building characteristics with reference to the treated floor area

		Value		Criteria	Alternative criteria	Fullfilled?[2]
	Treated floor area m²	5014.3				
Space heating	Heating demand kWh/(m²a)	13.39	≤	15	-	yes
	Heating load W/m²	13	≤	-	10	
Space cooling	Cooling & dehum. demand kWh/(m²a)	0	≤	15	15	yes
	Cooling load W/m²	0	≤	-	10	
	Frequency of overheating (> 25 °C) %	-	≤	-		-
	Frequency excessively high humidity (> 12 g/kg) %	0	≤	10		yes
Airtightness	Pressurization test result n_{50} 1/h	0.6	≤	0.6		yes
Non-renewable Primary Energy (PE)	PE demand kWh/(m²a)	115.10	≤	120		yes
Primary Energy Renewable (PER)	PER demand kWh/(m²a)	88	≤	-	-	-
	Generation of renewable energy (in relation to projected building) kWh/(m²a)	0	≥	-	-	

[2] Empty field: Data missing; '-': No requirement

I confirm that the values given herein have been determined following the PHPP methodology and based on the characteristic values of the building. The PHPP calculations are attached to this verification.

Passive House Classic? **yes**

Task:	First name:	Surname:	Signature:
1-Designer	Marken	Consulting	
Certified Passive House Consultant	Issued on: June 4 2018	City: Vancouver	

It can be seen that the heating demand intensity is 13.39 kwh per square meter each year which is a lot lower than the previously analyzed projects. It is due to insulation and other technologies used in the construction and ventilation that this is possible. Again, we assume that the heating demand intensity is 26.2 kwh per square meter for the sake of comparison.

With the same method as before we estimate the BTU requirement of the building to be 1,869,089 BTU/hr. We take the life cycle of the heat pump to be 20 years. A price of a typical heat pump with a VRF system that can serve multiple zones would be in the range of 3000 to

4000 dollars. We take it to be 3700 dollars with a heating capacity of 48000 BTU/hr (from totalhomesupply). From this we estimate the replacement cost to be around 150,000 dollars after 20 years in today's price. We multiply it by a factor of 1.7 to account for maintenance and any other possible costs. Also, note that electric baseboards makeup only a little portion of the cost in this project and thus we neglect it. (around a thousand dollars)

With the same assumptions as before we calculate the NPV of the cost to be $1,298,460.51 or $210.89 per square meter or 19.59 per square foot. Therefore, we can see that for warmer areas such as Lower Mainland and Vancouver Island, the all-electric system and specifically heat pumps are more cost-efficient than all gas system or a hybrid system between electric baseboards and heat pumps. However, for heating only, electric baseboards might be more cost-effective since the capital cost is much lower than heat pumps and we do not need any ductwork, condenser units, and design fees. This is something we evaluate in the next section where we take into consideration only the electric heating devices. (different heat pumps and electric baseboard heaters). The NPV of the utility cost is $2.29 per square foot.

Table 13: Cash flows of the cost in Fort St John project

	A	B	C	D	E	F	G	H	J	L	N	Q
16												
17	Years	Capital Co	Maintenar	Utility Cost	Total Operati	Cash Flows	NPV	NPV per sqft	NPV per sqm	Utility Cost NPV	Utility Cost NPV per m2	Utility Cost NPV per sqf
18	0	862,439	0		$0.00	$862,439.00	$1,298,460.51	$19.59	$210.89	$151,624.13	$24.63	$2.29
19	1	0	0	$5,258.06	$5,258.06	$5,258.06						
20	2	0	0	$5,323.81	$5,323.81	$5,323.81						
21	3	0	0	$5,390.39	$5,390.39	$5,390.39						
22	4	0	0	$5,457.80	$5,457.80	$5,457.80						
23	5	0	0	$5,526.06	$5,526.06	$5,526.06						
24	6	0	0	$5,595.17	$5,595.17	$5,595.17						
25	7	0	0	$5,665.16	$5,665.16	$5,665.16						
26	8	0	0	$5,736.02	$5,736.02	$5,736.02						
27	9	0	0	$5,807.78	$5,807.78	$5,807.78						
28	10	0	0	$5,880.43	$5,880.43	$5,880.43						
29	11	0	0	$5,954.00	$5,954.00	$5,954.00						
30	12	0	0	$6,028.50	$6,028.50	$6,028.50						
31	13	0	0	$6,103.93	$6,103.93	$6,103.93						
32	14	0	0	$6,180.30	$6,180.30	$6,180.30						
33	15	0	0	$6,257.64	$6,257.64	$6,257.64						
34	16	0	0	$6,335.95	$6,335.95	$6,335.95						
35	17	0	0	$6,415.24	$6,415.24	$6,415.24						
36	18	0	0	$6,495.53	$6,495.53	$6,495.53						
37	19	0	0	$6,576.83	$6,576.83	$6,576.83						
38	20	0	374764.2	$6,659.16	$381,423.39	$381,423.39						
39	21	0	0	$6,742.51	$6,742.51	$6,742.51						
40	22	0	0	$6,826.92	$6,826.92	$6,826.92						
41	23	0	0	$6,912.39	$6,912.39	$6,912.39						
42	24	0	0	$6,998.93	$6,998.93	$6,998.93						
43	25	0	0	$7,086.56	$7,086.56	$7,086.56						
44	26	0	0	$7,175.29	$7,175.29	$7,175.29						

The main reason that heat pumps are more efficient is that they have much less utility cost than baseboard heaters since they have a COP of greater than one. However, in colder climates, if the temperature drops too much, the COP decreases significantly. Since the Northern region has much colder climates than the Lower Mainland and Vancouver Island this could be an issue.

