Zu House

CGX
COULOMB GEOEXCHANGE

ALTERNATIVE HEATING FEASABILITY STUDY

Three Suite Residential Building – Edmonton Alberta

Abstract

This study compares the different capabilities of the installation of a ground source heat pump versus an air source heat pump under different building envelope designs.

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1. Overview

The three-suite residential building, located in Edmonton, is anticipated to have the building envelope retrofit to either standard building code or an upgraded house insulation design. The home will have a (3) Level suite (yellow zone), Main Level Suite (Green Zone) and a lower-level basement suite (Red Zone). The home and garage suite will utilize a new, electrified, heating and cooling system. The owners wish to make an informed decision about the costs and efficiencies for alternative heating and cooling systems based on each building envelope design. The alternative types of heating that will be explored are natural gas furnace, air source heat pumps and ground source heat pumps.

2. Zone Layout and Building Design

The building heat loss and air flow assumption for each scenario can be seen below:

Table 1 - Construction Assumptions

Item	Standard Insulation	Upgraded Insulation
Infiltration	2.5 ACH	1.0 ACH
Exterior walls	16.9 R-value	R32 Main and R40 Top Level R-value
Foundation walls	16.2 R-value	28 R-value
Attic Ceiling	49.2 R-value	70 R-value
Flat Ceiling	28.5 R-value	60 R-value
Window	0.29 U-value	0.18 U-value
	0.43 SHGC	0.22 SHGC
HRV Efficiency	70%	70%

Please see below for the zone layout for the main home:

