



Arctic Energy
Alliance

Yellowknife Cold-Climate Heat Pump Study

Final Report – Mini-Split System

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Glossary

Capacity – Capacity as used in this report refers to the amount of heating (or cooling) that the heat pump can provide, measured in kW.

Central-split system – A central-split system is a system that uses the central heating system of the house to distribute the heating or cooling from the heat pump. Phase 2 of this study uses central-split systems to distribute heating and cooling through the furnace ducts.

Coefficient of performance (COP) - Coefficient of performance has been abbreviated to “COP” throughout this report. The coefficient of performance is a common metric for measuring the efficiency of heat pumps. It can be defined as a ratio of energy delivered to or removed from a space relative to the electricity required by the system to perform the work. If the energy provided or removed is greater than the electricity consumed by the heat pump, the coefficient of performance will be greater than 1.

Cold-climate air-source heat pump (CCASHP) – cold-climate air source heat pump has been abbreviated to “CCASHP” throughout this report.

Consumption – Consumption as used in this report refers to the amount of electricity used by the heat pump to heat (or cool) the units, measured in kWh.

Gigajoule (GJ) – A unit of energy. One gigajoule (GJ) is roughly equivalent to the energy from two BBQ propane tanks.

Greenhouse gases (GHG) – Greenhouse gas(es) has been abbreviated to “GHG” in this report and refers to the emissions generated when burning fossil fuels.

Heat recovery ventilator (HRV) – Heat recovery ventilator has been abbreviated to “HRV” throughout this report. An HRV is a ventilation system that exhausts “stale” indoor air and distributes “fresh” outdoor air while exchanging heat between the two. Both test units and the control unit of this study have HRVs.

Mini-split system (ductless system) – A mini-split system (or ductless system) is a system that does not operate through the central heating system of a house (typically a furnace or boiler) and instead has individual “heads” throughout the house that distribute heating or cooling to that space.

Short cycling – Short cycling refers to when the HVAC system turns on and off repeatedly and is unable to complete a full cycle, leading to reduced efficiency and increased wear and tear on the system.

Acknowledgments

This study was made possible through the generous support of Housing NWT and the Government of the Northwest Territories’ Department of Environment and Climate Change and Department of Infrastructure. The Arctic Energy Alliance also gratefully acknowledges the contractors and tenants who participated in this project.

Introduction

Heat pumps have become an increasingly popular heating technology in Canada in recent years. The Northwest Territories (NWT) has a unique climate, and there is limited research on how heat pumps perform in such climate conditions. The Arctic Energy Alliance is conducting a study to test the suitability of the technology in the NWT. The study has been divided into two phases: Phase 1 evaluates ductless mini-split heat pumps, while Phase 2 evaluates central-split heat pumps. Phase 1 has been completed, and this report discusses its findings.

The main objective of this study is to test cold-climate heat pump performance in real situations in the NWT. To accomplish this, a quantitative analysis of the energy consumed and delivered was conducted for a range of outdoor ambient temperatures, along with a cost and greenhouse-gas (GHG) analysis comparing heat pumps (electric heat) to other fuel sources. Qualitative observations such as challenges and causes of failure or non-optimal performance were noted.

Two cold-climate ductless mini-split heat pumps were installed in two units of a residential 8-plex. The units were analyzed using HOT2000 energy-modelling software to determine the sizing requirements for the heat pumps. The main heating source for all eight units was originally a biomass boiler connected to a hydronic baseboard system, with an oil-fired boiler for backup. The hydronic baseboards remain as the primary heating source for the six units without heat pumps, whereas baseboard heaters in the two units with heat pumps are reserved for when outdoor temperatures are below -30°C or when the heat pump alone cannot meet the interior set point. Monitoring systems were installed to measure the energy used by both the hydronic baseboards and in-suite HRVs in the two units with heat pumps, and in one unit with baseboards as the sole heating source (i.e., the control unit). On-site measurements of key heat pump system parameters, supplemental heating and corresponding outdoor environment conditions were collected at 5-minute intervals for each monitored site.

This report draws heavily on the technical report provided by RDH Building Science Inc. and is based on analysis of the data collected during the study period between May 1, 2023, and December 31, 2024.

The table below lists the naming conventions for the units and the corresponding heating systems that were measured.

NOMENCLATURE AND CORRESPONDING MEASURED HEATING SYSTEMS	
Location	Heating Systems
Unit A	heat pump, hydronic baseboards, HRV
Unit B (control)	hydronic baseboards, HRV
Unit C	heat pump, hydronic baseboards, HRV

Source: RDH Building Science Inc., Yellowknife Cold Climate Heat Pump Study: Mini Split System – Final Report. P. 11.



One of the outdoor heat pump units.



An indoor head unit for the heat pump.

Challenges

This section outlines the challenges encountered during Phase 1 of the study.

- In Unit A, persistent control issues led to the heat pump operating simultaneously with the hydronic baseboards, causing short cycling and reduced efficiency. Despite modifications made in April 2023, the supplemental heating was activated more frequently than intended, hindering the heat pump's performance as the primary heating source. Control of the mini-split heat pump operation was managed by the tenant to a certain degree, which contributed to suboptimal performance. There were also a few data collection challenges observed in Unit A.
- The heat pump filters were found to be clogged during multiple site visits, and this issue may have contributed to a water leak discovered in one of the units. In addition, one unit was found to be operating without a filter at one point. These observations highlight the need for regular maintenance per manufacturer recommendations.
- The number of local contractors with the necessary training and experience to install and service this equipment is limited. As heat pump technology is still relatively new in the region, contractor availability and technical expertise remain key concerns.



Dirty filter from Unit A (top) and missing filter from Unit C (bottom).

Results Analysis

Coefficient of Performance

Figure 1 below is a plot of the average heating and cooling coefficients of performance (COPs) for Units A and C at various outdoor operating conditions. The heating and cooling COPs were determined using the data collected from May 1, 2023, through December 31, 2024. The data shows the following:

1. It appears that Unit C's heat pump has a higher COP than Unit A, and that the Unit C heat pump closely follows the manufacturer's listed COP values. As noted in the "Challenges" section above, Unit A suffered from persistent control issues which resulted in the heat pump and hydronic system operating simultaneously, causing the heat pump to short cycle and affecting its COP. There were also issues with the monitoring equipment in Unit A, resulting in periods of time when we were unable to collect data. This missing data from Unit A over the winter months may have impacted the results for Unit A's COP.
2. In cooling mode, both units show average COPs above 2. However, the COP data from Units A and C do not closely match. Unit A operated in cooling mode significantly more frequently than Unit C, as shown by the number of data points on the secondary y-axis of Figure 1. For Unit A, there's a clear pattern: as the outdoor temperature increases, its COP decreases, which is what we would normally expect. On the other hand, Unit C's COP increases as the outdoor temperature increases, which goes against the expected values and does not match Unit C's performance. This can largely be attributed to a lack of data points from Unit C in cooling mode.

