POWER AND ENERGY CONSERVATION IN THE ARCTIC: A CASE STUDY ON THE CANADIAN FORCES STATION ALERT

Martin Kegel[1], Justin Tamasauskas[1], Gisele Amow[2], Mark Douglas[3] and Roberto Sunye[1]
[1]Natural Resources Canada, CanmetENERGY, Varennes, Canada
[2]Defence Research Development Canada, Ottawa, Canada
[3]Natural Resources Canada, CanmetENERGY, Ottawa, Canada

ABSTRACT

This paper presents an energy model developed for Canadian Forces Station Alert to evaluate potential energy efficiency improvement strategies including the application of renewable energy technologies. The energy model was validated using data collected for this purpose and then used to estimate potential energy savings for the site. Efficiency improvement strategies included upgrading the building envelope, installing efficient lighting fixtures and implementing automated controls predicting 35% annual fuel savings. An additional 5% annual fuel savings would be possible by optimizing the local district heating system and upgrading energy from sea water and ambient air through heat pumps.

INTRODUCTION

Challenged by harsh environments, remoteness, and a lack of local energy sources, Arctic Communities are confronted with having to find alternative and sustainable options for power and energy. The Canadian Forces Station Alert (CFS Alert), located on the northern tip of Ellesmere Island in Canada (82°28'N, 62°30'W) and considered the most northern permanently inhabited place on the planet, faces the same challenges inherent to these communities. The station has been in operation since the late 1950's and has undergone several changes to keep pace with technology advancement and operational requirements. At present, the station is comprised of 100 buildings, of which 70 are connected to the electrical grid and 50 are heated. Station population varies from 60 during the winter up to 300 during the summer. Power is generated onsite by four 950 kW JP-8 fired cogeneration units, which are also an integral part of the district heating loop meeting the space heating needs for 11 of the 50 heated buildings. The station can be divided into three building clusters, consisting of the core complex representing 92% of the heated floor area, the airfield representing 5% of the heated floor area and outlier buildings representing the remaining 3% of the heated floor area. Many of the buildings onsite are showing characteristic signs of wear having been exposed to the harsh arctic conditions for over 30 years. Annually, the station consumes over 2,000,000 L of fuel for electricity generation and space heating. Peak electrical loads in the winter can exceed 1,100 kW during the coldest periods and fall to less than 700 kW during the summer. As a result two cogeneration units operate during the winter and only one during the summer. With increasing fuel costs (real cost of $2 CDN per litre[1], close to $7 per litre fully burdened costs (Natural Resources Canada, 2007)) and dependency on transport for fuel, it is essential to find alternative and sustainable options for energy supply, which necessarily includes conservation.

PREVIOUS AND CURRENT STUDIES

Over the past 10 years, several studies (Sommer and Bouchard, 2004; Natural Resources Canada, 2007; Accutech Engineering, 2010) have been conducted at the Canadian Forces Station (CFS) Alert providing an evaluation of the stations' existing conditions and assessing the feasibility of potential renewable energy technologies and more conventional upgrades to the building envelopes. While common conclusions were drawn to show many of the buildings suffer from high air leakage rates and poor thermal insulation, the results were often incomplete due to a lack of onsite electricity and fuel monitoring to validate the results. In 2011, a Defence Research and Development Canada (DRDC) project was undertaken to assess alternative power and energy options to reduce the fuel burden for meeting electrical and thermal demands at the station. A key activity within this umbrella project is the determination of the baseline energy consumption, which included a comprehensive energy audit and development of validated energy models that can be used to estimate station energy end-uses and evaluate various efficiency measures. The DRDC project also targets alternative technology options such as renewable energy (photovoltaics, wind, sea water heat pumps, deep-well geothermal, small scale hydro) within the unique geology, climatology, military operational constraints and associated environmental impacts associated with application of these technologies at this site. This paper

---

[1] Cost derived from Energy Information Administration (EIA, 2012) and rates to deliver fuel from Thule to CFS Alert (Mr. G. Stewart, DND)

presents the development of the station baseline energy model, the assessment of potential energy saving measures, the preliminary analysis of a sea water heat pump system and some results of the district heating system optimisation. We believe that the general findings from this project would be of great interest to other Arctic Communities facing similar challenges.