Tabel 14: Fort St John weather by month

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature (°C)	-15.1	-11.1	-5.6	3.2	9.6	13.7	15.8	14.6	9.6	4.3	-7	-13.1
Min. Temperature (°C)	-19.5	-15.8	-10.6	-2.3	3.5	7.8	10	8.9	4.2	-0.2	-10.9	-17.3
Max. Temperature (°C)	-10.7	-6.4	-0.5	8.7	15.7	19.6	21.6	20.4	15.1	8.9	-3.1	-8.9
Avg. Temperature (°F)	4.8	12.0	21.9	37.8	49.3	56.7	60.4	58.3	49.3	39.7	19.4	8.4
Min. Temperature (°F)	-3.1	3.6	12.9	27.9	38.3	46.0	50.0	48.0	39.6	31.6	12.4	0.9
Max. Temperature (°F)	12.7	20.5	31.1	47.7	60.3	67.3	70.9	68.7	59.2	48.0	26.4	16.0
Precipitation / Rainfall (mm)	31	24	25	21	42	68	76	58	42	27	28	29

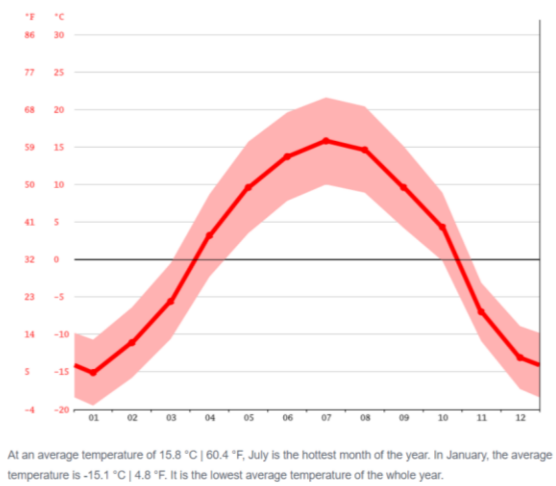
Data: 1982 - 2012

Between the driest and wettest months, the difference in precipitation is 55 mm | 2 inch. The average temperatures vary during the year by 30.9 °C | 87.6 °F.

As can be seen from Table 14, the temperature might drop below -15 degrees Celsius during Jan, Feb, and Dec. Therefore, the COP could drop significantly and get close to one during these months. We know that the COP gets one and the heat pump performs like an electric heater when the temperature drops approximately below -18 degrees Celsius. Therefore, we can estimate based on the above weather data that the average COP will be around 2 during the year in this cold weather conditions. [16]

With these assumptions, the NPV of the cost would be $1,413,283.49 or 229.54 per square meter or 21.33 per square foot. And this is almost the same as using baseboard heaters. Therefore, in the Northern region where the climate is cold, using heat pumps could be costly since the temperature drops too much and the COP is compromised, and using electric baseboards could be the better option if that is the case. The NPV of the utility cost is $4.02 per square foot.

Figure 2: Fort St John Avg Temperature



Comparing Standard VS Cold Climate Heat Pumps

In this section, we want to compare 2 different heat pumps for colder climates in the northern region. The first one is a typical type of heat pump which has a low capital cost. However, the COP is going to be compromised when the temperature drops during colder seasons below -10 degrees Celsius. The second one is more expensive. However, it is designed for colder climates and can operate up to -27 degrees Celsius.

There are many cold climate heat pumps available including Mitsubishi, Fujitsu, Daikin, Panasonic, Lennox, etc. For this study, we consider the Mitsubishi brand. There are many models of Mitsubishi heat pumps that can operate in cold temperatures as low as -27 degrees Celsius. We consider the H2i Series ductless heat pump of Mitsubishi which uses the MXZ-3C30NAHZ2 condenser. It is a 2-zone system with 2 separate air handlers.

Then we consider a typical heat pump which can not operate at colder temperatures. For our comparisons of heat pumps to be analogous we consider another type of Mitsubishi heat pump. This model is MUZ-D36NA-1 condenser which can only operate at temperatures above -10 degrees Celsius.

After that, we compare our results with the case of only electric baseboard heaters. Then, in the following section, we analyze the feasibility of solar panels. This should give us a comprehensive view of the costs of different modern technologies available in the market. This is especially useful for renovation projects to decide which system is more cost-effective.

For our Comparison, we assume a hypothetical case where we want to heat and cool a 64 square meter unit. This unit requires a heating power of 29k BTU/hr or around 9 kw. The analysis that follows is also beneficial for renovation projects where we want to re-install the HVAC system.

Cold Climate Heat Pump

We consider the H2i Series ductless heat pump of Mitsubishi which uses the MXZ-3C30NAHZ2 condenser. This heat pump has a power of 30k BTU/hr which is sufficient to heat our hypothetical unit in the northern region. It is a 2-zone ductless heat pump.

Table 15: Specifications of Cold Climate Heat Pump

SPECIFICATIONS: MXZ-3C30NAHZ2, contd.

OPERATING RANGE:

	Outdoor
Cooling	D.B. 14 to 115° F [D.B. −10 to 46° C]*1
Heating	W.B. -13 to 65° F [W.B. −25 to 18° C]

*1. D.B. 5 to 115° F [D.B. −15 to 46° C], when an optional Air Outlet Guide is installed.

ENERGY EFFICIENCIES:

Indoor Unit Type	SEER	EER	HSPF	COP @ 47°F	COP @ 17°F
Non-ducted (06 + 06 + 09)	18.0	12.5	11.0	4.00	2.65
Ducted and Non-ducted	17.00	11.40	10.40	3.85	2.58
Ducted (09 + 09 + 09)	16.0	10.3	9.8	3.70	2.50

NOTES:
- Minimum of two Indoor Units must be connected to the MXZ-3C30NAHZ2.
- Minimum installed capacity cannot be less than 12,000 Btu/h.
- Total connected capacity must not exceed 130% of outdoor unit capacity.
- System can operate with only one Indoor Unit turned on.
- Information provided at 208/230V.
- For Reference:
  - MXZ-C Technical & Service Manual for detailed specifications and additional information per Indoor Unit Combination.
  - MXZ Series Multi-Zone Indoor/Outdoor Combination Table for allowed unit combinations.