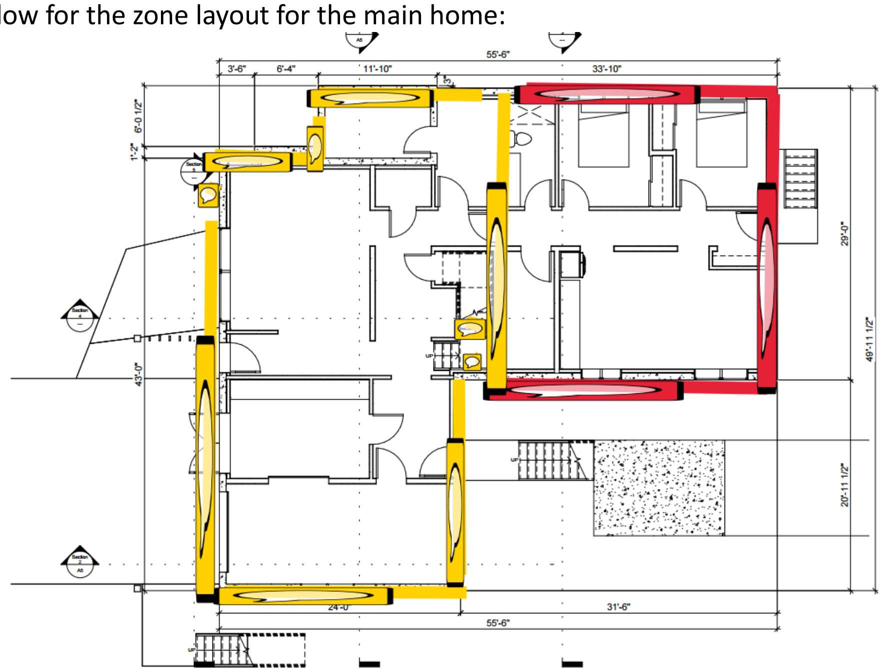

Figure 1 - House Basement Layout

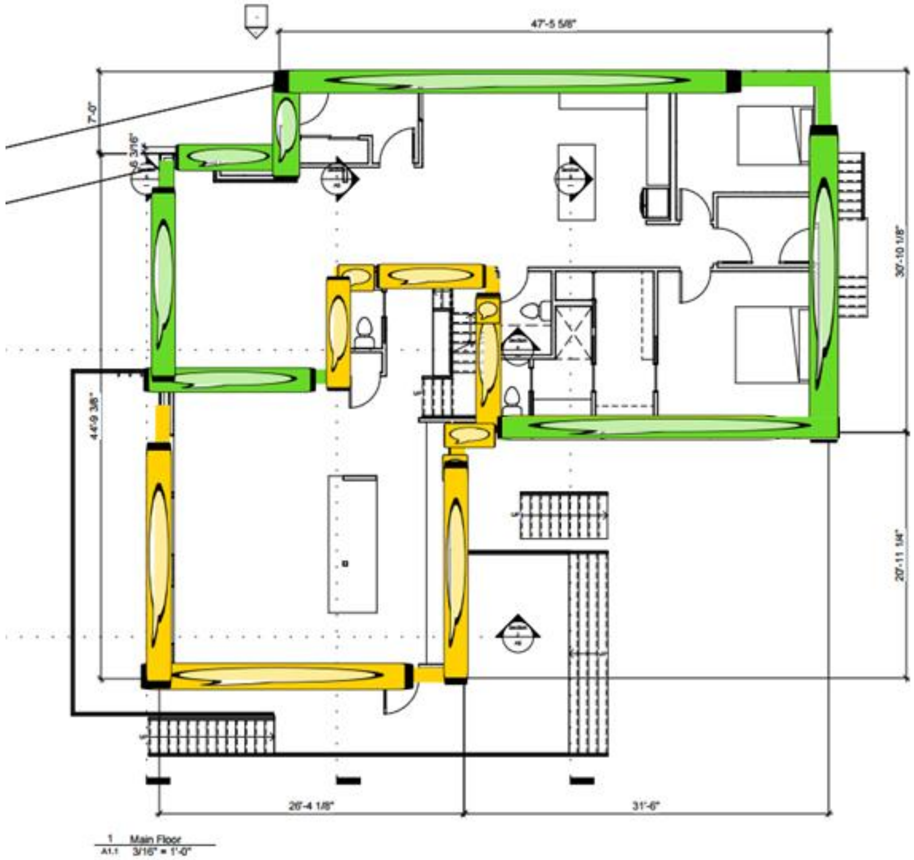

Figure 2 - Home Main Floor Plan

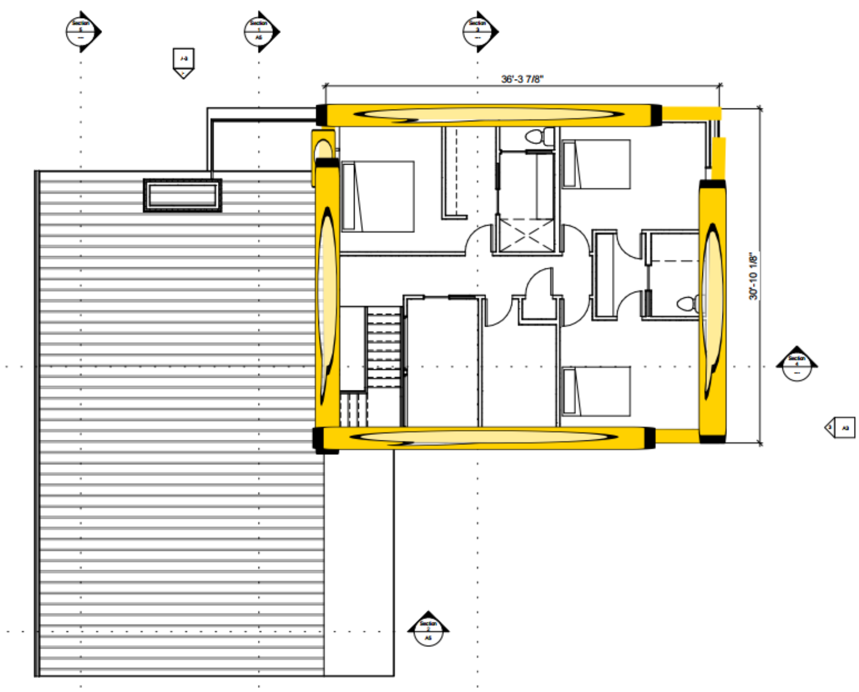

Figure 3 - Home Second Floor Plan

3. Building Loads

To accurately design a heating and cooling system it is important to determine the heating and cooling loads for the building. This will allow for an economic design and avoid oversizing of equipment to heat and cool the building. The model for this building is based on historical weather data in Edmonton, AB.