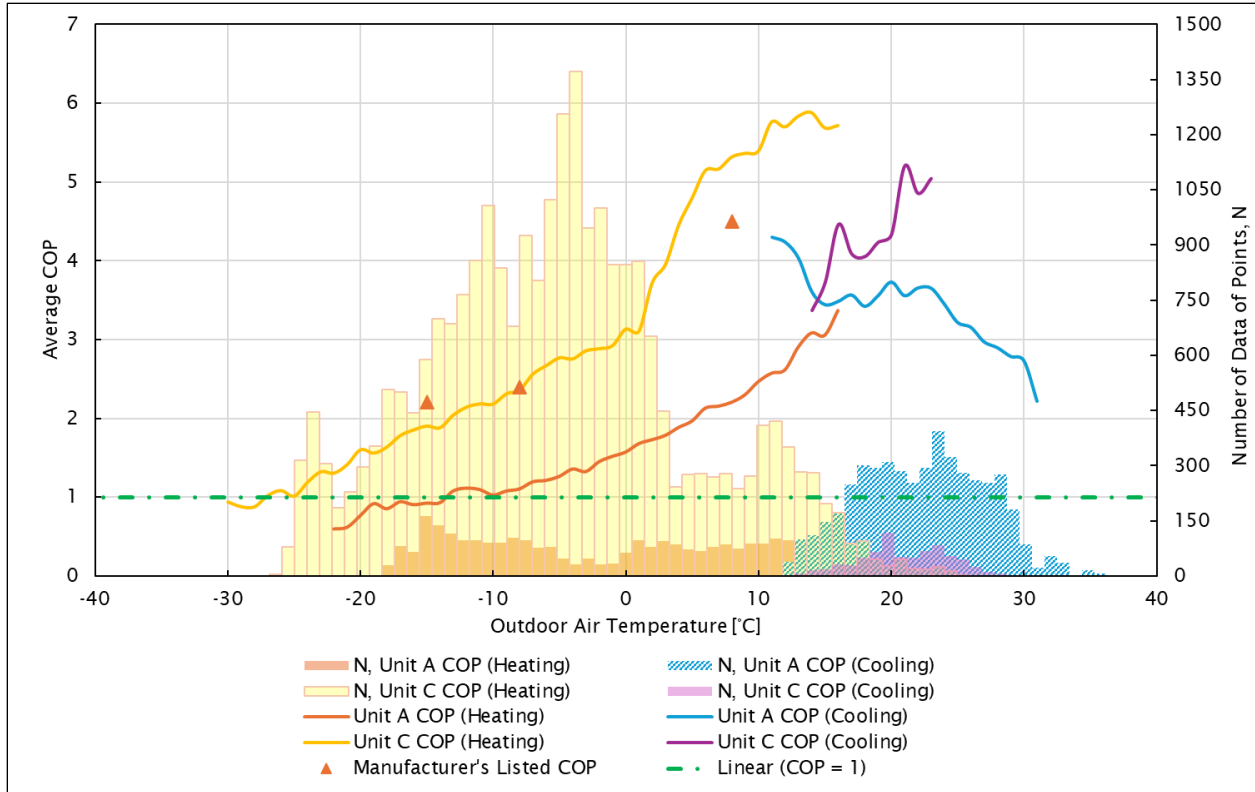


Figure 1 – Heat pump average heating and cooling COPs at various outdoor operating conditions for the monitoring period between May 1, 2023, and Dec. 31, 2024, are plotted as various line plots on the primary y-axis. The number of data points collected during this period, *N*, are plotted on the secondary y-axis.

Source: RDH Building Science Inc., Yellowknife Cold Climate Heat Pump Study: Mini Split System – Final Report. P. 18.

Below is a plot of the average heating (or cooling) energy provided to the space, and electrical energy consumed by the heat pump at various outdoor operating conditions (Figure 2). The chart shows that Unit C's heat pump supplies more energy than it consumes when outdoor temperatures are above -25°C and unit A's heat pump supplies more energy than it consumes when outdoor temperatures are above -13°C.