MVZ CONNECTION RULES:
- Only 1 MVZ may be used on any system.
- When an MVZ is connected, total connected capacity must be 100% or less.
- When an MVZ is connected, no P-Series indoor units can be used (PCA, PLA, or PEAD).

When the temperature drops significantly so do the COP of the heat pump and the capacity. Therefore, we might need a 2500W electric baseboard as a backup when this happens. However, the electric baseboard is usually cheap and it costs around 150 dollars.

This system costs around 6800 dollars including the baseboard heater(iwae.com). According to the above specs table, the COP drops to 2.65 from 4 at -8 degrees Celsius. Based on that, using the same approach as previous sections we can calculate the cash flows and the NPV of the cost.

The NPV of the cost would be $21,557.08 which is equivalent to $31.29 per square foot or $336.83 per square meter. The utility cost NPV is $5,613.72 or $87.71 per square meter or $8.15 per square foot.

Again we assumed a 60-year life-cycle for the building. The efficient life of the heat pump is 20 years. We multiplied the cost of the heat pump by a factor of 1.2 to account for any possible service and maintenance cost. Since there is no ductwork here, the maintenance cost is significantly reduced.

Table 16: Cash flows of the cold-climate heat pump

	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
16																						
17	Utility Cos	Total Opera	Cash Flows	NPV	NPV per sqft		NPV per sqm		Utility Cost NPV		Utility Cost NPV per m2			Utility Cost NPV per sqf								
18		$0.00	$6,760.00	$21,557.08	$31.29		$336.83		$5,613.72		$87.71			$8.15								
19	$180.97	$180.97	$180.97																			
20	$183.82	$183.82	$183.82																			
21	$186.71	$186.71	$186.71																			
22	$189.65	$189.65	$189.65																			
23	$192.63	$192.63	$192.63																			
24	$195.67	$195.67	$195.67																			
25	$198.76	$198.76	$198.76																			
26	$201.89	$201.89	$201.89																			
27	$205.08	$205.08	$205.08																			
28	$208.32	$208.32	$208.32																			
29	$211.61	$211.61	$211.61																			
30	$214.95	$214.95	$214.95																			
31	$218.35	$218.35	$218.35																			
32	$221.81	$221.81	$221.81																			
33	$225.32	$225.32	$225.32																			
34	$228.89	$228.89	$228.89																			
35	$232.51	$232.51	$232.51																			
36	$236.20	$236.20	$236.20																			
37	$239.95	$239.95	$239.95																			
38	$243.76	$12,345.12	$12,345.12																			
39	$247.63	$247.63	$247.63																			
40	$251.56	$251.56	$251.56																			
41	$255.56	$255.56	$255.56																			
42	$259.63	$259.63	$259.63																			
43	$263.76	$263.76	$263.76																			
44	$267.95	$267.95	$267.95																			

Standard Heat pump

We consider the M Series ductless heat pump of Mitsubishi which uses the MUZ-D36NA-1 condenser. This heat pump has a power of 36k BTU/hr which is sufficient to heat our hypothetical unit in the northern region in normal temperatures. However, when the temperature drops, we need electric baseboard heaters as a backup. It is a single-zone ductless heat pump.

Table 17: Specifications of the standard heat pump

M-SERIES — **SUBMITTAL DATA: MSZ-D36NA-8 & MUZ-D36NA-1**

36,000 BTU/H WALL-MOUNTED HEAT-PUMP SYSTEM — MITSUBISHI ELECTRIC

Job Name:	
System Reference:	Date:

GENERAL FEATURES
- Catechin and anti-allergy enzyme filters for high air-purification capabilites
- Updated sleek, compact indoor unit design
- Remote-controlled wide airflow enables ideal horizontal air distribution
- Self-check function—onboard diagnostics
- Advanced microprocessor control
- Auto restart following a power outage
- Hand-held Wireless Remote Controller
- Anti-allergy Enzyme Filter
- Limited warranty: five years parts and seven years compressors

ELECTRICAL REQUIREMENTS
Power Supply .... 208 / 230V, 1-Phase, 60 Hz
Breaker Size .... 25 A

Voltage
Indoor - Outdoor S1-S2 .... AC 208 / 230V
Indoor - Outdoor S2-S3 .... DC ±24V
Indoor - Remote Controller .... MHK1 DC 3V
PAR-31MAA DC 12V
PAC-YT53CRAU DC 12V

OPERATING RANGE

		Indoor Intake Air Temp.	Outdoor Intake Air Temp.
Cooling[4]	Maximum	90° F (32° C) DB 73° F (23° C) WB	115° F (46° C) DB
	Minimum	67° F (19° C) DB 57° F (14° C) WB	14° F (-10° C) DB
Heating	Maximum	80° F (27° C) DB 67° F (19° C) WB	75° F (24° C) DB 65° F (18° C) WB
	Minimum	70° F (27° C) DB 60° F (16° C) WB	14° F (-10° C) DB 13° F (-11° C) WB

[4] Applications should be restricted to comfort cooling only; equipment cooling applications are not recommended for low ambient temperature conditions.

Indoor Unit
MCA .... 1 A
Blower Motor (ECM) .... 0.76 F.L.A.
Airflow

When the temperature drops significantly so do the COP of the heat pump and the capacity. Therefore, we need two 2500W electric baseboards as a backup when this happens. However, the electric baseboard is usually cheap and it costs around 200 dollars in total.

This system costs around 5300 dollars including the baseboard heater(iwae.com). The COP of the heat pump is 2.4 at around 8 degrees Celsius and drops to 1 at -15 degrees. Therefore, we estimate the average COP of the heat pump throughout the year would be 1.24 in the North because of extreme cold temperatures.

The NPV of the cost would be $20,316.07 which is equivalent to $29.49 per square foot or $317.44 per square meter. The utility cost NPV is $7,745.34 or $121.02 per square meter or $11.24 per square foot.

Again we assumed a 60-year life-cycle for the building. The efficient life of the heat pump is 20 years. We multiplied the cost of the heat pump by a factor of 1.2 to account for any possible service and maintenance cost. Since there is no ductwork here, the maintenance cost is significantly reduced.

