ANALYSIS OF HEAT PUMP SYSTEMS IN THE CANADIAN HIGH ARCTIC

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Abstract
This paper presents a sea water heat pump and cogeneration energy efficiency analysis conducted for the Canadian Forces Station Alert, located in the high Arctic. Three energy efficiency strategies were evaluated for the station's airfield located close to the Arctic Ocean. The station as well as the airfield annual fuel savings were compared for a sea water heat pump system powered by the station's main power plant, a small scale district heating system located at the airfield and a combination of four micro-cogeneration units and a sea water heat pump system. The sea water heat pump system powered by the main power plant was determined to be the most energy efficient, reducing the annual fuel consumption (electricity generation and space heating fuel) at the airfield by 27%. The small-scale district heating system was the least energy efficient achieving only 14% fuel savings primarily because of the added electricity generating capacity not required at the station.

Key Words: High Arctic, Heat Pumps, Renewable Energy

1 INTRODUCTION

Confronted with harsh environmental conditions, remoteness, lack of local resources and continually increasing fuel costs, arctic communities are challenged with finding alternative and sustainable options for fuel and power. The Canadian Forces Station (CFS) Alert, located at the northern tip of Ellesmere Island in Canada (82°28'N, 62°30'W), faces the same challenges inherent to these communities. The station, considered to be the most northerly permanently inhabited location, has been in operation since the late 1950's and has undergone numerous changes to keep pace with operational requirements in addition to technology advancements. At present, the station is comprised of over 100 buildings, of which over 70 are connected to the station's electrical grid and 50 are heated through fuel-fired boilers and furnaces, electrically or through the station's district heating loop. Electricity at the station is generated through four 950 kW JP-8 fired cogeneration units, which also meet a large portion of the heating load for 11 of the 50 heated buildings. The station has an approximate total heated floor area of over 20,000 m², with 89% of the station footprint located in the core complex and the remaining 11% located at the airfield and various outlier buildings.

Annually, the station consumes over 2,100,000 L of JP-8 (diesel jet fuel) used for the cogeneration of electricity and heat (80%) and for additional space heating needs (back-up) with direct fired fuel boilers/furnaces (20%). Peak electrical loads in February and March can exceed 1,100 kW with the peak demand falling below 650 kW during the summer. With increasing fuel costs approaching $7 per liter, 5 times higher than in Southern Canada (Natural Resources Canada 2007), and the dependency of importing all fuel through transport, it is essential to find alternative and sustainable energy solutions.

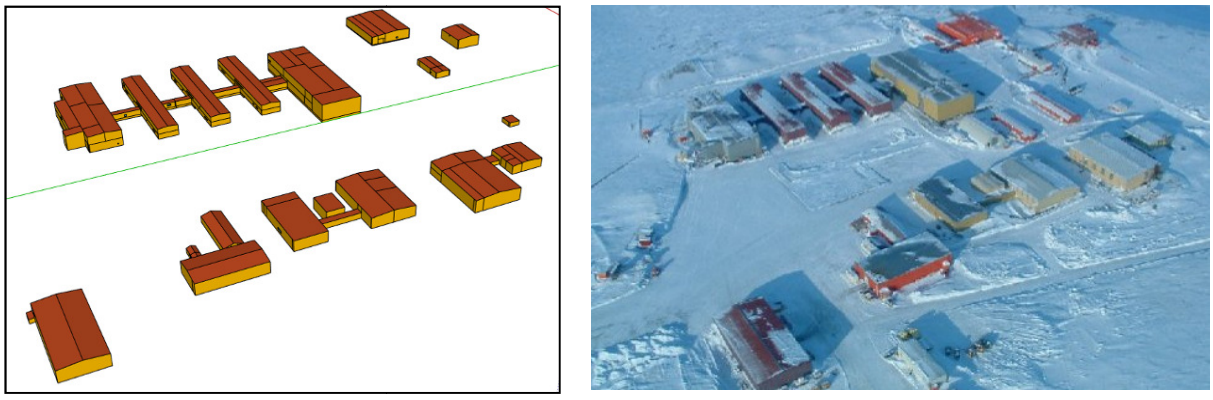
While solar and wind energy are some of the obvious solutions for alternative power and energy, both have their challenges and are seasonal in nature. Alternatively, the use of the Arctic Ocean as a renewable energy source could be viable. With a constant sea water temperature close to 0°C, heat pumps could be utilized to upgrade the energy of the sea water to meet the space heating demands. While the use of the ocean as a viable renewable energy source has been demonstrated in several Norwegian military bases (Underland 2004), these bases are on a centralized electrical grid, which is different from most arctic regions where electricity is produced off-grid. Thus in order for a sea water heat pump (SWHP) system to be a viable alternative, a careful balance between the electrical and heat demands must be determined to ensure the systems are operated to their fullest potential.