MONITORING

To determine the baseline energy consumption, it was important to measure and monitor the electricity consumption of the station and several key buildings. While the power plant operators record the electricity generated at the station, no regular information on the distribution of electricity within the station had been undertaken due to the lack of instrumentation for this purpose. To acquire this new information, permanent electricity sub-meters were installed in the two largest buildings as well as in the main power plant. In the power plant the seven feeder lines to the station are monitored providing an overview of the electricity distribution to specific building clusters (Figure 1) and respective heated floor areas.

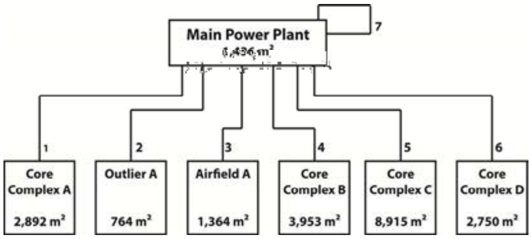

Figure 1 Monitored electrical feeder lines and respective heated floor area

For the larger buildings with fuel-fired heating systems, the fuel consumption is recorded manually by the heating technician whenever the fuel storage tanks are filled. Performance details of the district heating system, predominantly installed in series to the local fuel-fired heating systems, are generally unknown. Thus, heat flow meters were installed recently in all relevant buildings to determine the amount of energy used for space heating needs and how it compares to the original design conditions. Preliminary results indicate the district heating system may not be working at its full potential, an issue which will be investigated when results from the new heat meters are obtained.

Fuel consumption for electricity production is currently not monitored and is simply estimated by assuming constant power plant efficiency. Since electricity production represents close to 85% of the fuel consumption of the station, there are future plans to install a fuel monitoring system, to have a better idea of the cogeneration unit performance.

Without substantially increasing the cost by installing electrical submeters in each building, some refinement in the station energy flows was estimated by developing building energy models. The energy models were then used to predict the baseline energy consumption and compared with the monitored electrical consumption and ultimately used to assess various energy saving measures.

BUILDING ENERGY MODEL DEVELOPMENT

An extensive effort was undertaken to develop detailed building energy models of the station to evaluate various energy saving measures. TRNSYS v. 17 was selected due to its ability to accommodate non-standard HVAC systems including the integration of renewable energy systems in building energy models. While requiring a more detailed component approach effort than other building energy simulation tools, it was thought necessary to have an energy model capable of assessing both standard and non-standard efficiency measures in the analysis.

In total, building energy models for each of the fifty heated buildings were developed ranging in size and complexity from simple single-zone models with baseboard heating to complex ten-zone models incorporating a district heating system. Figure 2 and Figure 3 compares the energy model to an aerial view of the station (Troyanik, 2013).