Thus the standard heat pump is more cost-efficient in this situation. This is due to the higher capital cost of the cold climate heat pump. However, the utility cost of the cold-climate heat pump is significantly lower. Thus in larger projects, it is efficient to use more expensive heat pumps. This is because of the economies of scale and the big utility cost in larger projects. Also, notice that the difference is not significant and is in the margin of error (within 10%).

Now we found that despite the significant drop in COP, the standard heat pump is more cost-effective. So I am guessing using just electric baseboards might be even more cost-effective. We will analyze this in the next section.

Table 18: Cash Flows for the standard heat pump system

Years	Capital Co	Maintenar	Utility Cos	Total Opera	Cash Flows	NPV	NPV per sqft	NPV per sqm	Utility Cost NPV	Utility Cost NPV per m2	Utility Cost NPV per sqf
0	5,330	0		$0.00	$5,330.00	$20,316.07	$29.49	$317.44	$7,745.34	$121.02	$11.24
1	0	0	$255.09	$255.09	$255.09						
2	0	0	$258.86	$258.86	$258.86						
3	0	0	$262.68	$262.68	$262.68						
4	0	0	$266.56	$266.56	$266.56						
5	0	0	$270.50	$270.50	$270.50						
6	0	0	$274.50	$274.50	$274.50						
7	0	0	$278.56	$278.56	$278.56						
8	0	0	$282.68	$282.68	$282.68						
9	0	0	$286.87	$286.87	$286.87						
10	0	0	$291.12	$291.12	$291.12						
11	0	0	$295.44	$295.44	$295.44						
12	0	0	$299.82	$299.82	$299.82						
13	0	0	$304.28	$304.28	$304.28						
14	0	0	$308.80	$308.80	$308.80						
15	0	0	$313.38	$313.38	$313.38						
16	0	0	$318.04	$318.04	$318.04						
17	0	0	$322.78	$322.78	$322.78						
18	0	0	$327.58	$327.58	$327.58						
19	0	0	$332.46	$332.46	$332.46						
20	0	9541.46	$337.42	$9,878.88	$9,878.88						
21	0	0	$342.45	$342.45	$342.45						
22	0	0	$347.56	$347.56	$347.56						
23	0	0	$352.74	$352.74	$352.74						
24	0	0	$358.01	$358.01	$358.01						
25	0	0	$363.36	$363.36	$363.36						
26	0	0	$368.80	$368.80	$368.80						

Electric Baseboard System

It would be beneficial if we consider this project without any heat pumps which only uses electric baseboard heaters. This would be useful if no cooling is required in the building and we need only heating. Since electric baseboard heaters cost much less to purchase and install, they might be the better option. However, the COP of electric baseboards is 1 and it would increase the utility cost, especially in milder climates since the COP of heat pumps would not be compromised.

The price of a 2500 watt electric baseboard heater is around 150 dollars (Homedepot). Since a heating power of around 10 kw is required, we need 4 electric baseboard heaters for this unit. The total cost of this system would be 600 dollars.

Following the same procedure, we can calculate the cash flows for this system. The NPV cost of this system would be $10,409.62 or $15.11 per square foot or $162.65 per square meter which is a lot lower than the heat pump systems in previous sections. The NPV cost of the utility cost for this system would be $8,790.76 or $137.36 per square meter or $12.76 per square foot.

Even though the utility cost of heat pump systems is much lower than the electric baseboard heaters, the small capital cost of electric baseboards makes it much more cost-effective.

Table 19: Cash flows for the electric baseboard heater system

	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
16														
17	Utility Cos	Total Oper	Cash Flow:	NPV	NPV per sqft		NPV per sqm		Utility Cost NPV		Utility Cost NPV per m2			Utility Cost NPV per sqf
18		$0.00	$600.00	$10,409.62	$15.11		$162.65		$8,790.76		$137.36			$12.76
19	$291.44	$291.44	$291.44											
20	$295.66	$295.66	$295.66											
21	$299.94	$299.94	$299.94											
22	$304.28	$304.28	$304.28											
23	$308.68	$308.68	$308.68											
24	$313.16	$313.16	$313.16											
25	$317.70	$317.70	$317.70											
26	$322.31	$322.31	$322.31											
27	$326.99	$326.99	$326.99											
28	$331.74	$331.74	$331.74											
29	$336.56	$336.56	$336.56											
30	$341.45	$341.45	$341.45											
31	$346.42	$346.42	$346.42											
32	$351.46	$351.46	$351.46											
33	$356.58	$356.58	$356.58											
34	$361.77	$361.77	$361.77											
35	$367.04	$367.04	$367.04											
36	$372.40	$372.40	$372.40											
37	$377.83	$377.83	$377.83											
38	$383.35	$1,725.96	$1,725.96											
39	$388.95	$388.95	$388.95											
40	$394.64	$394.64	$394.64											
41	$400.41	$400.41	$400.41											
42	$406.27	$406.27	$406.27											
43	$412.21	$412.21	$412.21											
44	$418.25	$418.25	$418.25											

Standard Heat Pump in Normal Climates

For the sake of comparison, it is useful to consider the standard climate heat pump in the warmer regions where the COP of the heat pump does not drop.

We consider a cheaper kind of heat pump. The brand of the heat pump is Senville. The model of the heat pump is SENL-18CD/X which has the capacity of 18000 BTU and is sufficient for our hypothetical unit. The COP of this heat pump is 3.1.

With the same procedure as before, we calculate the cash flows like the table below. The NPV of the cost would be $9,067.13 or $13.16 per square foot or $141.67 per square meter. For this warmer region in the south, the electric baseboard heater NPV cost would be $9,900.19 which is more than the heat pump. Thus, as we move to warmer climates the heat pumps become more cost-effective.