The objective of this paper is to present the continued effort to evaluate renewable energy integration strategies at the CFS Alert through the use of sea water heat pumps. In particular, the main focus is to evaluate and compare three scenarios:

- An airfield SWHP connected to the station electrical grid
- An airfield district heating system
- An airfield SWHP connected to building micro-cogeneration systems

2 PREVIOUS WORK

Over the past 10 years several studies have been undertaken (Sommer and Bouchard 2004; NRCan 2007; Accutech Engineering 2010) to evaluate the station's existing conditions, propose improvements to the envelope of various buildings and evaluate the feasibility of utilizing various renewable energy sources. More recently, Defence Research and Development Canada in conjunction with Natural Resources Canada (NRCan) conducted an extensive energy audit of the station as part of a larger task to evaluate alternative power and energy options for arctic locations, including heat pumps. This work included the installation of electrical and district heat flow meters to acquire detailed station energy consumption and also included the development of an extensive and detailed energy model of the station (50 buildings, some shown in Figure 1a), which was validated with the recorded station energy consumption. Further details of the work undertaken can be found in two papers by Kegel et al. (2012, 2013). An overhead view of the station is shown in Figure 1b (Troyanik 2013).



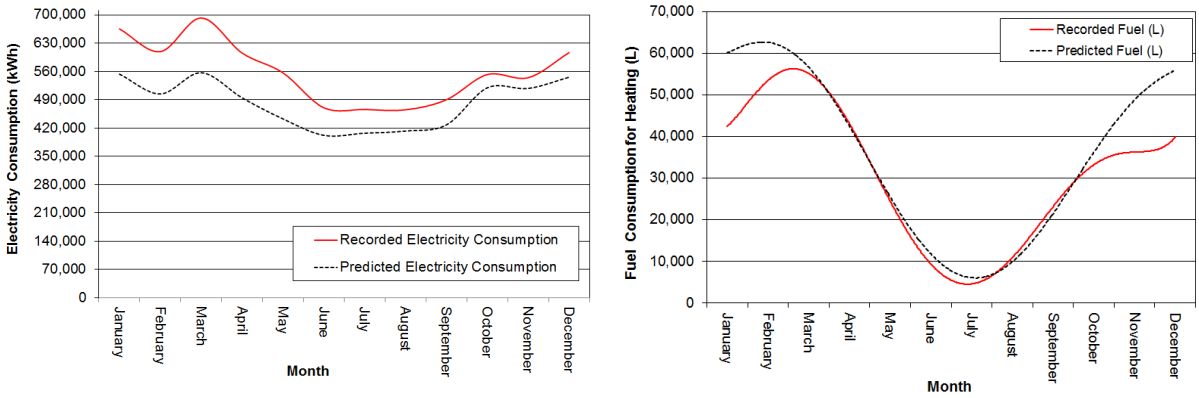
(a) (b)

Figure 1: (a) Building energy model of station (b) Overhead view of CFS Alert

3 BASE LINE STATION ENERGY CONSUMPTION

To perform the feasibility analysis of the sea water heat pump system, the developed TRNSYS (Klein et al. 2010) energy model of the station was used. The station baseline

energy consumption results from the simulation were validated with the recorded electricity production (Figure 2a) and space heating fuel consumption (Figure 2b) data showing a similar trend and with a maximum deviation of 15%, thus demonstrating the validity of the energy model to perform the analysis. Differences between the recorded and predicted electricity and fuel consumption are attributed to station operational changes (such as failing to record the fuel consumption of some buildings) as well as some unknown equipment electrical loads.



(a) (b)

Figure 2: (a) Predicted versus recorded electricity consumption (b) Predicted versus recorded space heating fuel consumption

While a portion of the station global fuel consumption can be attributed to the station operational demands, the buildings also show characteristic signs of wear and age having been exposed to harsh arctic conditions for over 30 years. The energy audit identified potential areas to reduce energy-use at the site such as building envelope and lighting efficiency improvements. Thus, prior to simulating the implementation of any type of renewable energy system, it is assumed that the station would first address the standard energy efficiency measures as well as extend its district heating loop as described below.

With lighting and building envelope energy efficiency measures implemented into the energy model, simulations showed the station is expected to consume ~1,500,000 L annually (~84% for electricity and heat production and ~16% for back-up space and DHW heating) with a peak electrical demand of 750 kW. With the station district heating system operating at design conditions, approximately 28,000 L of back-up space heating fuel is required for all buildings connected on the district heating loop with approximately 33% of the annual available heat recovered from the power plant rejected outdoors (mostly during the summer period). Further details of the energy efficiency measure analysis can be found in Kegel et al. (2012).