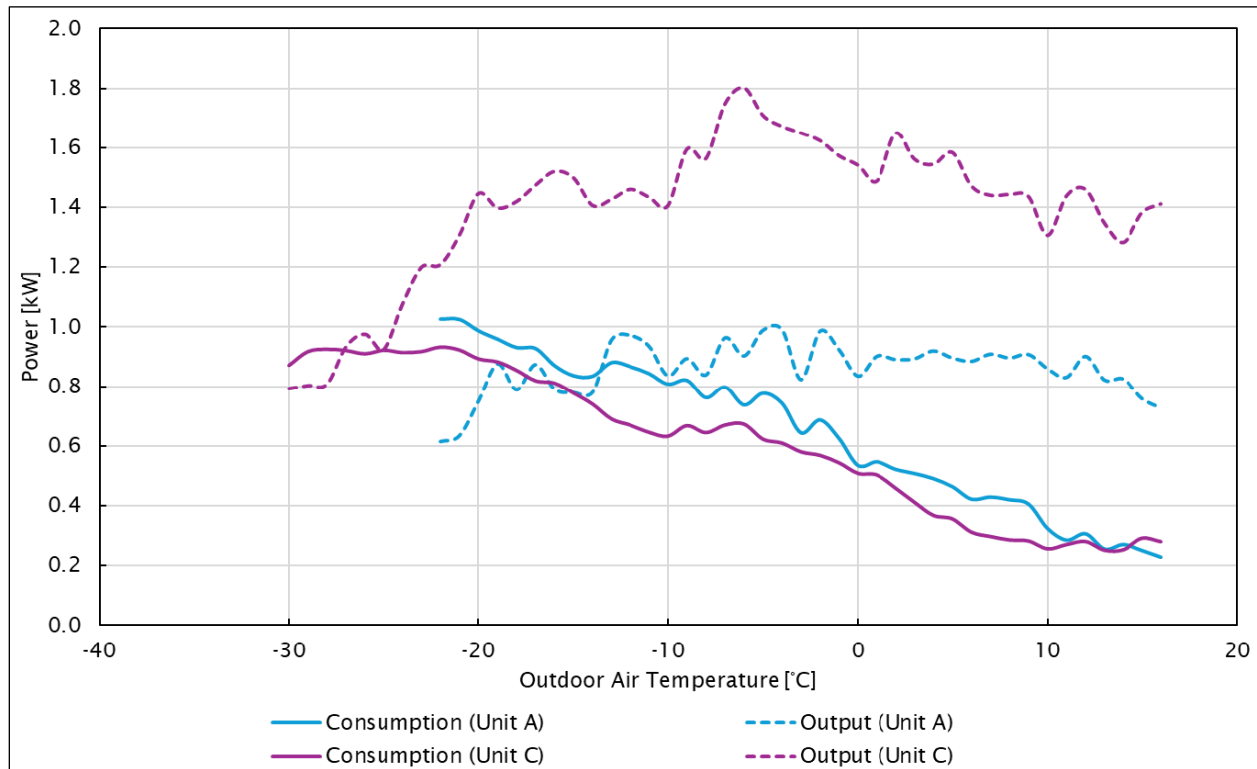


Figure 2 – Heat pump consumption and output (for heating and cooling) at various outdoor operating conditions for the monitoring period from May 1, 2023, to December 31, 2024.

Source: RDH Building Science Inc., Yellowknife Cold Climate Heat Pump Study: Mini Split System – Final Report. P. 20.

Cost and GHG Analysis

The technical analysis results discussed above were applied to a representative average home in Yellowknife. The tables and figures in this section present the resulting cost and GHG analysis, based on fuel prices from AEA’s five-year average *Fuel Cost Library*.

Things to note:

- Cold-climate air-source heat pump (CCASHP) numbers are based on COPs of Unit C (the unit in which the heat pump was operating without significant issues).
- ‘Full year of heating with CCASHP’ number assumes 100%-efficient electric heating below -30°C
- All numbers below reflect residential fuel and electricity rates, sourced from AEA’s *Fuel Cost Library – 5-Year Average – Winter 2025*.
- An average Yellowknife house heating load of 118,630 MJ was used for the analysis
- The GHG emission values of heat pumps and electric heating are referring to the GHG emissions from electricity generation. Even though Yellowknife runs primarily on hydroelectricity, there are still times when we rely on fossil fuels to generate power. For example, low water levels may result in a higher proportion of power being generated from diesel generators. The GHG emissions shown in the graphs below are based on approximately 3% of total electricity coming from diesel generation.
- The following efficiency percentages, representing the efficiency of a new top-end heating appliance (“Best New Efficiency”) and the efficiency of the average heating appliance currently installed (“Currently Installed Average Efficiency”), were used for energy sources other than CCASHPs:

Fuel Type	Best New Efficiency
Oil	96%
Pellets	85%
Propane	98%
Electricity	100%

Fuel Type	Currently Installed Average Efficiency
Oil	80%
Pellets	75%
Propane	78%
Electricity	100%

Cost and GHG Analysis – Best New Efficiency (Per GJ)

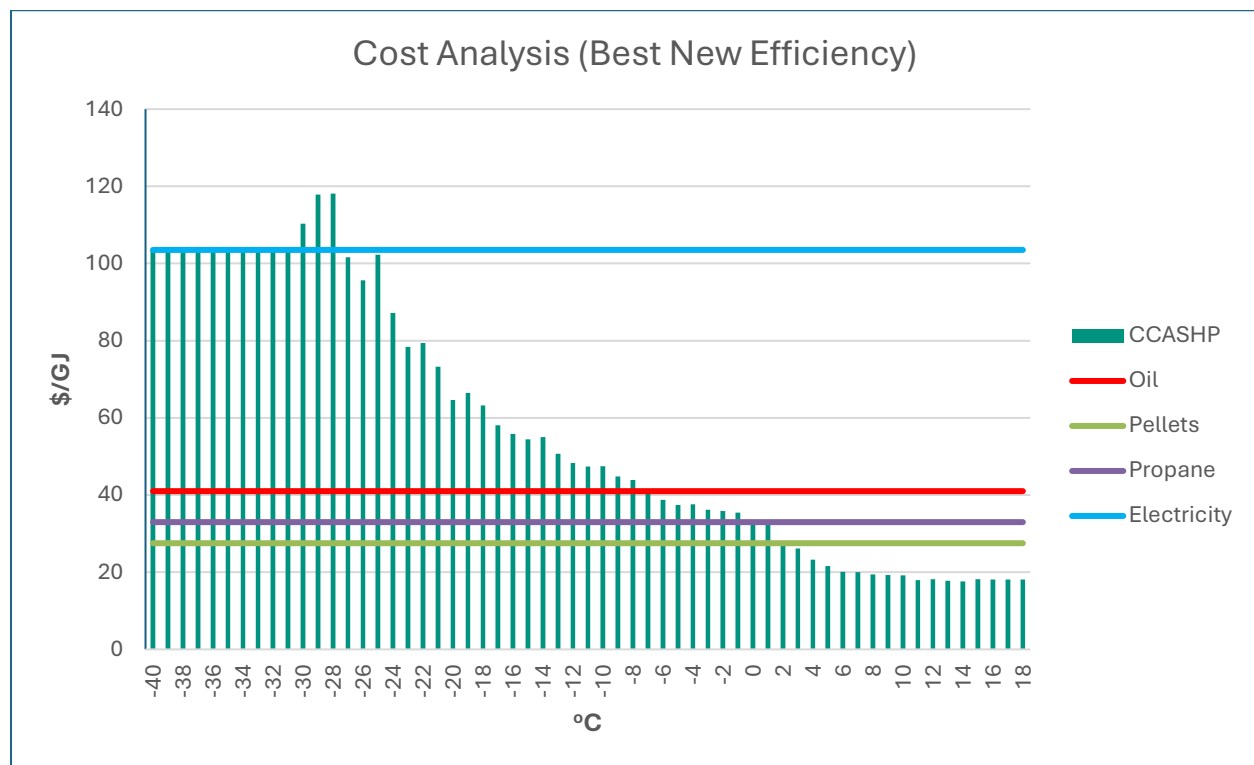
The graphs below compare CCASHP heating with other heating sources, using best new appliance efficiencies shown in the table above.