Table 20: Cash Flows for Standard heat pump in warmer climates without COP drop

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
16																
17	Capital Co	Maintenar	Utility Cos	Total Oper	Cash Flow:	NPV	NPV per sqft		NPV per sqm		Utility Cost NPV		Utility Cost NPV per m2			Utility Cost NPV per sqf
18	1,500	0		$0.00	$1,500.00	$9,067.13	$13.16		$141.67		$5,529.40		$86.40			$8.03
19	0	0	$178.04	$178.04	$178.04											
20	0	0	$180.85	$180.85	$180.85											
21	0	0	$183.70	$183.70	$183.70											
22	0	0	$186.61	$186.61	$186.61											
23	0	0	$189.55	$189.55	$189.55											
24	0	0	$192.55	$192.55	$192.55											
25	0	0	$195.60	$195.60	$195.60											
26	0	0	$198.70	$198.70	$198.70											
27	0	0	$201.84	$201.84	$201.84											
28	0	0	$205.04	$205.04	$205.04											
29	0	0	$208.29	$208.29	$208.29											
30	0	0	$211.60	$211.60	$211.60											
31	0	0	$214.95	$214.95	$214.95											
32	0	0	$218.37	$218.37	$218.37											
33	0	0	$221.83	$221.83	$221.83											
34	0	0	$225.36	$225.36	$225.36											
35	0	0	$228.94	$228.94	$228.94											
36	0	0	$232.59	$232.59	$232.59											
37	0	0	$236.29	$236.29	$236.29											
38	0	2685.214	$240.05	$2,925.27	$2,925.27											
39	0	0	$243.88	$243.88	$243.88											
40	0	0	$247.76	$247.76	$247.76											
41	0	0	$251.72	$251.72	$251.72											
42	0	0	$255.73	$255.73	$255.73											
43	0	0	$259.82	$259.82	$259.82											
44	0	0	$263.97	$263.97	$263.97											

Conclusion

Therefore, we can conclude that in the northern region where there is a significant temperature drop, it is more cost-efficient to use normal heat pumps along with electric baseboard heaters than using the more expensive cold-climate heat pumps, however the difference is not large in terms of cost. And it is even more cost-effective to use electric baseboard heaters where cooling is not required. And using baseboard heaters in the north is very cost-effective.

However, as we move to warmer regions where the COP drop is not significant, heat pumps become more attractive. As we learned in the last section, they are more cost-efficient than the electric baseboard heaters in warmer climates in BC.

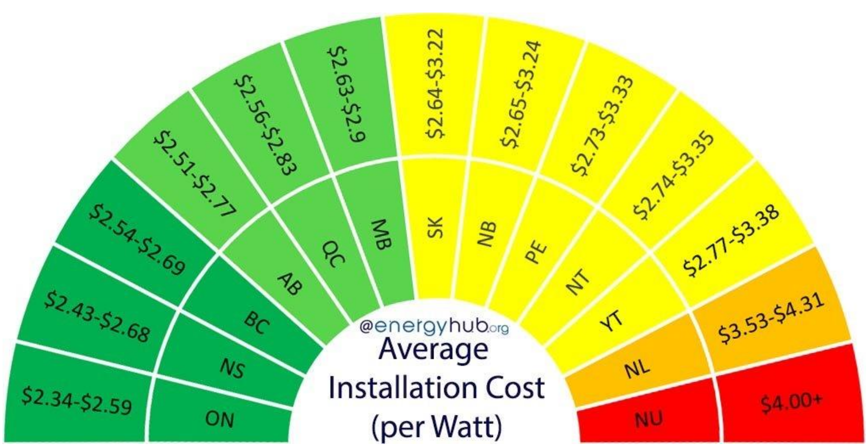
Solar Panels

In this section, we consider the possibility of installing solar panels and use the electricity for space heating in conjunction with electric baseboard heaters or heat pumps. The price of solar panels has dropped 89% since 2010 and is expected to drop by 34% and 63% by 2030 and 2050 respectively. (Mackenzie)

The website energyhub.org lists the price of solar panels across Canada and the number of average sunlight hours in each province. We use the information available on this website to calculate the size of the system we need in terms of the power in watts. The price of solar panels per watt is available and thus we multiply the required power by this number to get the total capital cost of the system.

In the figure below you can see the installation price of the solar panels per watt. In BC we take it to be 2.6 dollars per watt which include the capital and the installation cost.

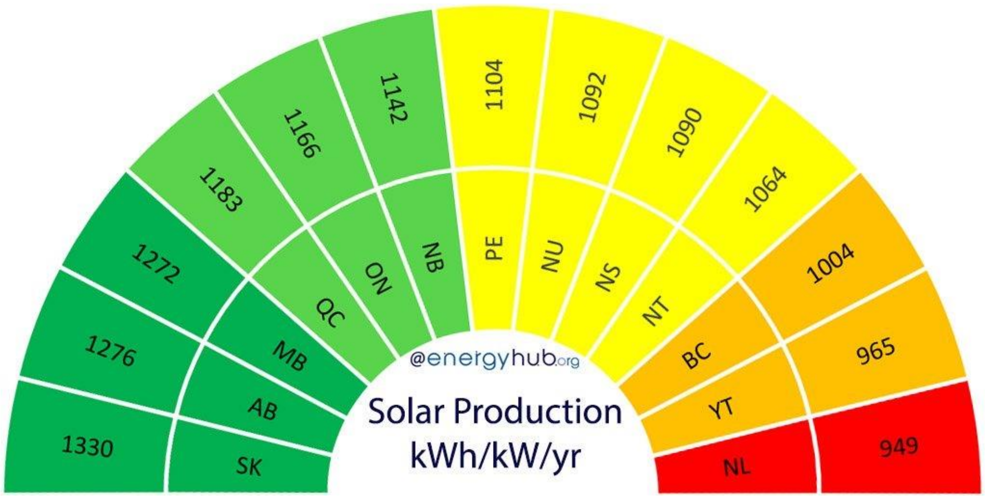
Figure 3: Average installation cost of solar panels per watt across Canada [18]



Similar to previous projects we analyzed throughout this study, we take the thermal energy demand intensity to be 26.2 kwh per square meter per year. And we take a hypothetical 64 square meter unit that we want to heat throughout the year.