To ensure the recovered heat from the generators are fully optimized for use, this study also considered extending the district heating loop to other adjacent buildings in the core complex. The added heating load on the district heating system reduces the heat rejected to the outdoors from 33% to 13% and as a result, it is anticipated that the annual station consumption fuel consumption would be 1,450,000 L (50,000 L total savings). With the added district heat demand capacity, the back-up fuel fired heater consumption in this network increases from 28,000 L to 62,500 L. This is expected as the space heating demand exceeds the heat recovery energy available to a greater extent in the winter months. Figure 3 shows the relationship between the energy available from the district heating system and the heat demand of the buildings connected to the district heating loop. It can be seen that during the winter, there is a greater demand of energy from the district heating loop than available and excess heat is available during the summer. It should also be noted that the amount of district heat energy available correlates directly to the amount of electricity

produced. Thus any increase in the electrical demand increases the amount of district heating energy and similarly any decrease in the electrical demand decreases the amount of district heating energy available.

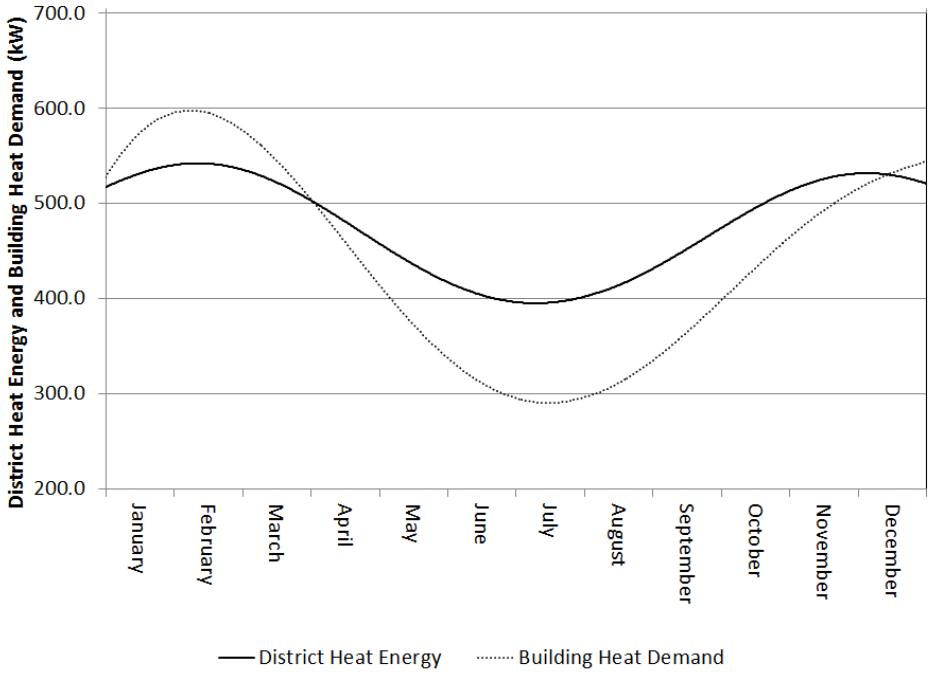


Figure 3: Relationship between station district heating energy and building heat demand (simulated)

The predicted baseline fuel consumption of the station (after lighting and building envelope energy efficiency measures as well as the extended district heating were implemented) and percentage of unused heat recovery from the main power plant is summarized in Table 1.

Table 1: Modified baseline annual station energy consumption and percentage of unused heat recovery

Scenario	Power Plant Fuel (L)	Space Heating Fuel (L)	Total Station Fuel (L)	% of Heat Recovery not used
Base Case	1,256,957	191,328	1,448,285	13%

The annual electrical and thermal efficiency of the power plant is 33% and 24%, respectively. The combined annual efficiency is 57% with a maximum potential of 65% (if the heat recovered could be utilized throughout the year).

At the airfield, the annual building electricity consumption is estimated to be ~200,000 kWh with a peak electrical demand of 46 kW after implementing the lighting and envelope energy efficiency measures. Fuel fired heaters are installed in the five largest airfield buildings which consume a total of 33,500 L of fuel annually for space heating. The remaining small buildings at the airfield are heated electrically. Since the airfield is electrically fed from the main power plant, the electrical load on the cogeneration units corresponds to 51,400 kWh eq. (185 GJ) of additional district heating energy (cogenerated) available annually to meet the space heating loads at the core complex, which is equivalent to approximately 6,750 L of fuel. Table 2 summarizes the annual fuel consumption of the airfield.