Figure 2 Overhead view of CFS Alert

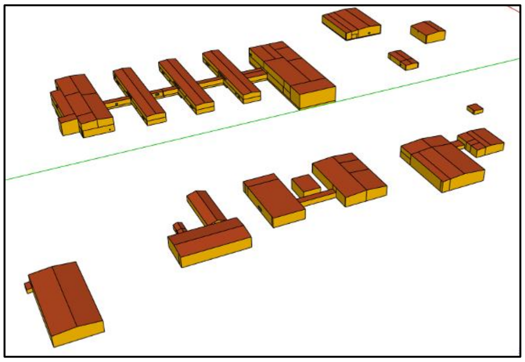

Figure 3 Building energy model of core complex

Details and operating characteristics of the buildings were determined during two site visits – one during the midnight sun period (May 2011) and one during the polar night period (January 2012). Many of the buildings were not provided with automated controls and as a result the energy consumption of the station was largely event driven. To estimate the typical operating schedules and temperature set-points, space temperatures, lighting and occupancy schedules were recorded during the site visits to get a general idea on how the buildings were being operated. Notes were taken for equipment with significant power draws and operating schedules were established based on observations and discussions with onsite personnel. Heating equipment details were gathered onsite, and manufacturer rated performance data was used in the energy models. Larger buildings were found to be typically heated through hot water distribution systems with the fuel fired boilers connected in series with the district heating loop. Medium sized buildings were predominantly heated by fuel-fired furnaces and smaller buildings were heated electrically. Construction details of the building envelope were inspected in each building and compared with available architectural drawings. Wall constructions varied from steel framed, mineral fibre filled walls with severe thermal bridging (RSI values less than 2 m ·°C/W), to prefabricated panels mounted on the steel structure (RSI value of 4 m ·°C/W). Infiltration was measured through blower door tests conducted in three different buildings with different building envelope constructions. Results varied between an air leakage rate of 0.33 L/s/m envelope area to 0.5 L/s/m envelope area. Measured results were applied to the buildings with similar envelope constructions too large to perform a blower door test on. Buildings were found to typically suffer from panel separation caused by snow entering the cladding as well as the thermal expansion and contraction during the spring period. A preliminary performance estimate of the district energy system was determined by measuring the flow rate with an ultrasonic flow meter when one and two cogeneration units were running. Measurements were compared to design conditions indicating the system was operating at 50% of its design capacity. For various reasons, operation of the district heating system was adjusted over previous years to ensure proper operation of the cogeneration units. Heat flow meters to measure the district heating system performance were installed recently and once commissioned the energy models will be updated. Light fixtures varied depending on the space function however incandescent bulbs and metal halide fixtures were identified as the predominant lighting types in many buildings. Standard TRNSYS components were used to model the mechanical components of a building.

ENERGY MODEL VALIDATION

The electrical sub-metering at the main power plant recorded the electricity distribution to the seven feeder lines serving all buildings at CFS Alert. The monthly electricity flow recorded at each feeder was compared to the predicted electricity consumption from the energy model. From Figure 4 it can be seen that the predicted electrical consumption trend of the energy model followed very closely to what was recorded under-predicting the electricity typically by 15%, which was attributed to unknown electrical loads of the station, infiltration rates and assumed operation characteristics of the buildings.

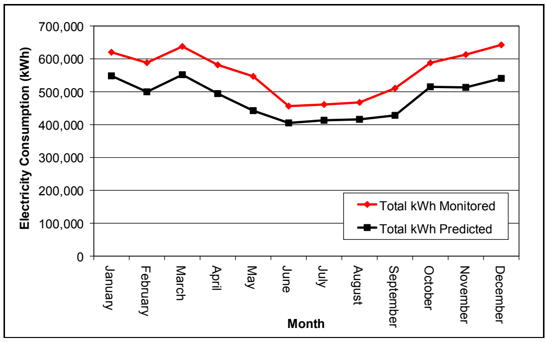

Figure 4 Monitored versus predicted electricity consumption

Fuel consumption for space heating is typically around 50,000 L during the colder winter months and down to 10,000 L in the warmer summer months. For the buildings connected to the district heating loop, the space heating demands are met by the district heating system the majority of the time. Adjustments were made in the air infiltration rates and heat exchanger effectiveness of the district heating loops in order to calibrate the model. The predicted fuel consumption of the energy model follow the recorded fuel consumption trend very closely (Figure 5), with a larger deviation in the winter months attributed to the operating characterstics of some buildings and missing data.

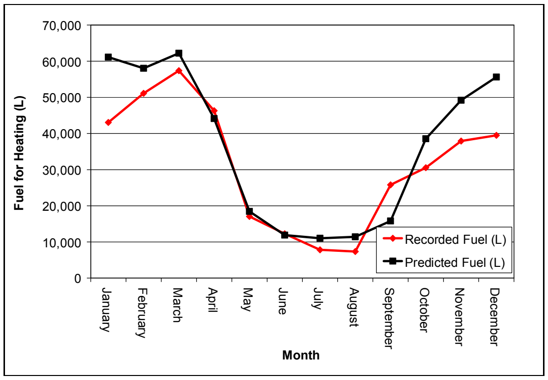

Figure 5 Recorded versus predicted fuel consumption for space heating

Using the validated energy model of the station, a more detailed breakdown of the station energy consumption was performed to identify and rank potential energy saving strategies. Globally, space heating and interior lighting represent a significant portion of the total fuel consumption of the station taking the actual generator efficiency into account.