In the figure below you can see the solar energy output in terms of hours per year across Canada. British Columbia gets 1004 hours of equivalent full sunlight.

Figure 4: Annual Average Equivalent Sunlight Hours Across Canada [18]



Based on the above information, the required power of the solar panels is 1.67 kw. Therefore, the capital cost for this solar system would be 4342 dollars.

First, we consider using electric baseboard heaters along with these panels for heating. We can then calculate the cash flows and the NPV of the cost. Notice that the average cost of utility is zero here since the solar panels meet the heating demand of the house on average. You can see the cash flows in the table below.

Table 21: Cash Flows for the Solar Panels system with Electric Baseboard heaters

	A	B	C	D	E	F	G	H	J	L	N	Q
16												
17	Years	Capital Co	Maintenar	Utility Cos	Total Opera	Cash Flows	NPV	NPV per sqft	NPV per sqm	Utility Cost NPV	Utility Cost NPV per m2	Utility Cost NPV per sqf
18	0	4,642	0		$0.00	$4,642.31	$12,423.57	$18.03	$194.12	$0.00	$0.00	$0.00
19	1	0	0	$0.00	$0.00	$0.00						
20	2	0	0	$0.00	$0.00	$0.00						
21	3	0	0	$0.00	$0.00	$0.00						
22	4	0	0	$0.00	$0.00	$0.00						
23	5	0	0	$0.00	$0.00	$0.00						
24	6	0	0	$0.00	$0.00	$0.00						
25	7	0	0	$0.00	$0.00	$0.00						
26	8	0	0	$0.00	$0.00	$0.00						
27	9	0	0	$0.00	$0.00	$0.00						
28	10	0	0	$0.00	$0.00	$0.00						
29	11	0	0	$0.00	$0.00	$0.00						
30	12	0	0	$0.00	$0.00	$0.00						
31	13	0	0	$0.00	$0.00	$0.00						
32	14	0	0	$0.00	$0.00	$0.00						
33	15	0	0	$0.00	$0.00	$0.00						
34	16	0	0	$0.00	$0.00	$0.00						
35	17	0	0	$0.00	$0.00	$0.00						
36	18	0	0	$0.00	$0.00	$0.00						
37	19	0	0	$0.00	$0.00	$0.00						
38	20	0	10253.74	$0.00	$10,253.74	$10,253.74						
39	21	0	0	$0.00	$0.00	$0.00						
40	22	0	0	$0.00	$0.00	$0.00						
41	23	0	0	$0.00	$0.00	$0.00						
42	24	0	0	$0.00	$0.00	$0.00						
43	25	0	0	$0.00	$0.00	$0.00						
44	26	0	0	$0.00	$0.00	$0.00						

Therefore, the NPV of the cost is $12,423.5 or $18.03 per square foot or $194.12 per square meter. Thus, it costs more than the case where we had electric baseboards and paying for utility through BC Hydro. It is almost 25% more expensive. However, as the cost of solar panels decreases, this option becomes more attractive year by year.

Next, we follow the same procedure to calculate the scenario where we combine the solar panels with regular heat pumps for normal weather conditions in warmer areas in BC. You can find the cash flows in the table below.

Table 22: Cash Flows for solar panels system with standard heat pump

	A	B	C	D	E	F	G	H	J	L	N	Q
16												
17	Years	Capital Co	Maintenar	Utility Cos	Total Opera	Cash Flows	NPV	NPV per sqft	NPV per sqm	Utility Cost NPV	Utility Cost NPV per m2	Utility Cost NPV per sqf
18	0	3,237	0		$0.00	$3,236.92	$8,224.14	$11.94	$128.50	$0.00	$0.00	$0.00
19	1	0	0	$0.00	$0.00	$0.00						
20	2	0	0	$0.00	$0.00	$0.00						
21	3	0	0	$0.00	$0.00	$0.00						
22	4	0	0	$0.00	$0.00	$0.00						
23	5	0	0	$0.00	$0.00	$0.00						
24	6	0	0	$0.00	$0.00	$0.00						
25	7	0	0	$0.00	$0.00	$0.00						
26	8	0	0	$0.00	$0.00	$0.00						
27	9	0	0	$0.00	$0.00	$0.00						
28	10	0	0	$0.00	$0.00	$0.00						
29	11	0	0	$0.00	$0.00	$0.00						
30	12	0	0	$0.00	$0.00	$0.00						
31	13	0	0	$0.00	$0.00	$0.00						
32	14	0	0	$0.00	$0.00	$0.00						
33	15	0	0	$0.00	$0.00	$0.00						
34	16	0	0	$0.00	$0.00	$0.00						
35	17	0	0	$0.00	$0.00	$0.00						
36	18	0	0	$0.00	$0.00	$0.00						
37	19	0	0	$0.00	$0.00	$0.00						
38	20	0	6571.892	$0.00	$6,571.89	$6,571.89						
39	21	0	0	$0.00	$0.00	$0.00						
40	22	0	0	$0.00	$0.00	$0.00						
41	23	0	0	$0.00	$0.00	$0.00						
42	24	0	0	$0.00	$0.00	$0.00						
43	25	0	0	$0.00	$0.00	$0.00						
44	26	0	0	$0.00	$0.00	$0.00						

It can be seen from the above table that the NPV of the cost of this scenario is $8224.14 or $11.94 per square foot or $128.5 per square meter. It is less expensive than the case where the heat pump was used and the utility bills were paid through BC Hydro.

However, using solar panels with heat pumps is risky, since in the winter in BC we have the lowest number of sunlight hours and heating is most required. Therefore, we are forced to use the electricity from the grid as the solar panels do not have enough capacity to power the heat pumps.

Hence, we assume the solar panels are connected to the grid and they can give electricity to the grid when there is a surplus or take electricity when there is a deficit. In this case, the solar panels combined with heat pumps are on average more cost-effective than using just heat pumps.