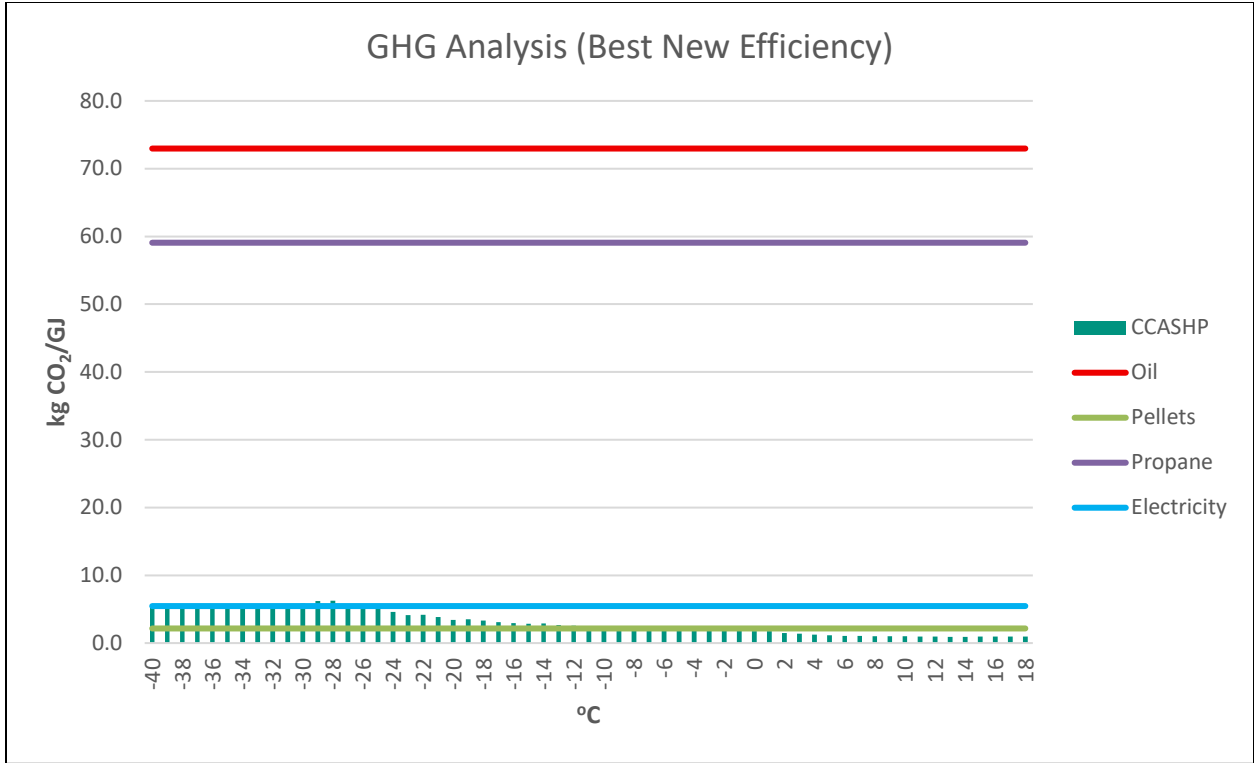
The first graph shows the cost of each GJ of heat delivered at various outdoor temperatures. Similarly, the second graph shows GHG emissions for each GJ of heat delivered.

Values for CCASHP heating are shown with vertical bars. Other fuel sources are represented with horizontal lines. The CCASHP bars can be compared with the horizontal lines to identify the temperatures at which CCASHP heating becomes more cost-effective and results in lower GHG emissions. For example, the first graph below shows that CCASHP heating is cheaper than oil heating down to approximately -7°C, below which oil becomes the cheaper heating option.

A detailed breakdown of similar switchover temperatures and associated savings for all fuel sources has been provided in the “best case scenario” section further in the report.

The second graph shows that heating with a CCASHP can save a significant amount of GHGs compared to heating with fossil fuels in hydro communities like Yellowknife. Only wood pellets and electric resistive heating have comparable amounts of GHG production.