ENERGY EFFICIENCY ANALYSIS

Prior to implementing any renewable energy technology deemed feasible in the larger DRDC study, it was important to first address the common issues that could be improved with conventional energy efficiency measures. Using the energy model, the potential energy and cost savings could be quantified in order to help rank the efficiency measures under consideration. The efficiency measures were categorized in two groups – short term measures which require relatively small capital expenditures and longer term measures, which require significantly more capital and planning. The overall goal of the efficiency measures were selected to address the identified high energy end use areas (space heating and interior lighting).

Short term efficiency improvement strategies

From site observations, many buildings suffer from high infiltration levels and thermal bridging which is characteristic in northern environments. While reducing the thermal bridging requires significantly more effort, infiltration levels can be easily reduced by sealing the numerous holes found in the building envelope as well as weather-stripping garage doors to prevent air leakage.

Incandescent light bulbs and metal halide light fixtures are still used predominently throughout the station. Without any form of controls many of the light fixtures are left on the entire day. While replacing metal halide fixtures requires some effort, incandescent light bulbs can be replaced with compact fluorescent or LED light bulbs and occupancy control sensors can be installed in transient spaces to turn lights off when unoccupied.

It was also identified that all of the space heating boilers had manual temperature set-point controls. As a result, the heating technician would adjust the boiler temperature set-points manually depending on the exterior conditions. It was found that this ultimately results in overheating and in some instances can result in injecting heat into the district heating loop instead of extracting heat. An automated outdoor reset boiler temperature control strategy is proposed to automatically adjust the setpoint temperature based on outdoor conditions.

Long term efficiency improvement strategies

Many of the buildings at the station are over 30 years old and are showing signs of wear that is characteristic in northern environments. Infrared images taken of some building envelopes indicated collapsing insulation and significant thermal bridging. Many buildings have RSI values below 2 m ·°C/W, well below the prescribed minimum insulation level of 5.5 m ·°C/W for walls and 7.0 m ·°C/W for roofs (NRC, 2011). Furthermore, buildings constructed with prefabricated panels were showing high signs of air leakage at roof and wall joints caused by failure of sealing provisions due to thermal expansion and contraction of the panels. In the majority of buildings, the wall panels are mounted onto the building steel framing members, offering opportunities to add an interior wall skin to improve insulation levels, reduce infiltration and provide an additional barrier for separating panels. The interior wall panel would be filled with polyurethane insulation providing a vapour barrier and improved level of insulation. In many instances the building envelope RSI values are expected to improve by 300% from 2.1 m ·°C/W to 6.6 m ·°C/W. Infiltration levels of 0.17 L/s/m envelope area were targeted as sugested by the US Army Corps of Engineers (Zhivov et al., 2011).

Additional site observations made in regards to lighting indicated that many of the high bay light fixtures are never turned off, either because of the long warm up period, or poor location of the light switch. Many of the high bay light fixtures are of mercury vapour, high pressure sodium and metal halide type having ballast powers between 210 W and 465 W. While these light fixtures provide some of the space heating needs, there is minimal benefit when electricity is produced onsite through fuel fired generators with a 40% electrical efficiency. Space heating demands could be met by the fuel fired heating system or even the district heating loop. It is therefore proposed to replace the inefficient high bay light fixtures with equivalent induction light fixtures, offering longer life, improved control and typically draws half the power requirements of the fixture it is replacing. With the improved control, occupancy control sensors can be installed to turn the majority of lights off during periods of non-use.

ECONOMIC ANALYSIS

A cost analysis is provided for the station to prioritize efficiency measures and establish a budget. The economic analysis are based on real costs identified for southern environments, and does not currently include any allowance for deployment in northern environments. Material costs were derived from RSMeans 2012 mechanical cost data (RSMeans, 2012) and various online sources. Labour hours were estimated from RSMeans as well in addition to discussions with contractors familiar with working at the station. Labour rates typical for the station were applied to calculate simple payback periods by dividing the costs of the efficiency improvement strategy by the anticpated global fuel savings. A contingency of 20% was applied to all measures in keeping with the accuracy of the overall cost estimates.