Sensitivity Analysis

Until this point, we have considered different HVAC systems we can potentially use for space heating and the life cycle costs associated with them. We found out that the all gas system incorporating hydronic heating has the highest capital cost. It has one of the lowest utility costs alongside heat pump systems. However, the high capital cost of gas systems makes it the most expensive option.

We are concerned that some assumptions and forecasts might not hold perfectly. Therefore, we do a sensitivity analysis to find out what happens to cost when some input parameters change and which system is more cost-effective in each scenario.

Firstly, the rate increase we assumed for the natural gas price might be too high. Especially because of the recent pandemic crisis in 2020, the oil price and its related products have dropped significantly. Therefore, we can expect the price of natural gas to not increase that much soon and the increase, in the long run, should be milder.

Secondly, the life cycle we assumed for the buildings is 60 years which is reasonable. However, some buildings might last up to 80 years and some up to 50 years. Thus, we consider these two variations in input parameters and their effect on the cost of the system. The scenarios are demonstrated in the table below.

Table 23: Different scenarios for input variables in our projects

	Electricity price increase	Gas price increase	Life cycle
Scenario 1	2%	3%	60 years
Scenario 2	1.24%	3.88%	80 years
Scenario 3	1.24%	3.88%	50 years
Scenario 4	2%	3%	80 years
Scenario 5	2%	3%	50 years

Now we take the numbers in the above table to calculate the costs associated with the projects.

Scenario 1:

	All Gas (Hastings)	EBB+HP (Bowser)	HP+EBB (Fort St John)	HP+EBB with COP drop
NPV	$2,822,427.56	$413,068.00	$1,327,203.92	$1,464,292.93
NPV per square foot	$21.93	$22.92	$20.03	$22.09

	Cold Climate HP in North	Standard HP in North	EBB in North	EBB in South	Standard HP in South
NPV	$21,986.73	$21,159.06	$11,455.35	$10,945.92	$9,480.42
NPV per square foot	$31.92	$30.71	$16.63	$15.89	$13.76

Scenario 2:

	All Gas (Hastings)	EBB+HP (Bowser)	HP+EBB (Fort St John)	HP+EBB with COP drop
NPV	$2,991,114.02	$418,191.94	$1,391,435.39	$1,517,918.55
NPV per square foot	$23.25	$23.20	$21.00	$22.90

	Cold Climate HP in North	Standard HP in North	EBB in North	EBB in South	Standard HP in South
NPV	$24,733.40	$23,179.65	$11,684.46	$11,036.26	$10,288.33
NPV per square foot	$35.90	$33.65	$16.96	$16.02	$14.93

Scenario 3:

	All Gas (Hastings)	EBB+HP (Bowser)	HP+EBB (Fort St John)	HP+EBB with COP drop
NPV	$2,802,396.58	$382,359.67	$1,286,922.94	$1,393,047.68
NPV per square foot	$21.78	$21.21	$19.42	$21.02

	Cold Climate HP in North	Standard HP in North	EBB in North	EBB in South	Standard HP in South
NPV	$21,080.32	$19,677.82	$9,692.19	$9,182.76	$8,596.75
NPV per square foot	$30.60	$28.56	$14.07	$13.33	$12.48

Scenario 4:

	All Gas (Hastings)	EBB+HP (Bowser)	HP+EBB (Fort St John)	HP+EBB with COP drop
NPV	$2,951,762.80	$447,900.06	$1,430,498.47	$1,587,241.77
NPV per square foot	$22.94	$24.85	$21.58	$23.95

	Cold Climate HP in North	Standard HP in North	EBB in North	EBB in South	Standard HP in South
NPV	$25,317.30	$24,325.31	$13,105.63	$12,457.42	$10,850.01
NPV per square foot	$36.75	$35.31	$19.02	$18.08	$15.75

Scenario 5:

	All Gas (Hastings)	EBB+HP (Bowser)	HP+EBB (Fort St John)	HP+EBB with COP drop
NPV	$2,784,792.02	$399,837.70	$1,309,904.73	$1,433,832.26
NPV per square foot	$21.64	$22.18	$19.77	$21.64

	Cold Climate HP in North	Standard HP in North	EBB in North	EBB in South	Standard HP in South
NPV	$21,423.84	$20,351.84	$10,528.30	$10,018.86	$8,927.20
NPV per square foot	$31.10	$29.54	$15.28	$14.54	$12.96

Therefore, we that the results do not change much in each of these 5 scenarios. Still, in all of these scenarios, the heat pumps are a better option compared to electric baseboard heaters in the warmer areas in BC and electric baseboards are a better choice in colder climates.

However, we notice as the gas price increase drops to 3% per year, the gas system becomes more attractive which is not surprising. Also note that as the life cycle of the projects increases to 80 years, the gas system becomes more cost-effective. This is due to the utility bills savings that occur in the gas system in the long run.

Still, the heat pump combined with electric baseboard heaters is a better choice in warmer climates compared to the gas system (Scenario 4). However, in this scenario where the life cycle is 80 years and the price increase in gas is lower, the gas system performs better in terms of cost compared to electric baseboards in the south. It is also a better option this time in the north compared to the heat pump.

In conclusion, as the life cycle of the building or the rate increases changes, our results are not affected significantly. But the increase in the life cycle of the building makes the gas system more attractive in terms of cost due to savings in utility bills. Therefore, notice that the payback period for the gas system is much longer than the electric systems and thus is riskier.

Summary, Recommendations, and Limitations

Summary of the results & Recommendations

In the tables below you can see the summary of the study results for the base case scenario.