Table 2: Baseline annual airfield energy consumption

Scenario	Power Plant Fuel (L)	Space Heating Fuel (L)	Fuel Savings at Core Complex (L)*	Total Fuel Consumption (L)
Base Case Airfield	53,570	33,541	-6,750	80,361

*Due to additional heat made available in the district heating loop by increased power generation

4 SEA WATER HEAT PUMP SYSTEM

The ambient temperatures in the arctic often fall well below -40°C, significantly reducing the heat capacity of heat pump systems that use air as a renewable heating source. In addition, the use of the ground is also unfeasible due to the depth of the permafrost (-14°C undisturbed ground temperature (Throop 2010) in CFS Alert) and the high imbalance between heating and cooling loads. The Arctic Ocean however is at a constant temperature year long and many locations have sufficient tidal currents to circulate sea water around the heat pump heat exchanger. With a constant temperature of -1.8°C (28.8°F) measured at a depth of 80 m (U.S. National Oceanographic Data Center: Global Temperature–Salinity Profile Programme 2006), the use of sea water as a renewable energy source was seen as a possibility to further reduce the overall fuel demand at the station.

To perform the analysis, the airfield was selected due to its proximity to the Arctic Ocean, as well as to its long distance from the main power plant, which makes the use of the available free heat from the station district heating loop unfeasible. This analysis will eventually be extended to the main complex at Alert.

A sea water heat pump (SWHP) network is proposed for the four largest airfield buildings, where the fuel fired furnaces would be replaced with water to air heat pumps. A brine loop would be the heat source for the heat pumps, the fluid circulated with a variable speed pump through a heat exchanger anchored in the Arctic Ocean. A schematic of the proposed network is shown in Figure 4.

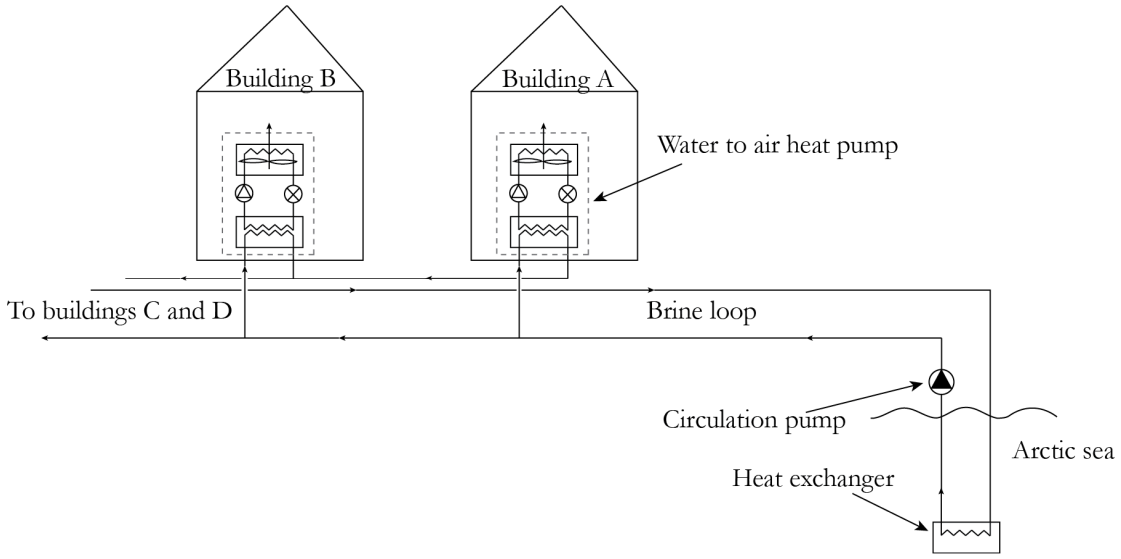


Figure 4: Schematic of the sea water heat pump

5 AIRFIELD ENERGY EFFICIENCY STRATEGIES

Three scenarios are considered in evaluating and comparing the potential of a SWHP system at CFS Alert.

- Scenario 1 evaluates a SWHP system at the airfield powered by the main power plant cogeneration units.

- Scenario 2 compares the SWHP system to a small scale district heating system implemented at the airfield.
- Scenario 3 evaluates a combination of scenario 1 and scenario 2, where building micro-cogeneration units are proposed supplementing and powering a SWHP system.

In order to obtain a successful energy efficiency strategy, achieving a good match between the building thermal and electrical loads and the cogeneration system capacity production of electricity and heat is necessary.

5.1. Scenario 1 – Sea water heat pump system at airfield fed by main power plant

This scenario evaluates the global station energy consumption by replacing the fuel fired heaters of the four largest airfield buildings with a SWHP system. The main power plant continues to supply electricity to the airfield grid and ultimately through the increased electrical load on the main power plant generators, more district energy heat becomes available for the core complex buildings (see Figure 3 for relationship).

The capacities of the water to air heat pumps in each building were selected to meet the maximum average 24 hour heating load for each building. The peak 24 hour heating loads ranged between 10 kW to 16 kW, and thus heat pumps with a rated capacity between 14 kW and 21 kW were selected. At operating conditions, the heat pumps have a heating COP between 3.1 and 3.5 (Daikin 2013).