RESULTS

Annually the station consumes over 2,000,000 L of fuel for space heating and electricity production. Implementing the proposed short term and longer term measures in the developed energy model, the anticipated global fuel consumption is predicted for each measure (Table 1) and simple payback periods estimated based on the economic analysis (Table 2). Short term efficiency measures are assumed to be implemented in the long term measures.

Table 1
Anticipated annual global fuel consumption

SCENARIO	ANNUAL FUEL CONSUMPTION
Base Case	2,045,000 L
Short Term	1,777,000 L
Long Term Envelope	1,501,000 L
Long Term Lighting	1,659,000 L
All Measures	1,383,000 L

Table 2
Anticipated real costs and simple payback periods

SCENARIO	REAL COST ($, CDN)	PAYBACK PERIOD
Base Case	$ 0	N/A
Short Term	$ 77,500	2 months
Long Term Envelope	$7,065,000	6.5 years
Long Term Lighting	$240,000	4 months
All Measures	$7,382,500	5.5 years

While the building envelope upgrades result in the largest costs, it also results in the greatest potential energy savings for the station. To reduce initial costs, and build confidence with the predictions, it is recommended that the building envelope be upgraded in some of the older buildings first, and an improved estimate on the cost required to upgrade the remaining building envelopes can be determined. The short payback periods of replacing inefficient light fixtures and sealing holes indicate that these measures should be implemented as soon as possible.

Implementing all measures, space heating and interior lighting energy end uses are estimated to reduce by 50% from current conditions. It is also estimated that the peak electrical load of the station reduces to 734 kW, resulting in the need for only one cogeneration unit to be in operation year long. This positive result has significant operational benefits for the station long term, most notably through improved loading of the single generator – leading to reduced wear and tear and improved fuel utilization.

DISTRICT HEATING AND RENEWABLE ENERGY

The district heating loop, recovering the waste heat off the cogeneration units, is an integral part in meeting the space heating demands. Since the heat captured from the cogeneration units saves fuel fired locally for space heating, we believe it is important to ensure that the district heating system operates at its fullest potential before undertaking more extensive retrofits at the station. The following scenarios (evaluated cumulatively) were analysed to anticipate the costs and benefits:

- Scenario 1: Base Case
- Scenario 2: Extension of district heating loop to other buildings
- Scenario 3: Sea water heat pump network to replace fuel fired heating systems at airfield
- Scenario 4: Cold climate air source heat pumps for remote fuel fired heated buildings
- Scenario 5: DHW heating by district heating loop

Scenario 1: Base Case

A first step would be to determine whether the existing district heating system would be capable of meeting the heating loads of the existing connected buildings with all the proposed efficiency measures (short term, long term envelope, long term lighting) implemented. Figure 6 shows the balance of the required and available heat recovery over a period of one year and indicates that there is excess heat recovery close to 96% of the time, especially in the summer when the electrical loads are high and there is no need for as much heat recovery. The balance also shows there are periods of excess heat in the the district heating system in the winter, and thus the system could be expanded to adjacent buildings, currently not on the district heating loop.

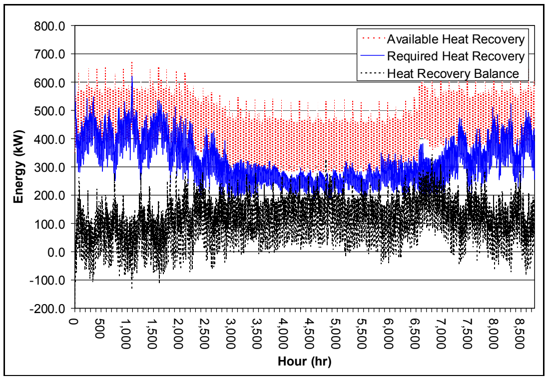

Figure 6 Predicted district heating system energy demand and availability

If the district system is maintained and controlled optimally, the predicted global station fuel consumption would be 1,340,500 L annually. Fuel fired back-up heating systems would be utilized 4% of the time to ensure comfort conditions are met.

Scenario 2: Extension of District Heating Network

Figure 7 presents the district heating energy demand and availability extending the network to five additional buildings in the proximity of the existing heating loop.