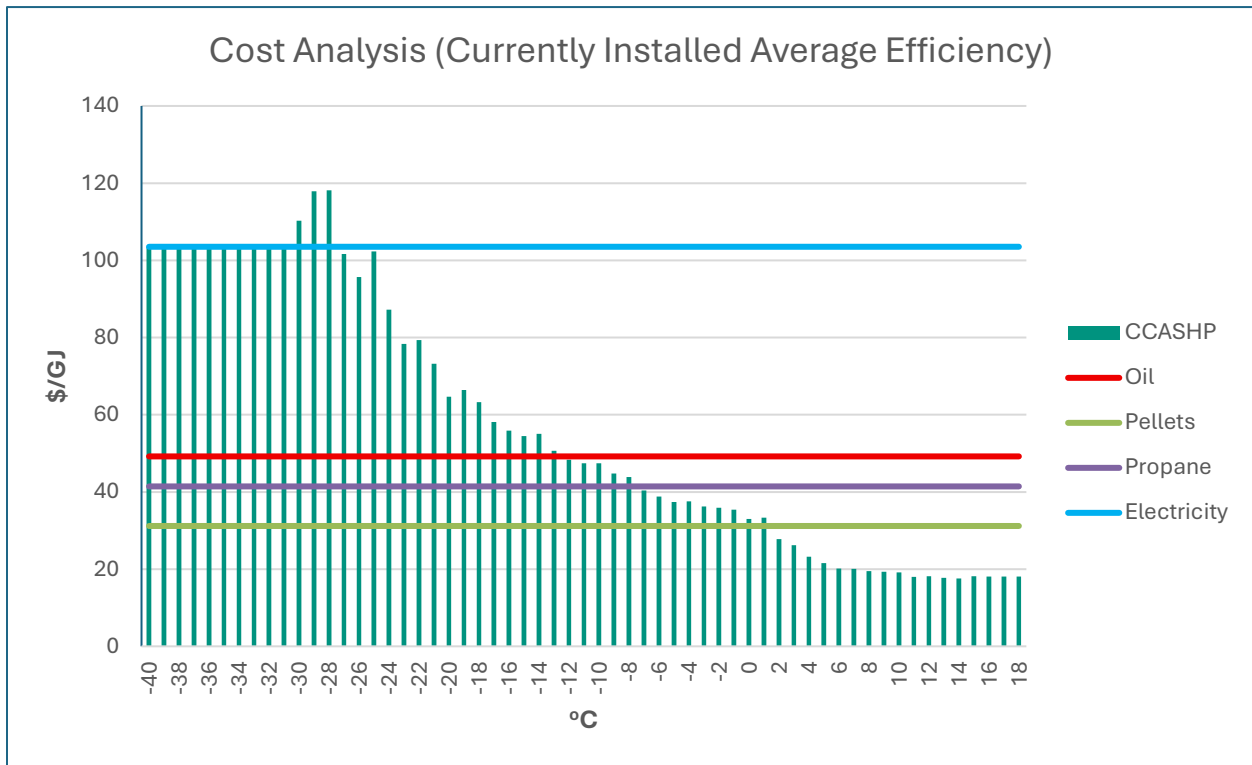




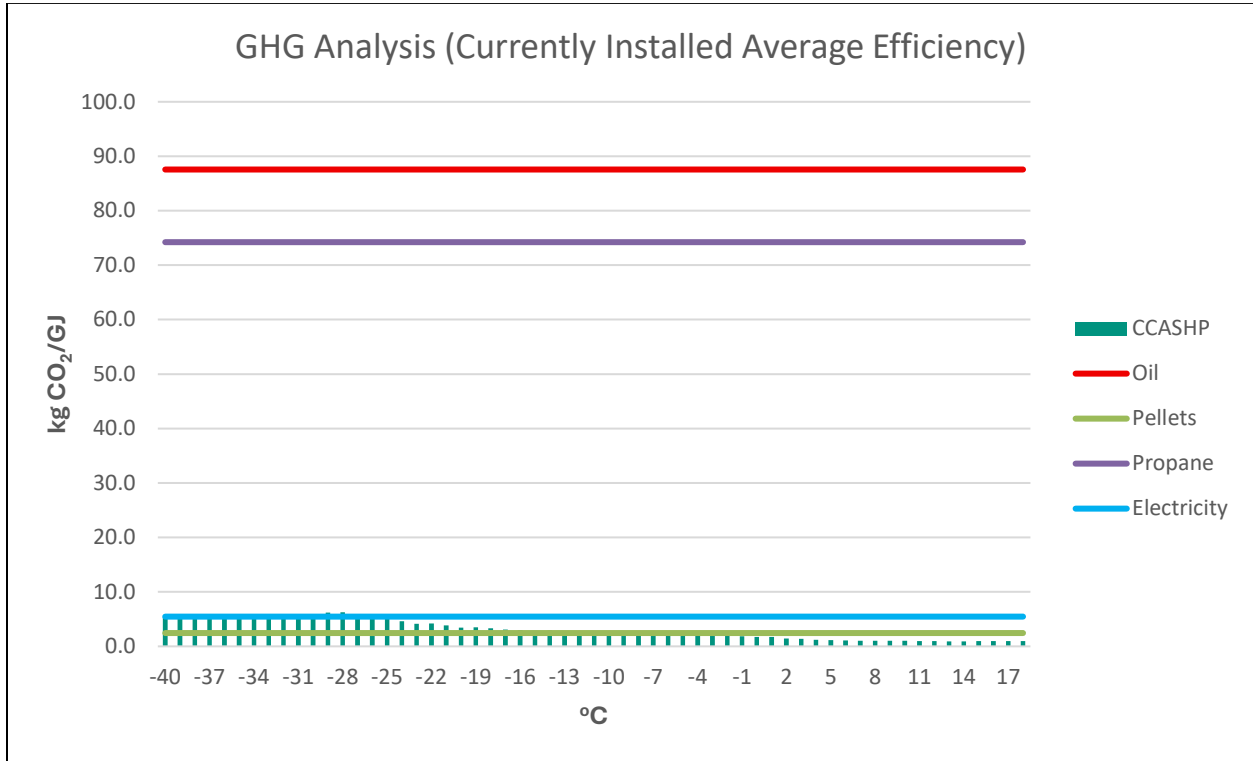
Cost and GHG Analysis – Currently Installed Average Efficiency (Per GJ)

Similar to the graphs above, the two graphs below compare CCASHP heating with other heating sources on a per-GJ basis, using the efficiencies of average heating appliances that are currently installed.

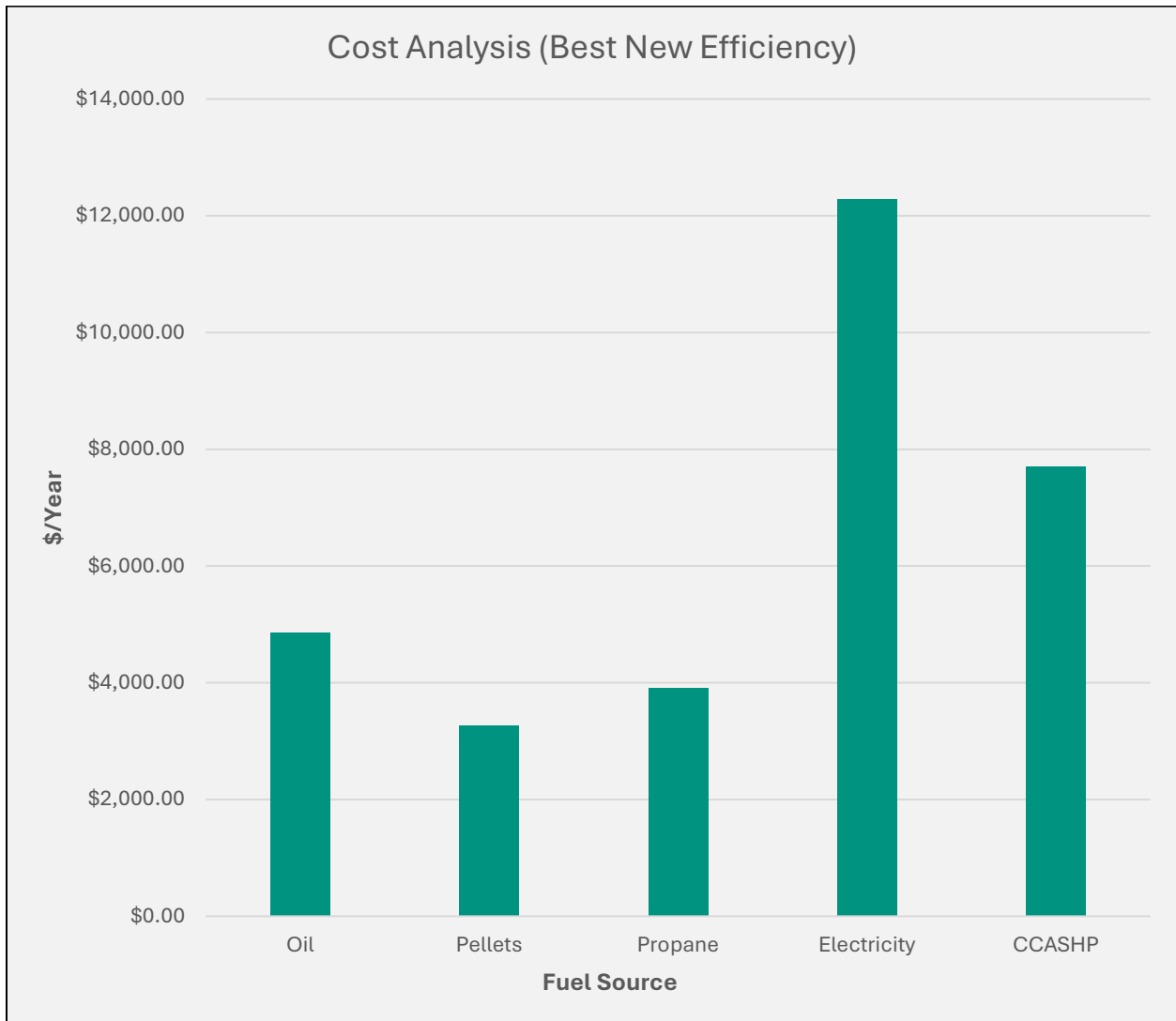
Like the “best new efficiency” appliances, there is a point at which average-efficiency appliances become cheaper to use than a CCASHP. A detailed breakdown of switchover temperatures and associated savings for all fuel sources has been provided in the “best case scenario” section further in the report.