The summary of each the building loads can be seen below:

Table 2 – Standard insulation building construction heating and cooling Loads

Yellow Zone (assuming 3 occupants)					
Design Loads				100% of Entire Home DHW Load (7 occupants)	
Cooling		Heating		DHW Heating	
kBtu	kBtu/hr	kBtu	kBtu/hr	kBtu	kBtu/hr
5,857	28.8	95,138	42.2	25725	5.6

Green Zone (assuming 2 occupants)			
Design Loads			
Cooling		Heating	
kBtu	kBtu/hr	kBtu	kBtu/hr
2,929	12.9	37,863	18.9

Red Zone (assuming 2 occupants)			
Design Loads			
Cooling		Heating	
kBtu	kBtu/hr	kBtu	kBtu/hr
452	3.2	29,343	10.7

Table 3 – Upgraded insulation building heating and cooling Loads

Yellow Zone (assuming 3 occupants)					
Design Loads				100% of Entire Home DHW Load (7 occupants)	
Cooling		Heating		DHW Heating	
kBtu	kBtu/hr	kBtu	kBtu/hr	kBtu	kBtu/hr
3,599	16.5	53,907	26.0	25725	5.6

Green Zone (assuming 2 occupants)			
Design Loads			
Cooling		Heating	
kBtu	kBtu/hr	kBtu	kBtu/hr
1,984	8.2	17,067	10.6

Red Zone (assuming 2 occupants)			
Design Loads			
Cooling		Heating	
kBtu	kBtu/hr	kBtu	kBtu/hr
228	1.7	22,862	8.1

Note:
It is ultimately up to the use operator of the house to control the loads. The above is a prediction of the expected heat requirements under the suggested occupancy, “normal” household activities, a heating setpoint of 72°F, a cooling setpoint of 75°F and historical weather in the Edmonton area.

The monthly estimated heating and cooling requirements for the standard construction scenario can be found in the figures below:

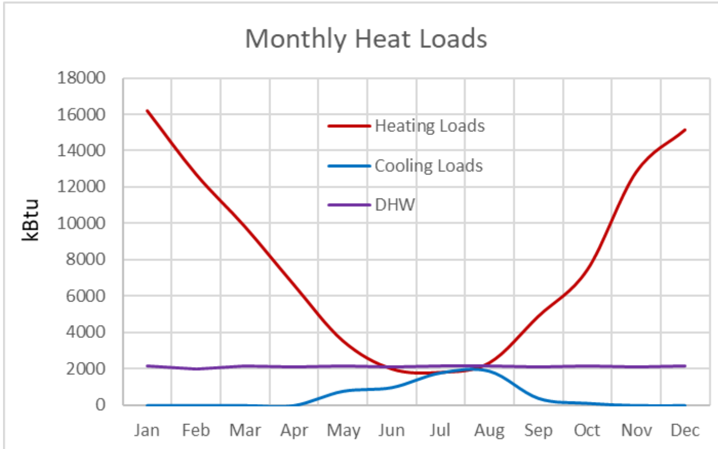

Figure 4 – Yellow Zone standard construction monthly heat loads

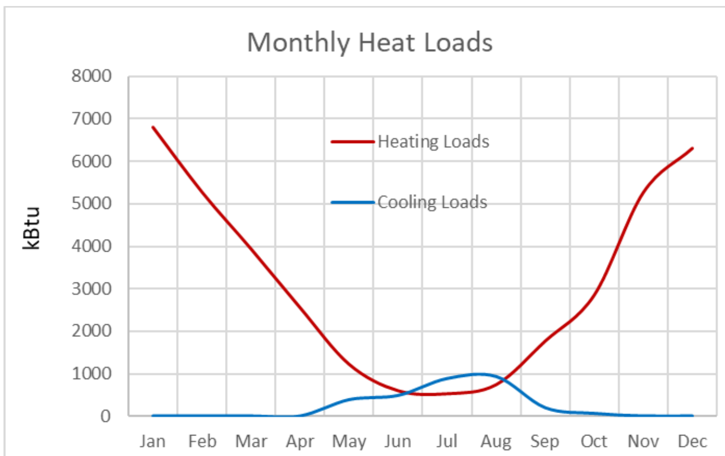

Figure 5 – Green Zone standard construction monthly heat loads

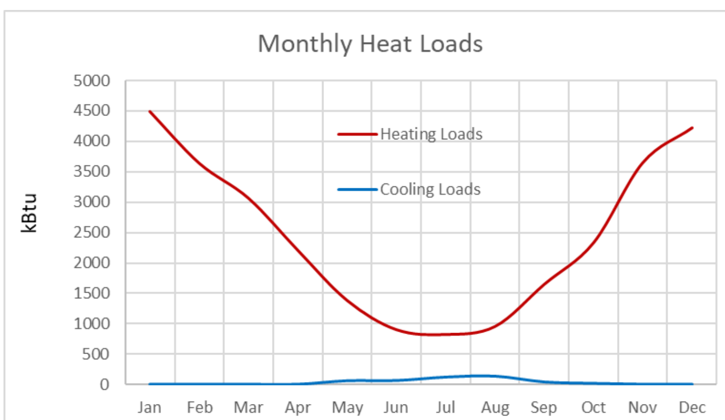

Figure 6 – Red Zone standard construction monthly heat loads

The monthly estimated heating and cooling requirements for the upgraded insulation construction scenario can be found in the figures below:

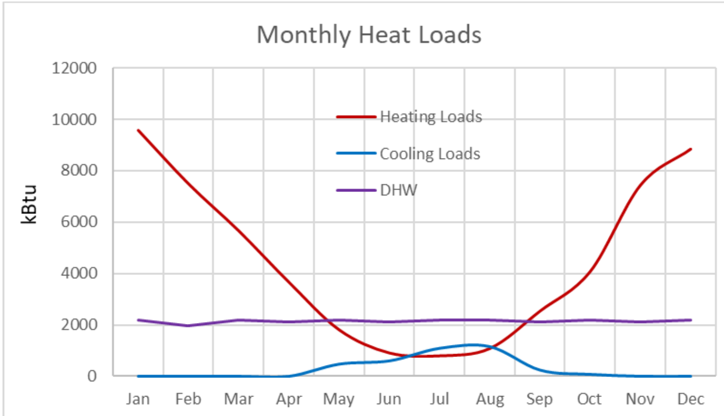

Figure 7 – Yellow Zone upgraded insulation construction monthly heat loads

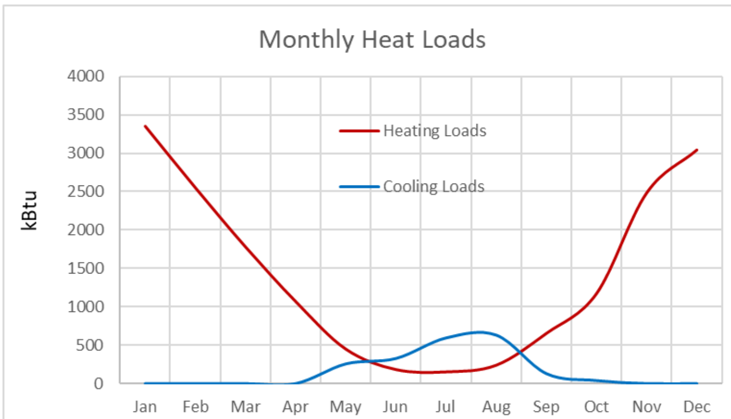

Figure 8 – Green Zone upgraded insulation construction monthly heat loads

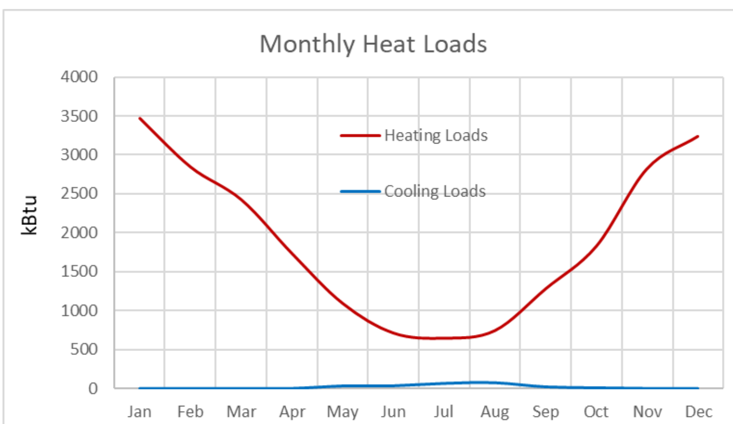

Figure 9 – Red Zone upgraded insulation construction monthly heat loads

4. Building Energy Requirements

4.1 Space Heating

The efficiency of the heating and cooling equipment selected for the conventional and alternative buildings is critical for calculating the energy consumption. For this comparison, we selected the following systems for comparison:

	Cooling COP	Heating COP
1. Natural gas and air conditioning	4.3 to 2.69	0.90
2. Heat Pump	4.3 to 2.69	1.00 to 3.88
3. Ground-source heat pump system	6.85	3.64 to 4.03

Based on the efficiencies mentioned above and an hourly heat load analysis, please see the table below illustrating the required annual energy usage for each system under each building scenario.

Table 4 – Standard construction expected energy use for each heating and cooling system

Alternative	Annual Cooling Energy Requirements (kWh)	Annual Space Heating Energy Requirements (kWh)	Annual DHW Heating Energy Requirements (kWh)	Total Energy Requirements (kWh)
1. Natural gas and Air Conditioning	2,105	52,867	8,034	63,007
2. Heat Pump	2,105	24,501	4,250	30,857
3. Ground-source heat pump system	1,314	14,319	3,652	19,285

Table 5 – Upgraded insulation construction expected energy use for each heating and cooling system

Alternative	Annual Cooling Energy Requirements (kWh)	Annual Space Heating Energy Requirements (kWh)	Annual DHW Heating Energy Requirements (kWh)	Total Energy Requirements (kWh)
1. Natural gas and Air Conditioning	692	30,558	6,973	38,223
2. Heat Pump	692	14,932	4,250	19,874
3. Ground-source heat pump system	411	8,874	3,652	12,937

Notes:

- (2) 60 Gallon Air Source Heat Pump Water Heater (ASHPWH) considered for natural gas and heat pump alternatives. The DHW loads include the additional loads for heating and reduced loads for cooling for the main furnace/heat pump or Air Conditioner. The tank construction used for this scenario is coated carbon steel.
- An indirect boiler was considered for the ground source heat pump. 70% of the loads are covered with the GSHP and 30% of the loads will be covered with an electric water heater. All tanks used for this scenario are stainless steel.

5. Estimated CO_2 and Environmental Impact

Please see below for the expected net annual emissions for each heating and cooling alternative with and without solar panels:

Table 6 – Expected Annual CO_2 Emission for Alternative Heating and Cooling System Designs for standard construction

Alternative	Net Annual CO2 Emissions without Solar Panels (lb.'s)	Estimated Annual CO2 Emissions with Solar Panels Electrical Offset (lb.'s)	Net Annual CO2 Emissions with Solar Panels Electrical Offset (lb.'s)
1. Natural gas rooftop unit conditioning	27,910	27,910	27,910
2. Air Source Heat Pump	36,411	25,637	Net Zero
3. Ground-source heat pump system	22,756	15,672	Net Zero