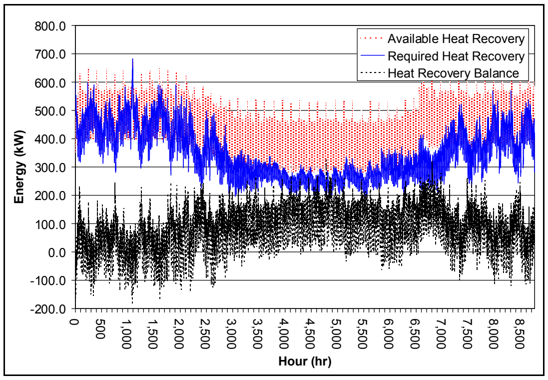

Figure 7 Predicted district heating system energy demand and availability with extension

As anticipated the results indicate that by extending the district heating network, there are less periods of excess heat during the winter. Annually, a back-up heating system would be required 13% of the time. It is predicted that the station annual fuel consumption would reduce to 1,310,000 L – savings of less than 3%, mainly because the back-up heating system is required and thus fuel savings are only attained during the shoulder and summer seasons when the heat demand is lower. A peak elecrical load of 730 kW is also estimated.

To eliminate the need for back up heating, storage for the heat recovery system could be implemented. In order to meet the heating demand the entire time, it is estimated a storage tank volume of 20,000 L would be required which would be a challenging proposition in such a northern environment.

Scenario 3: Sea Water Heat Pump

Additional fuel savings can be attained by replacing the fuel fired heating systems in several of the airfield buildings with a sea-water heat pump (SWHP) system. Ground source heat pumps would be unfeasible in the high arctic due to the depth of the permafrost and ambient temperatures below -40°C would result in continuous poor performance conditions for conventional air source heat pumps. Sea water heat pumps present an interesting solution since energy is upgrading from the surrounding body of water. For the analysis at CFS Alert, a constant sea water temperature of -1.8°C is assumed at a depth of 80 m (U.S. National Oceanographic Data Center: Global Temperature–Salinity Profile Programme, 2006) and the fuel fired heating systems of four airfield buildings would be replaced with heat pumps. Using manufacturer performance data for the heat pump at design conditions, the global SWHP system has a coefficient of performance of 2.9. Figure 8 is a diagram of the proposed system. Additional details of the system can be found in Kegel et al. (2012).

The benefits of replacing the fuel fired heating systems with the SWHP, increases the electrical load at the power plant, thereby increasing the amount of energy available in the district heating network. With a higher demand than availability during the winter with the proposed district heating network expansion (scenario 2), a SWHP system can provide annual fuel savings of 20,000 L. The district heating system energy balance is shown in Figure 9.

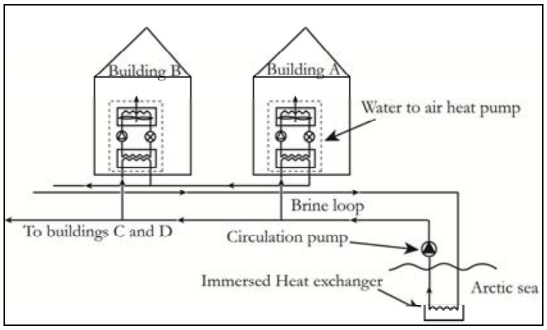

Figure 8 Proposed SWHP system

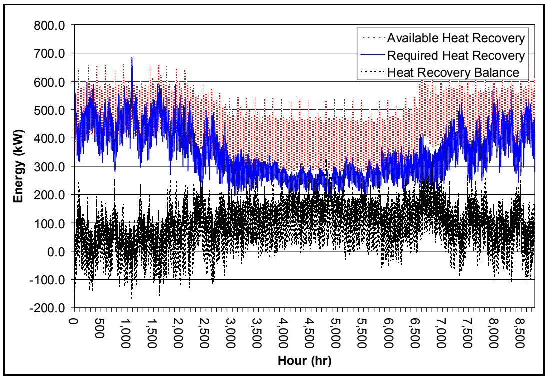

Figure 9 Predicted district heating system energy demand and availability with SWHP system

While the increase in the electrical demand at the power plant increased the amount of district heating energy, back-up heating systems are still required 10% of the time annually. As a result, the electrical load should likely be further increased, or the demand on the district heating loop reduced. To avoid the use of a back-up heating system, a storage volume of 10,000 L is estimated. A peak electrical load of 745 kW is also expected with the addition of of a SWHP network.