By implementing the SWHP system at the airfield, the power plant electrical and thermal efficiency would be 33% and 28%, respectively for an annual combined efficiency of 61%. This is an increase of 4% compared to the base case; however still below the maximum potential of 65% if all the heat recovered could be used. Of the additional heat recovery capacity made available, only 41% could be used to meet the space heating demand, while 59% would be rejected to the outdoors. The SWHP system has an annual COP of 2.6, which accounts for the part load performance of the water source heat pumps in addition to the pumping power required to circulate the secondary fluid from the Arctic Ocean to the heat pumps. Taking into account the useful thermal efficiency of the main power plant, the SWHP system would have an annual COP of 1.14, which is a 43% efficiency increase compared to a typical fuel fired furnace with an efficiency of 80%.

A larger impact would be seen if the core complex would have a constant demand for the heat recovery and thus have a need for the additional heat generated by the power plant. Nevertheless scenario 1 allows for a reduction of 27% in the total annual fuel consumption at the airfield compared to the base case (from 80,361 L to 58,385 L). Tables 3 and 4 summarize the annual fuel consumption of the station and airfield respectively, after implementing the SWHP system.

Table 3: Annual station energy consumption and percentage of unused heat recovery

Scenario	Power Plant Fuel (L)	Space Heating Fuel (L)	Total Station Fuel (L)	% of Heat Recovery not used
Scenario 1	1,276,063	150,248	1,426,311	14%

Table 4: Annual airfield energy consumption

Scenario	Power Plant Fuel (L)	Space Heating Fuel (L)	Fuel Savings at Core Complex (L)*	Total Fuel Consumption (L)
Scenario 1 Airfield	72,676	3,011	-17,302	58,385

*Due to additional heat made available in the district heating loop by increased power generation

To further evaluate the SWHP integration strategies, scenario 2 investigates the potential energy savings by implementing an airfield district heating network. The benefit here is meeting the space heating loads of the airfield through heat recovered from a local cogeneration plant.

5.2. Scenario 2 – Airfield cogeneration plant

The annual airfield electric demand and thermal demand of the four largest buildings are shown in Figure 5. This scenario considers sizing a cogeneration plant to meet the airfield building electrical loads only.

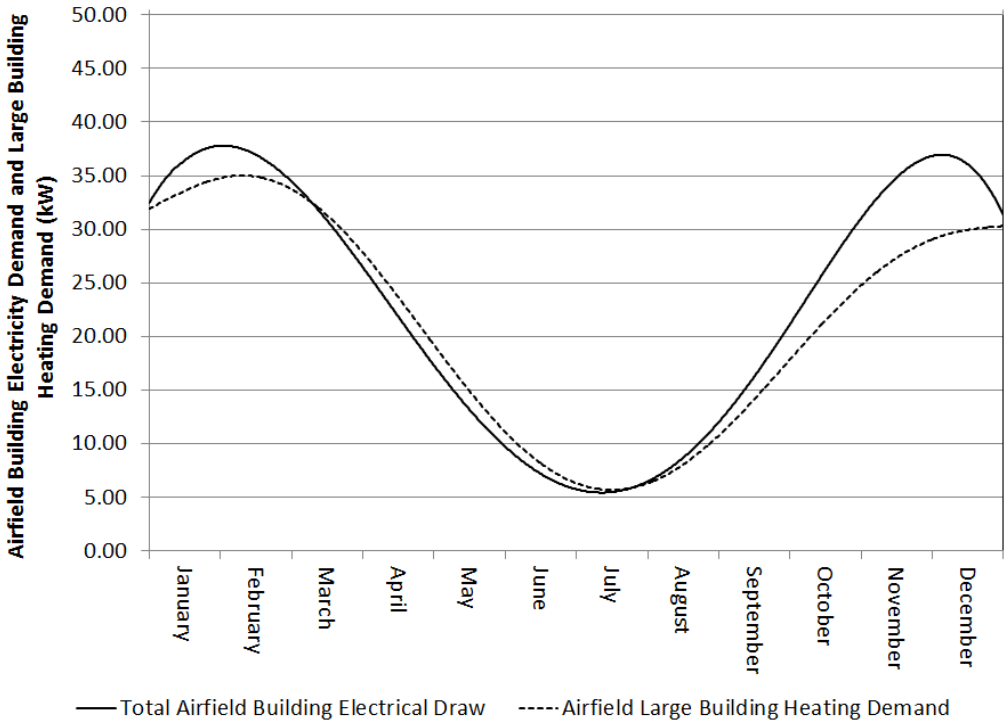


Figure 5: Airfield building electric draw versus airfield large building heating demand (simulated)

A 50 kW cogeneration plant is proposed with the heat recovered distributed to the four largest buildings at the airfield. With a preliminary estimate that the electrical and thermal efficiency of the cogeneration plant are equal, the four buildings will likely not require any significant supplemental heating.