Table 7 – Expected Annual CO_2 Emission for alternative heating and cooling methods for upgraded insulation construction

Alternative	Net Annual CO2 Emissions without Solar Panels (lb.'s)	Estimated Annual CO2 Emissions with Solar Panels Electrical Offset (lb.'s)	Net Annual CO2 Emissions with Solar Panels Electrical Offset (lb.'s)
1. Natural gas rooftop unit with air conditioning	17,240	17,240	17,240
2. Heat Pump	23,452	16,604	Net Zero
3. Ground-source heat pump system	15,265	10,532	Net Zero

Table 8 – Expected Annual CO_2 Emission for alternative heating and cooling methods for upgraded insulation construction

Assumptions:

- 540 g CO2 /kWh (Average Grid Electricity) - https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/output-based-pricing-system/federal-greenhouse-gas-offset-system/emission-factors-reference-values.html
- 1962 g CO2 / m^3 of natural Gas Heating https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/output-based-pricing-system/federal-greenhouse-gas-offset-system/emission-factors-reference-values.html
- It is assumed that 100% of the cooling load is from solar, 50% of the DHW is from solar and 10% of the heating load is from solar. (Where applicable)
- No solar offset consider with Natural Gas option
- It is assumed that there is enough room for solar on the roof for all options

6. Ground Heat Exchanger Design

Ground Heat Exchanger Specifications Standard Construction

Heat Pump:	Yellow Zone:	(5) ton water-to-water / water-to-air
	Green Zone:	(2.16) ton water-to-air
	Red Zone:	(1.25) ton water-to-air
Back-up Heating	Yellow Zone:	10 Kw
	Green Zone:	3 Kw
	Red Zone:	3 Kw
Total Borehole Length:	5 Holes 370' and 3 Holes 400' deep (2 ground. zones)	

Ground Heat Exchanger Specifications Upgraded Insulation Construction

Heat Pump:	Yellow Zone:	(3) ton water-to-water / water-to-air
	Green Zone:	(1.25) ton water-to-air
	Red Zone:	(1) ton water-to-air
Back-up Heating	Yellow Zone:	5 Kw
	Green Zone:	3 Kw
	Red Zone:	3 Kw
Total Borehole Length:	5 Holes at 390' deep	

Ground Heat Exchanger Specifications

Antifreeze Type:	20% Methanol
Design Entering Water Temperature:	30 °F
Estimated Ground Thermal Conductivity	Medium BTU / hr. ft. °F
Grout Bentonite:	Grout with graphite thermal conductivity booster
Borehole Spacing:	20' to 25' apart
Header Type:	Reverse Return
Piping Material HDPE:	DR11 PE 4710 (Insulated Indoors)