As with “best new efficiency” appliances, the graph below also shows that heating with a CCASHP can save a significant amount of GHGs compared to heating with fossil fuels in hydro communities like Yellowknife. Only wood pellets and electric resistive heating have comparable amounts of GHG production.

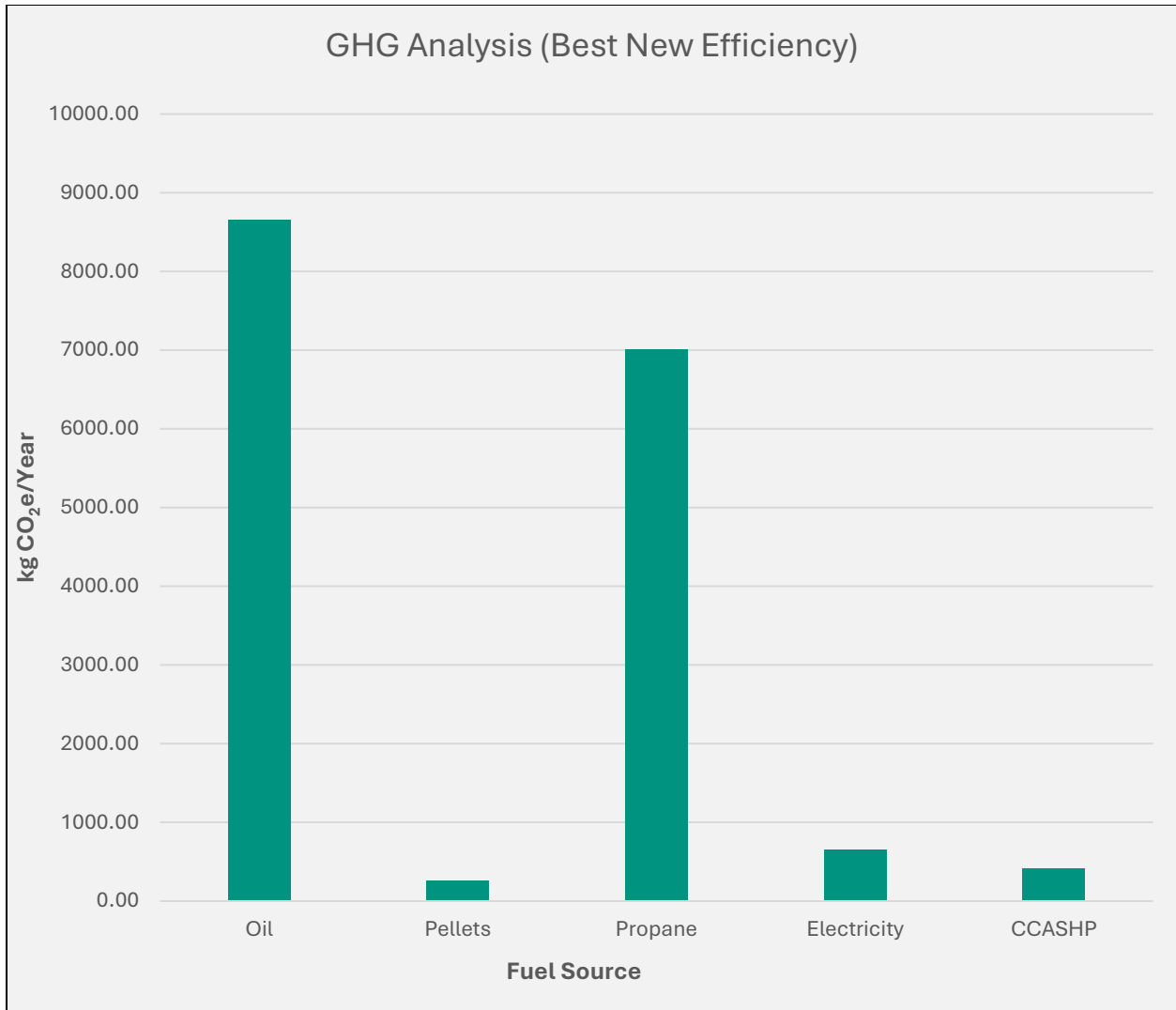


Cost and GHG Analysis – Best New Efficiency (Per Year)



Fuel Type	\$/yr
Oil	\$4,900
Pellets	\$3,300
Propane	\$3,900
Electricity	\$12,300
CCASHP	\$7,700