To complete the analysis and provide a comparison to scenario 1, the full load electrical efficiency of the proposed cogeneration plant was estimated to be 3.3 kWh/L (Diesel service and supply incorporated 2014) and assumed to follow the same part load efficiency curve as the main power plant. The cogeneration plant was also assumed to have the same thermal efficiency as the main power plant and ultimately has a combined efficiency of 73% at full load (electrical efficiency 32%, 41% thermal efficiency).

On an annual basis, the cogeneration plant would consume close to 65,000 L of fuel, having an annual electrical and thermal efficiency of 30% and 27%, respectively. The heat recovered from the cogeneration plant, meets the building heating loads the majority of the time, requiring only 1,500 L fuel of back-up heating. Overall, 29% of the energy recovered is not used (mostly rejected during the summer). With the reduced electrical demand at the main power plant, there is an increased demand for the back-up heating systems. At a slightly reduced load, the power plant electrical efficiency decreases to 33%; however the thermal efficiency increases to 29% for an overall efficiency of 61% compared to a maximum

potential efficiency of 65% if all heat recovered were utilized. Due to the reduced heat recovery energy, the core complex back-up heating systems would consume close to 70,000 L of fuel annually. Table 5 summarizes the total annual station fuel consumption of the proposed system.

Table 5: Annual station energy consumption and percentage of unused heat recovery

Scenario	Power Plant Fuel (L)	Space Heating Fuel (L)	Total Station Fuel (L)	% of Heat Recovery not used
Scenario 2	1,267,711	169,099	1,436,810	12%

In comparison with the Scenario 2 airfield cogeneration system, the sea water heat pump system from scenario 1 demonstrates better energy savings. While over 11,000 L of fuel would be saved over the base case (14% reduction) by implementing an airfield cogeneration system, the true potential of the savings are lost because of the increased use of the back-up heating systems in the core complex. If space heating loads are further reduced at the core complex, the implementation of an airfield cogeneration system could become beneficial as the required demand for the district heat energy at the core complex is reduced. Table 6 summarizes the annual fuel consumption of the airfield after implementing the airfield cogeneration plant.

Table 6: Annual airfield energy consumption

Scenario	Power Plant Fuel (L)	Space Heating Fuel (L)	Fuel Savings at Core Complex (L)*	Total Fuel Consumption (L)
Scenario 2 Airfield	64,324	4,560	0	68,884

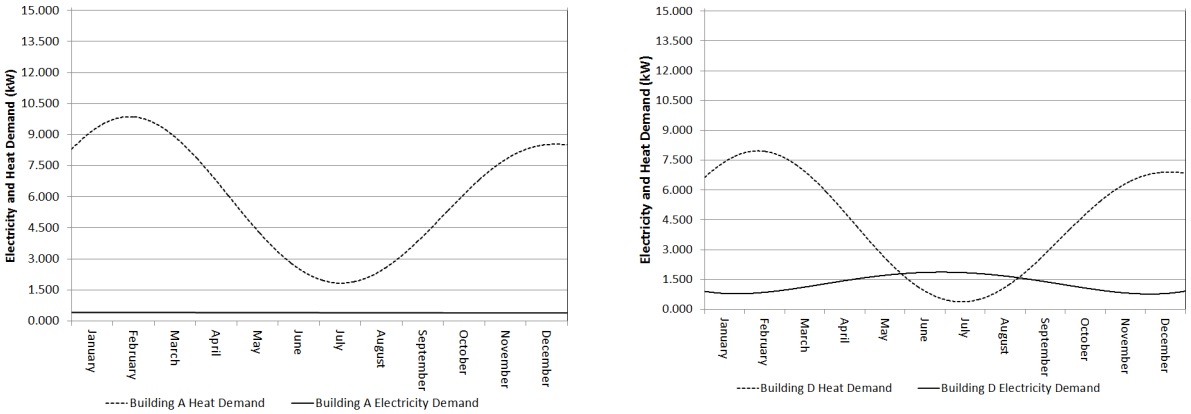
*Due to additional heat made available in the district heating loop by increased power generation

As an alternative, building-specific cogeneration units could be installed at the airfield, with a SWHP system used to balance the thermal and electrical loads. The benefit here would be that a small scale cogeneration and SWHP system could meet the thermal demands of the airfield, without significantly reducing the electric demand on the main power plant generators resulting in a decrease in heat recovery energy available.

5.3. Scenario 3 – Building specific cogeneration plants with sea water heat pump

Scenario 3 evaluates the potential of installing micro-cogeneration plants in the four large airfield buildings with a SWHP system installed to supplement the recovered heat from the cogeneration plants to meet the space heating loads. A comparison of the two typical airfield building electrical and thermal loads is presented in Figures 6a and 6b, showing a high imbalance between the electrical and thermal loads. The high thermal load in comparison to the building electrical demand of the four airfield buildings should make a micro cogeneration and sea water heat pump system a viable energy efficiency measure.