Scenario 4: Cold climate air source heat pumps

To further increase the electrical load on the generator without increasing the annual fuel consumption, the impact of adding cold climate air source heat pumps (CC ASHP) to two remote fuel heated buildings is considered. Due to the remote building locations, it would be impracticle to use the sea water heat pump or district heating network at these two locations. While CC ASHPs have decreasing performance as ambient temperatures fall, the systems have an equivalent performance to a SWHP at 5°C outdoor temperature and a COP of 1.5 at an ambient temperature of -20°C. A manufacturer performance curve for a CC ASHP is shown in Figure 10 (Mitsubishi Electric, 2012).

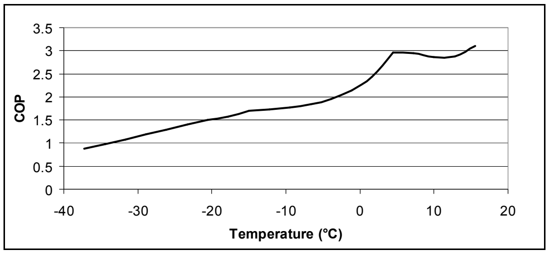

Figure 10 Coefficient of Performance versus ambient temperature for cold climate air source heat pump

Figure 11 shows the district heat available and demand after implementing the CC ASHP.

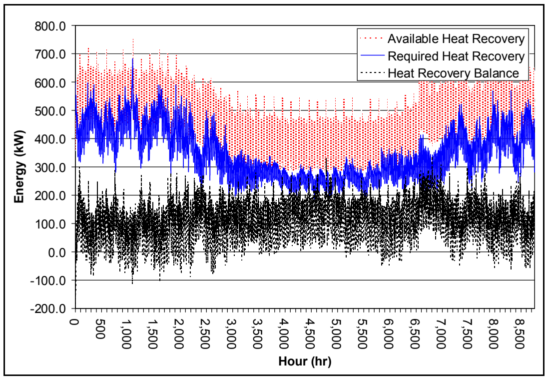

Figure 11 Predicted district heating system energy demand and availability with cold climate ASHP

By increasing the electrical load on the power plant, the district heating energy is able to meet the demand over 96% of the time, requiring only a 5,000 L storage volume to eliminate the need of back-up heating. However, only 3,000 L of fuel are saved annually and the peak demand increases to 810 kW.

Scenario 5: Use of District Heating for DHW

Since district heat does not have a high demand during the summer period when heating loads are low, additional energy savings could be obtained by using the district heating system for potable water heating in the three barrack buildings. In particular due to the nature of the station, the population increases 400% during the summer compared to the winter, this proposed measure could be of interest. Furthermore, since the district heating loop already exists in the barracks for space heating, a low cost efficiency measure is possible to heat the potable water. Figure 12 presents the district heating availability and demand adding the barrack potable water heating system to the network.

By adding the DHW production of the barracks to the district heating loop an additional 30,000 L of fuel can be saved annually. In addition, there is a larger demand for heat recovery during the summer months and due to the small population during the winter, a storage volume of only 6,000 L is required to avoid the use of any back-up heating systems.

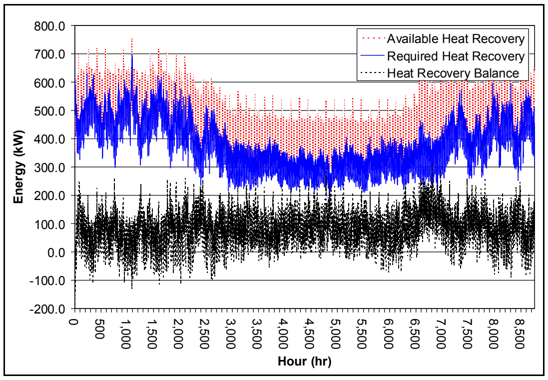

Figure 12 Predicted district heating system energy demand and availability with DHW heating

Summary of all scenarios

A summary of the estimated annual fuel consumption, peak electrical load and required district heating storage volume is presented in Table 3 for each scenario (evaluated cumulatively). A ranking and summary of the annual fuel savings is presented in Table 4.