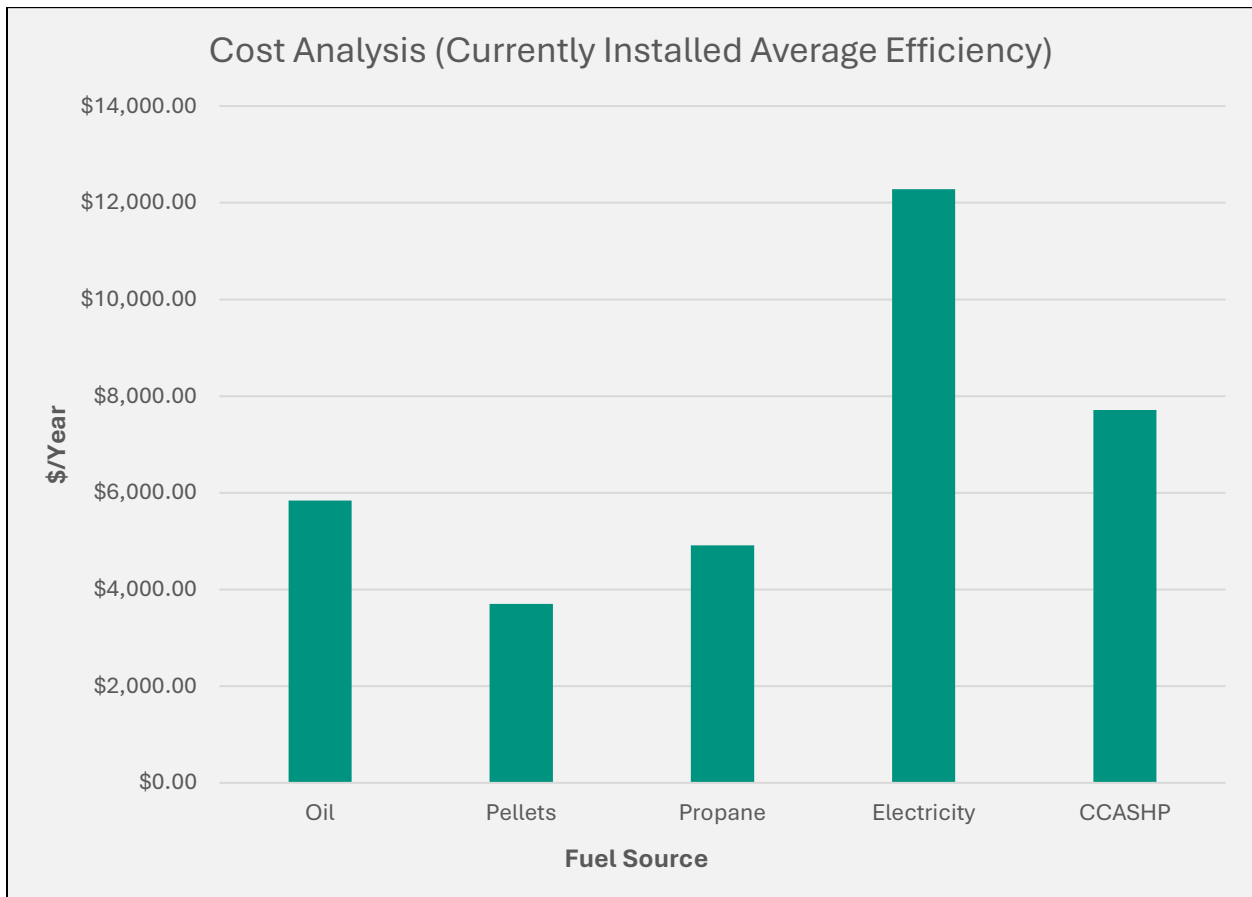
**Values have been rounded.*



Fuel Type	kg CO ₂ e/yr
Oil	8,700
Pellets	250
Propane	7,000
Electricity	650
CCASHP	400

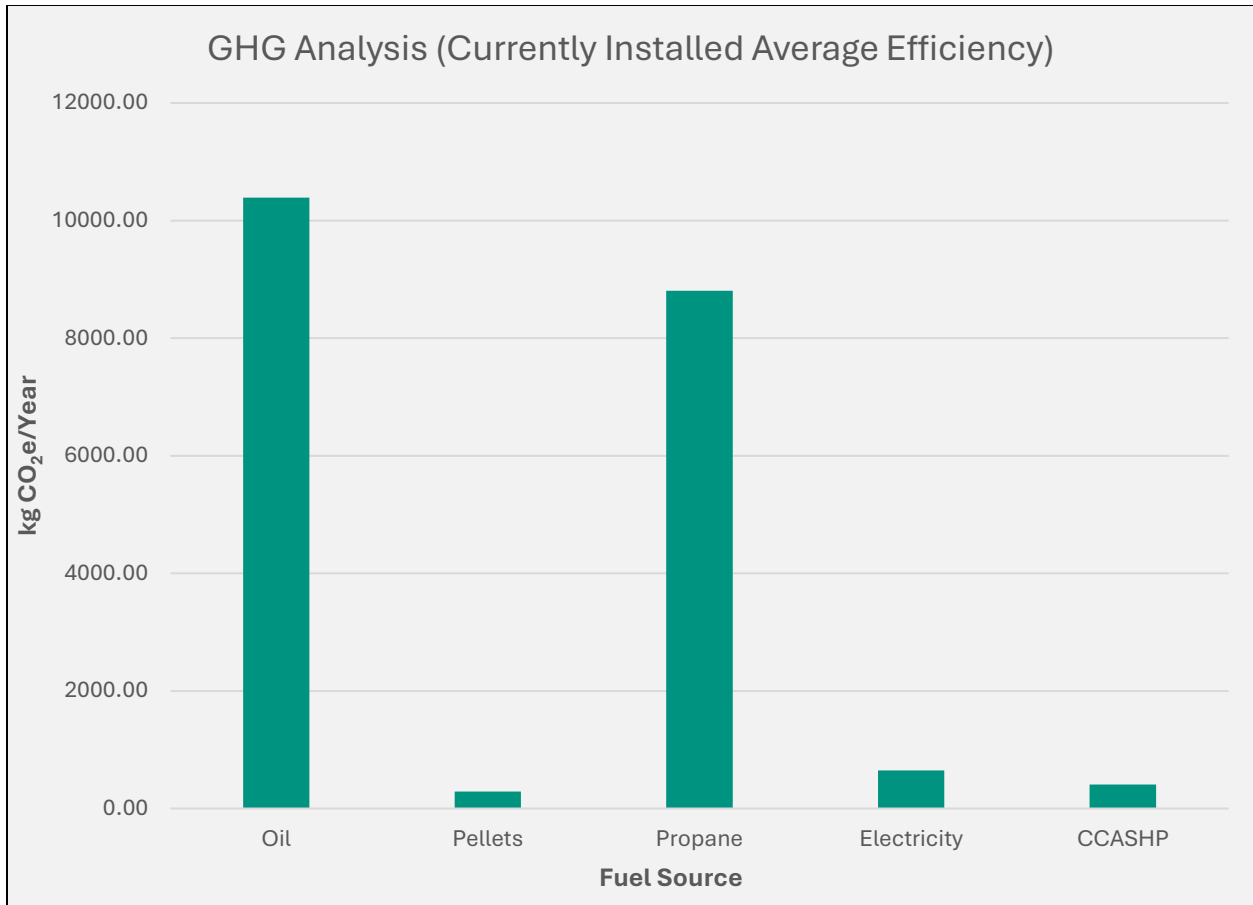
**Values have been rounded.*

Cost and GHG Analysis – Currently Installed Average Efficiency (Per Year)