A similar design strategy as the SWHP system proposed in scenario 1 (Figure 4) was used. However, in this scenario, the heat pumps are sized below the peak heating load, as a portion of the heat recovered from building micro-cogeneration unit would also be used to meet a portion of the heat load. For each building a heat pump was selected to minimize the building's annual fuel consumption. A micro-cogeneration unit was then sized to meet the building's peak electrical demand. The heat pumps are equipped with a back-up electric heater in the event there is insufficient capacity to meet the building heating load.



(a) (b)

Figure 6: Simulated electric draw versus building heating load for Buildings A and D

A summary of the selected heat pump size, operating COP (Daikin 2013) and cogeneration electric capacity are summarized in Table 7.

Table 7: Airfield building selected heat pump and cogeneration sizes

Building	Heat Pump Size	Heat Pump Operating COP	Cogeneration Size
Building A	10.6 kW (3 ton)	3.91	6 kWe
Building B	10.6 kW (3 ton)	3.74	7 kWe
Building C	7 kW (2 ton)	3.50	5 kWe
Building D	8.8 kW (2.5 ton)	3.52	8 kWe

To estimate the benefit of this proposed system, the micro cogeneration devices were assumed to have a full load operating efficiency of 2.8 kWh/L (AET 2009) and a thermal efficiency similar to the main power plant cogeneration unit of 41%. The part load performances of the micro-cogeneration units were assumed to be similar to the main power plant cogeneration units. The percentage of the heat load met by the heat pump, the cogeneration heat recovery and the back-up heating for one of the buildings is shown in Figure 7. All four buildings demonstrated similar energy end use profile, where it was found that the optimal solution was to have the SWHP meet the majority of the heating load, with the heat recovered from the cogeneration device used to meet the remainder.

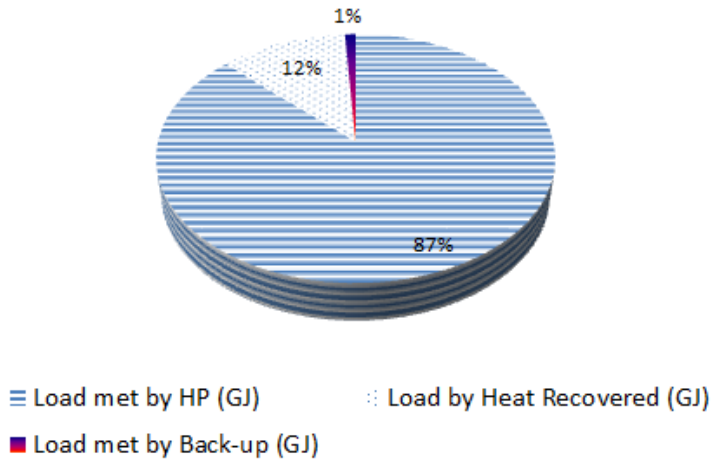


Figure 7: Percentage of heat load met by the heat pump, cogeneration heat recovery and back-up heating for Building A

Table 8 summarizes the estimated cogeneration plant electrical efficiency, thermal efficiency and global COP of the SWHP system. In all buildings with the exception of Building D, the global COP of the SWHP show improved values than the global COP calculated in scenario 1 with the SWHP network electricity fed by the main power plant. This is attributed to the improved performance of the heat pump, since they operate more often at full loads.

Table 8: Airfield building cogeneration efficiency and global sea water heat pump COP

Building	Electrical Efficiency	Thermal Efficiency	Global HP COP
Building A	25%	9%	1.28
Building B	24%	11%	1.26
Building C	24%	1%	1.17
Building D	24%	7%	1.03

The estimated annual station fuel consumption for this scenario is shown in Table 9.

Table 9: Annual station energy consumption and percentage of unused heat recovery

Scenario	Power Plant Fuel (L)	Space Heating Fuel (L)	Total Station Fuel (L)	% of Heat Recovery not used
Scenario 3	1,281,635	154,440	1,436,034	13%

Comparing the annual station fuel consumption results, the building-specific cogeneration devices with SWHPs allows for a reduction of 15% in the total annual fuel consumption at the airfield (from 80,361 L to 68,148 L). This scenario is not as good as scenario 1, but it is better than scenario 2 (without SWHP). Table 10 summarizes the annual fuel consumption of the airfield implementing the building cogeneration systems and SWHP network.

Table 10: Annual airfield energy consumption

Scenario	Power Plant Fuel (L)	Space Heating Fuel (L)	Fuel Savings at Core Complex (L)*	Total Fuel Consumption (L)
Scenario 3 Airfield	78,248	3,011	-13,111	68,148

*Due to additional heat made available in the district heating loop by increased power generation

5.4. Results Summary

A comparison of the base case with the three scenarios is presented in Table 11 for the airfield. Since the airfield makes up only a small portion of the entire CFS Alert complex, the global energy savings are not presented.