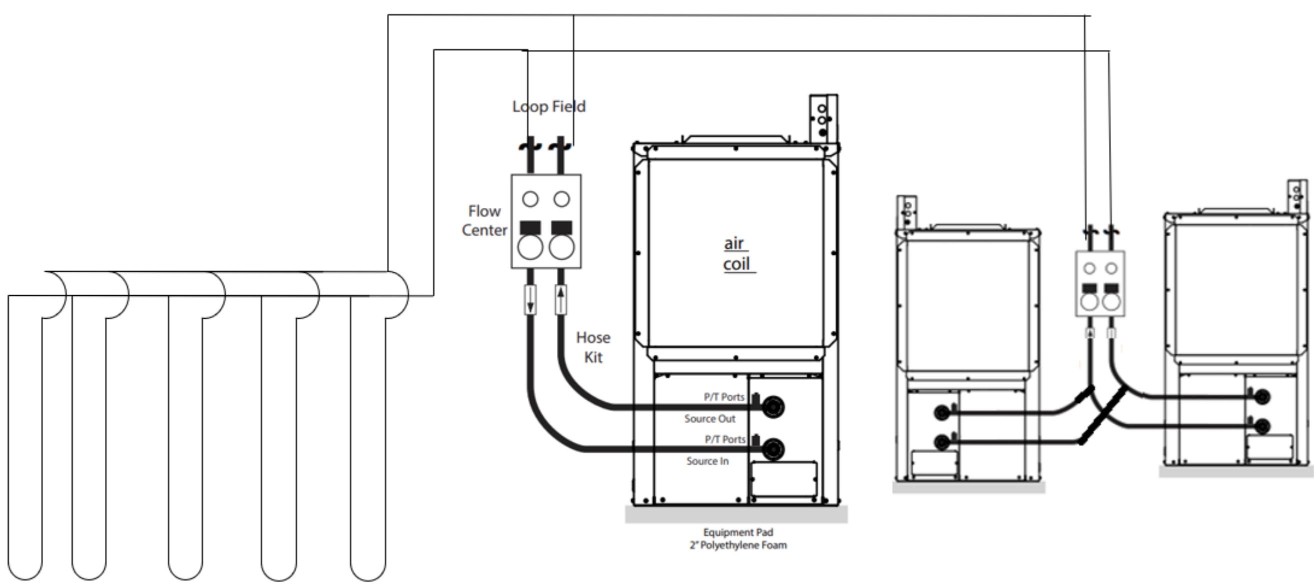

Figure 10 – Suggested 3-unit Ground source heat pump loop configuration

7. Estimated Economics for Each Heating and Cooling System

Table 9 - Capital Cost of Each Heating and Cooling Method

	Upgraded Insulation			Standard Construction	
Capital Costs	AC / Natural Gas	AC / ASHP	GSHP	AC / ASHP	GSHP
Building Envelope Upgrade Costs	$46,500	$46,500	$46,500	-	-
GHX System and Excavation Cost	-	-	$41,000	-	$64,000
Mechanical Equipment Costs*	$20,100	$30,000	$65,300	$30,000	$69,000
Domestic Hot Water	$10,300	$10,300	$11,700	$10,300	$11,700
Ductwork Costs and ERV's	$46,000	$46,000	$46,000	$46,000	$46,000
Solar Panels (To offset electricity)	-	$50,300	$32,700	$78,100	$48,800
Electrical Panel Upgrade**	$10,000	$40,000	$10,000	$40,000	$10,000
Total Cost	$132,900	$223,100	$253,200	$204,400	$249,500

*The mechanical equipment costs for the GSHP includes equipment, loop field piping, coring and sealing of concrete foundation, installing distribution manifold piping/pumps, addition of distilled water/methanol to the ground loop. Flushing/filtering/purging the ground loop and commissioning the system

**The ASHP will require a 400 Amp panel upgrade in lieu of a 200 Amp panel upgrade.

Table 10 – Operating Cost for each Heating and Cooling Method

	Upgraded Insulation			Standard Construction	
Operating Costs	AC / Natural Gas	AC / ASHP	GSHP	AC / ASHP	GSHP
1st Year Annual Heating/Cooling Costs	$2,644	($2,198)	($1,530)	($3,684)	($2,332)
1st Year Cost Savings Compared to Natural Gas	$0	$4,842	$4,174	$6,328	$4,976
Annual CO_2 Emmsions lb's (NG or Grid)	17,240	16,604	10,532	25,637	15,672

Table 11 - Financial Analysis of for each Heating and Cooling Method

	Upgraded Insulation			Standard Construction	
Financial Analysis	AC / Natural Gas	AC / ASHP	GSHP	AC / ASHP	GSHP
Return on Investment [30 years]	-	$162,139	$139,905	$239,649	$190,811
Internal Rate of Return [30 years]	-	7%	5%	10%	6%
Simple Payback	-	14 Years	18 Years	11 Years	16 Years
Annual CO_2 Emissions lb.'s (NG or Grid) [30 years]	517,190	498,111	315,948	769,108	470,146

Assumption:

- *Electrical Consumption Rate is $0.15 / kWh (Estimate Inclusive of variable and Fixed Fees for Natural Gas AC)*
- *Natural Gas Consumption Rate is $7/ GJ with a $70/month fixed fee*
- *An Increase of an additional $15 / Ton of CO_2 Emitted Annually*
- *An Average Inflation Rate of 5% for all energy charges.*
- *Solar estimate includes a solar club import/export rate of ($0.3 / kWh Summer and $0.12 / kWh Winter). Based on advertised rates by Park Power $0.07 per kWh has been added to electricity being imported.*
- *Carbon offset credits (Estimated at $.05 / kWh (offset only)).*
- *The cost of the solar panels is estimated at $2.25 per installed watt. Sizing is based on an E/W configuration.*
- *This analysis assumes that solar incentive policies do not change in the next 30 year*

8. Discussion About Results

When comparing alternative forms of electrified heating and cooling the main aspects there are many aspects to consider. Please see below for the study conclusions:

1. Environmental Impact: After completing the analysis for this report, the system with the lowest CO_2 emission (with and without the addition of solar) is the ground source heat pump (with upgraded insulation). Please note that the annual grid emissions for the ASHP alternatives are relatively similar to the natural gas heating alternatives.

2. Capital Cost: The natural gas option has the lowest upfront cost.

3. Operating Costs: The least efficient methods of electrified heating (without additional insulation) offer the highest return on investment. This result is due to the increase in the allowable size of the solar array and the high export rates available in the summer months (while the majority of the energy is consumed at a lower rate in the winter months).

4. Grid Sustainability: The ground source heat pump system is the most sustainable option for Edmonton's grid. Unlike air source heat pumps (ASHP), which require full backup heating systems in winter, GSHP systems only need smaller supplemental heating systems. Additionally, GSHPs consume less power overall, reducing strain on the city's grid infrastructure.

5. Solar Roof Area: The electric vehicle market is expanding, and many homeowners are installing additional solar panels to power their electric cars. Due to the efficiency of GSHP, the house will require less solar panels (when compared to an ASHP) allowing room to expand the solar array to cover the energy requirement of future or currently owned electric vehicles.

6. Air Conditioning and Heating of Cities: Air conditioners output thousands of BTU/s per hour during the peak months of summer. A paper named "Anthropogenic heating of the urban environment due to air conditioning" (F. Salamanca1, M. Georgescu1,2, A. Mahalov1, M. Moustaoui1, and M. Wang1) illustrates that air conditioners can heat up urban areas up to 1°C in the evening causing additional power consumption. This is known as an urban heat island effect. Ground source heat pumps store the air-conditioned energy in the ground for use in the wintertime for heating while reducing the heat island effect.

7. Solar Policies: Currently the solar policies in Alberta strongly incentivize solar production. These policies may not last forever once the grid becomes overwhelmed. It is plausible that policies will incentivize reduction in CO_2 usage over solar production in the future. Since the majority of the energy used to heat the house lies underneath the property the GSHP offers a better electrified heating solution to hedge policy changes.

8. Back-up Power: The backup power requirements for a GSHP system are approximately ¼ to ½ of an ASHP system on the coldest days of the year. This is can be especially beneficial if homeowners choose to install backup batteries, as it extends the time a home can function during grid outages. In emergency situations, this advantage could be crucial in preventing water lines from freezing while waiting for power to be restored.

9. Electrified Heating Public Perception: The most efficient way to heat and cool a house is a ground source heat pump. In Alberta's climate, ASHPs are a less efficient form of electrification due to their higher electrical demands and associated CO2 emissions, particularly in colder conditions. To truly reduce environmental impact and set a standard for how homes should be built, GSHPs provide the best solution.

Although the addition of upgraded insulation and a GSHP have higher upfront costs and lower operating income, these upgrades are recommended due to the reduced emissions, grid sustainability, reduced solar roof area requirements, reduced utility policy change risks, back-up power requirements and public perception of electrified heating; it is recommended to implement a ground source heating system for this home.