Table 24: Summary of the BC Housing Projects analysis

	All Gas (Hastings)	EBB+HP (Bowser)	HP+EBB (Fort St John)	HP+EBB with COP drop
NPV	$2,846,801.00	$391,208.16	$1,298,460.51	$1,413,283.49
NPV per square foot	$22.12	$21.70	$19.59	$21.33

Table 25: Summary of the Hypothetical Project with different electrical system

	Cold Climate HP in North	Standard HP in North	EBB in North	EBB in South	Standard HP in South	Solar panels with EBB	Solar Panels with HP
NPV	$21,557.08	$20,316.07	$10,409.62	$9,900.19	$9,067.13	$12,423.57	$8,224.14
NPV per square foot	$31.29	$29.49	$15.11	$14.37	$13.16	$18.03	$11.94

As we found out in the study, the all gas system might seem appealing at first due to low utility bills, however, the high capital cost of this system makes it a worse business case in comparison to heat pumps. This is especially true in warmer climates of British Columbia like the lower mainland, Vancouver Island, and the interior where heat pumps can operate efficiently without a large decrease in their nominal COP.

Heat pumps also provide the possibility of cooling during hot days of summer. Cooling is another benefit of a heat pump which we did not consider and assign dollar values in this study. However, as the climate is getting warmer, the number of over-heating hours in some regions is exceeding the permitted limit of 20 hours per year[3]. Thus, by installing heat pumps in buildings, not only the heating is more cost-effective compared to the gas system in most regions, but also cooling is provided during the summer.

Yet as we move to colder climates in the north, the gas system becomes more cost-effective. But even in this case, the gas system is still a bit more expensive than heat pumps, but the difference becomes smaller.

In the case of heat pumps, the economies of scale are also important. We found as the size of the building and the heat pump system increases, the cost per square foot is decreased in the life cycle of the building.

In the next part of the study, we compared cold climate heat pump vs normal climate heat pump alongside electric baseboard heaters in the north for a hypothetical project. We found out that the normal climate heat pump with baseboard heaters as backup is the better option in terms of cost. However, the difference is not that significant and is in the margin of error.

Then we considered installing baseboard heaters instead of heat pumps in the cold climate of the north. You can see that the baseboard heater is a lot cheaper in terms of NPV cost (almost $10k vs $20k). The reason is the low capital cost of baseboard heaters. They cost around $0.1 per watt, whereas the heat pumps cost around $0.6 per watt. The heat pump we considered for this study is a Mitsubishi M series. There are also cheaper brands available like Senville. The Mitsubishi performs better in colder climates according to the manual specifications.[19]

In southern regions where the climate is warmer, using heat pumps is a lot more cost-effective. As you can see from table 25, using heat pumps is even better than baseboard heaters in this climate.

After that, we studied the use of solar panels for heating. We assumed the solar panels are connected to the electrical grid and they can get electricity when there is a deficit and supply it when there is a surplus. We analyzed two cases where we combined solar panels with either the baseboard heaters or heat pumps. Combining with electric baseboards is not very appealing in terms of cost, since using electrical baseboards alone is cheaper. However, combining them with heat pumps for heating where the electricity for heating is supplied from the solar panels makes them a good choice. The reason is we are not paying for utility bills and there are only the capital and the maintenance costs.

In the sensitivity analysis, in the end, the results were not affected much. We realized as the life cycle for the projects becomes longer the all gas system becomes more appealing in terms of cost.

Therefore, I recommend using standard heat pumps for warmer climates in the Lower Mainland, Vancouver Island, and the Interior region. Especially for larger projects where there are economies of scale, this option is even more appealing. This HVAC system has the cheapest life cycle cost is warmer climates. Moreover, it provides cooling which is a huge benefit over other systems.

As we move to colder climates of the north where there is a possibility of performance drop in the heat pumps due to extreme weather conditions, the gas option and electric baseboards become more attractive. Due to the very low capital cost of electric baseboard heaters, this option is more cost-effective than any other HVAC system in this situation. Therefore, I recommend using primarily electric baseboards for heating in these areas. Where cooling is required, it is recommended to use standard heat pumps along with electric baseboard heaters instead of the more expensive cold climate heat pumps.

Solar panels are also an appealing option for heating. As the price of photovoltaic panels has been dropping year by year, they have become more effective in terms of cost. According to our analysis, it is recommended to use electrical baseboard heaters in conjunction with heat pumps in warmer areas as they cost less than just using heat pumps in these regions. However, during the colder months when heating is most required, we get the least sunlight hours, and thus they must be connected to the grid to make up for this deficit. But on average, since we are not paying for utility, they are much cheaper than using just heat pumps.

Furthermore, consider the risks of these projects. The all gas system is one of the riskiest options since the payback period is very long and they require a high capital investment. Also, carbon taxes might go up even further and that creates another risk. The electric baseboard heaters are the least risky ones since they have very low capital cost. Heat pump projects do have a low level of risk since the payback period is shorter and they provide cooling.

Limitations

The results were derived based on the different assumptions mentioned. We are assuming a new construction where we have the possibility of installing different kinds of HVAC systems. We are also assuming the property has the capacity of these electrical loads. However, in many cases where we want to re-install the HVAC system for renovations projects, there is not enough electrical capacity to add these new electrical loads to the building for heating.

In this case, we have to cover any additional necessary cost of infrastructure for our projects. Getting these additional loads is costly and sometimes we have to upgrade the existing transformer which is also costly. We did not take into consideration these additional costs for old buildings where there is not enough electrical capacity. This is something to take into consideration where applicable.

We also did not take into consideration the building envelope, insulations, and other factors affecting the heating demand intensity of the building. But we assumed the same heating demand intensity for all the projects for the sake of comparison. These additional factors do affect the cost of HVAC systems indirectly and should be taken into consideration in a separate study.

We were also forced to compare projects with different sizes in terms of cost per square foot. Though in most cases the costs go up linearly with respect to size, sometimes larger projects are more complex or costly because of the ductwork or other complexities. And sometimes the larger projects are cost-saving due to economies of scale. So, there might be some issues with the Hastings project due to the large size of the building and also because it is used for other purposes other than residential. However, if we consider similar projects with different sizes for gas systems, the cost of this project seems reasonable. (check [20])

Moreover, the type of heat pumps affects the life cycle cost significantly. This is because the capital cost contributes greatly to the NPV of cost. Using cheaper heat pumps reduce the cost of ownership significantly. We tried to quote the prices of typical heat pumps to avoid this problem.

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