Table 11: Comparison of the simulated energy efficiency scenarios

Scenario	Annual Airfield Fuel Consumption (L)	% Fuel Savings
Base Case	80,361	--
Scenario 1	58,385	27%
Scenario 2	68,884	14%
Scenario 3	68,148	15%

Comparing the annual airfield fuel consumption, it can be seen a SWHP system offers the largest fuel consumption savings of 27% at the airfield. Interestingly, of the three scenarios considered, the SWHP fed by the main power plant predicts the most fuel savings compared to the scenarios incorporating a district heating recovering heat from a site specific cogeneration system. This result highlights the benefit of the SWHP implementation and the importance of maximizing the electricity generating capacity of the main power plant to increase the load and heat recovery capacity of the existing district heating loop rather than increasing the electricity and district heating energy capacity by installing additional localized cogeneration units.

6 Conclusion

This study has investigated the potential of sea water heat pumps (SWHP) system in the Canadian Forces Station Alert, located in the high Arctic. Three energy efficiency strategies were developed and evaluated for the station's airfield located close to the Arctic Ocean. In the first scenario, SWHPs replaced the fuel fired heating systems of the four largest airfield buildings. By incorporating this system, close to 22,000 L of fuel could be saved annually, which represents 27% energy savings at the airfield. The second scenario evaluated a small district heating system at the airfield with a local cogeneration system sized to meet the airfield building peak electrical load. Approximately 11,500 L of annual fuel savings (14% reduction) are predicted. The third efficiency strategy compared the fuel consumption of four micro-cogeneration units installed at the four largest airfield buildings with the recovered heat supplementing a smaller sized SWHP system. Annually, 12,200 L of fuel savings (15% reduction) at the airfield were predicted. The SWHP system fed by the main power plant demonstrated the greatest energy saving potential of the three scenarios evaluated; primarily because no additional electrical generating capacity was added to this system and the SWHP system increased the load and the heat recovery energy of the main power plant cogeneration units. The results in this study show that the implementation of a SWHP system at the airfield is a promising strategy. A similar system could be considered at the main complex in the future if electrical loads could be substantially reduced (100 kW or more) through energy saving measures such as additional lighting measures, variable frequency drives for pumps and fans and further reductions in receptacle loads. The approach taken to evaluate the use of renewable energy at the Canadian Forces Station Alert can also be extended to other northern communities facing similar challenges on fuel dependency and lack of local resources.

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8 References

Accutech Engineering Inc. 2010. "Building Envelope Upgrade CFS Alert," Accutech Engineering Inc. Winnipeg, Canada.

AET 2009. "Integration of Cogeneration and Heat-Driven Cooling (Business Confidential)". Advanced Engine Technology Ltd., Ottawa, Canada.

Daikin, 2013. "Smartsource™ Single Stage Horizontal and Vertical Water Source Heat Pumps," Daikin Industries, Ltd, New York, USA.

Diesel Service and Supply 2013. Date of Access February 2014 <http://www.dieselserviceandsupply.com/temp/Fuel_Consumption_Chart.pdf>

Kegel M., Langlois, A., Amow, G., Wilkens, L., Scott, J., MacKenzie, G., and Sunye, R., 2012. "Energy Conservation and Integration of Heat Pump Technologies in Arctic Communities," ASHRAE Cold Climate HVAC Conference, Calgary, Alberta, Canada.

Kegel M., Tamasauskas, J., Amow, G., Douglas, M., and Sunye, R., 2013. "Power and Energy Conservation in the Arctic: A Case Study on the Canadian Forces Station Alert," International Building Performance Simulation Association Conference, Aix-les-Bains, France.

Klein S.A. et al., 2010. “TRNSYS 17 – A TRaNsient SYstem Simulation program, user manual,” University of Wisconsin-Madison, Solar Energy Laboratory, Madison, USA.

Natural Resources Canada 2007. “Energy Usage and Project Implementation Study CFS Alert”. Natural Resources Canada, Ottawa, Canada.

Sommer A., and Bouchard D., 2004. “Energy Systems and Renewable Energy Technologies Evaluation for CFS Alert – Final Report”. Royal Military College of Canada, Kingston, Canada.

Throop, J., 2010. “Spatial and Temporal Variability in Permafrost Conditions, Northern Canada”. University of Ottawa, Ottawa, Canada.

Troyanik, J. 2013. Last Accessed February 2013 <http://www.troywoodintarsia.com/alert/aerial5.html>

Underland, H., 2004. “On Top of the World: Arctic Air Base Warmed with Heat Pump Technology,” Norwegian Defense Estates Agency, Norway.

U.S. National Oceanographic Data Center: Global Temperature–Salinity Profile Programme 2006. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Oceanographic Data Center, Silver Spring, Maryland, 20910. <http://www.nodc.noaa.gov/GTSPP/>. Last Accessed: July 2012.