Fuel Type	\$/yr
Oil	\$5,800
Pellets	\$3,700
Propane	\$4,900
Electricity	\$12,300
CCASHP	\$7,700

**Values have been rounded.*



Fuel Type	kg CO ₂ e/yr
Oil	10,400
Pellets	300
Propane	8,800
Electricity	650
CCASHP	400

**Values have been rounded.*

Cost Comparison – Best New Efficiency

	\$/kwh
Electricity cost (current)	\$0.37
Electricity cost required for CCASHP to be equivalent to oil heating	\$0.24
Electricity cost required for CCASHP to be equivalent to pellet heating	\$0.16
Electricity cost required for CCASHP to be equivalent to propane heating	\$0.19

*Values reflect full year of heating with CCASHP.

	\$
Oil cost per litre (current)	\$1.51
Oil cost required for oil heating to be equivalent to CCASHP	\$2.40
Pellets cost per tonne (current)	\$449
Pellet cost required for pellet heating to be equivalent to CCASHP	\$1,061
Propane cost per litre (current)	\$0.86
Propane cost required for propane heating to be equivalent to CCASHP	\$1.69

* Values reflect full year of heating with CCASHP.

Cost Comparison – Currently Installed Average Efficiency

	\$/kwh
Electricity cost (current)	\$0.37
Electricity cost required for CCASHP to be equivalent to oil heating	\$0.28
Electricity cost required for CCASHP to be equivalent to pellet heating	\$0.18
Electricity cost required for CCASHP to be equivalent to propane heating	\$0.24

*Values reflect full year of heating with CCASHP.

	\$
Oil cost per litre (current)	\$1.51
Oil cost required for oil heating to be equivalent to CCASHP	\$2.00
Pellets cost per tonne (current)	\$449
Pellet cost required for pellet heating to be equivalent to CCASHP	\$936
Propane cost per litre (current)	\$0.86
Propane cost required for propane heating to be equivalent to CCASHP	\$1.35

*Values reflect full year of heating with CCASHP.

Best Case Scenario – Best New Efficiency

The table below shows how much a homeowner would expect to pay/save when using a combination of CCASHP and fuel heating, using a best-case switchover point. Note that the table below shows the results of calculations for a typical home in Yellowknife with a heating appliance rated at the best new efficiency—every building will be different.

Fuel Source	CCASHP + Fuel Cost			Savings Compared to Full Year with Fuel Heating	Savings Compared to Full Year with CCASHP Heating	Switchover Temperature
	CCASHP (Electricity) \$	Fuel \$	Total			
Oil	\$930	\$3,550	\$4,480	\$380	\$3,230	-7°C
Pellets	\$280	\$2,880	\$3,160	\$100	\$4,550	3°C
Propane	\$320	\$3,400	\$3,720	\$180	\$3,980	2°C

**Values may show minor discrepancies due to rounding.*

Best Case Scenario – Currently Installed Average Efficiency

The table below shows how much a homeowner would expect to pay/save when using a combination of CCASHP and fuel heating, using a best-case switchover point. Note that the table below shows the results of calculations for a typical home in Yellowknife with a heating appliance rated at the currently installed average efficiency—every building will be different.

Fuel Source	CCASHP + Fuel Cost			Savings compared to Full Year with Fuel Heating	Savings compared to Full Year with CCASHP Heating	Switchover Temperature
	CCASHP (Electricity) \$	Fuel \$	Total			
Oil	\$1,470	\$3,700	\$5,170	\$670	\$2,550	-12°C
Pellets	\$320	\$3,220	\$3,540	\$160	\$4,170	2°C
Propane	\$930	\$3,590	\$4,520	\$390	\$3,190	-7°C

**Values may show minor discrepancies due to rounding.*

Discussion

This report summarizes results from monitoring conducted between May 1, 2023, and December 31, 2024. Overall, the results show that cold-climate ductless air-source heat pumps can provide most of the heating needed in sub-arctic regions. However, a backup heating system is still required during extremely cold periods when outdoor temperatures fall below the heat pump's operating limits.

The study found that heat pumps work especially well during milder winter conditions and during the spring and fall “shoulder seasons.” Using the heat pump during these times can reduce the need for other heating fuels and greatly reduce the GHG emissions associated with heating a house. It is important to note that the heat pump in Unit C offset nearly 100% of the heating requirements for September, October, and November of 2023 and 2024, and a good portion of the heating requirement in December 2024. However, the high cost of electricity in the Northwest Territories remains an important consideration, and depending on the other fuel source used, it will likely be cheaper to run whichever other heating system is installed when it's colder than about -12 to 2 degrees Celsius (see switchover temperatures in the table above)¹. Properly sizing the equipment for the home's heating needs and using the right control settings will help ensure the heat pump operates as efficiently as possible.

Operational issues—particularly related to control systems—negatively impacted performance, especially in Unit A. Control of the mini-split heat pump operation was managed by the tenant to a certain degree, which contributed to suboptimal performance. The research highlights the need for optimized control strategies, regular maintenance and robust monitoring to fully leverage the advantages of heat pump systems. However, it is recognized that controls with this type of single-room heating system are always subject to the whims of the occupants. Phase 2 of this research involves testing central-split heat pumps in other buildings, which should limit sporadic control issues.

The number of local contractors with the necessary training and experience to install and service this equipment is limited, which is a site-specific issue. Because this technology is still relatively new in the region, homeowners may find it difficult to locate qualified installers or technicians, and this limited availability can affect installation timelines and ongoing service support. Situations like this can add additional steps, costs, and coordination when installing new electric heating equipment.

For more technical information on Phase 1 of the study, please refer to RDH's *Yellowknife Cold Climate Heat Pump Study: Mini Split System – Final Report*. The Arctic Energy Alliance continues to test cold-climate heat pump technology with Phase 2 of the study, with monitoring expected to continue for another two years.

¹ The economic break-even point would be enhanced if we included a “\$-value” for the amount of GHG avoidance

Sources

- RDH Building Science Inc., *Yellowknife Cold Climate Heat Pump Study: Mini Split System – Final Report*.