Table 3
Annual fuel consumption, peak electrical load and required district heating storage

SCENARIO	ANNUAL FUEL (L)	PEAK LOAD (KW)	STORAGE VOL. (L)
1	1,340,500	734	5,000
2	1,310,000	730	20,000
3	1,290,000	745	10,000
4	1,287,000	809	5,000
5	1,257,000	809	6,000

Table 4
Annual fuel consumption, peak electrical load and required district heating storage

SCENARIO	ANNUAL FUEL SAVINGS (L)	RANK
1	42,500	1
2	30,500	2
3	20,000	4
4	3,000	5
5	30,000	3

CONCLUSIONS

An extensive building energy model for Canadian Forces Station Alert has been developed in order to evaluate various energy efficiency improvement strategies including the potential application of renewable energy technologies. The energy model was validated with actual electrical consumption data collected using new instrumentation provided for this purpose. The study evaluated several conventional energy efficiency measures ranging from lighting improvements, reducing infiltration levels to building envelope upgrades. Payback periods ranged between 2 months for standard lighting and infiltration reduction measures to 6.5 years for building envelope improvements. It is recommended to perform all efficiency measuress sequentially beginning with straight forward activities such as lighting and infiltration reduction improvements and finishing with building envelope retrofits. Overall, a 35% reduction in fuel is anticipated by implementing all conventional efficiency measures.

To evaluate the impact and benefits of optimising the district heating system and use of renewable energy through heat pumps, five additional scenarios were evaluated. While the scenarios vary in the fuel savings potential, it is important to recognize the dependance between the amount of district heating available and the electricity production. This issue points to the careful analysis required in upgrading the station, as one improvement affects other performance measures, so the net effects must be carefully weighed in situations where the implementation is phased in with a series of projects spanning years of operation. Thus, although the fuel savings attained by using renewable energy through heat pumps are not as significant as one would wish, it is important to recognize that through the increase in electrical demand, additional heat is made available in the district heating network, demonstrating improved fuel saving benefits.

FUTURE WORK

To date, only the use of sea water as a renewable energy source has been evaluated for CFS Alert. Future plans are to evaluate the use of photovoltaics to meet the electrical demand of the station. The use of solar could present an interesting scenario, in which the use of the cogeneration unit can be significantly reduced during the summer when the heat recovered from the cogeneration units is not as essential. Another concept which is being considered is to combine the operation of smaller diesel gen sets with heat pumps to serve buildings currently heated with fuel. This hybrid system approach would generate more heat and electricity than contained within the fuel to the generator by virtue of the renewable energy harvested from the environment by the heat pump.

While environmental impact plays an important role, it has not been evaluated so far. The authors plan to take this into account in the future work as well. An economic analysis of all systems will also be done to provide guidance on the best energy savings methods. Energy models will also be updated once the heat flow meter data on the district heating system becomes available, which may lead to indentification of further upgrade pathways and their associated benefits. While no station is permanent, the long history of CFS Alert at least affords the opportunity to consider longer term projects to improve the energy efficiency and sustainability of the station, and for this reason the considrable efforts reported here are justified.

ACKNOWLEDGEMENTS

The authors thank Mr. David Strong and Wanda Deong of the Arctic Management Office (1 Canadian Air Division) for financial and logistical support for this project as well as Defence R & D Canada, 8 Wing Trenton CE and Natural Resources Canada. We also wish to acknowledge the contributions of Larry Wilkens, John Scott, Gordon MacKenzie, Tom Mackintosh, Gloria Yu and Antoine Langlois to this study. Without them, this collaboration would never have been possible.

REFERENCES

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

Energy Information Administration (EIA) 2012, Last Accessed October, 2012 <www.eia.gov>.

Kegel M., et al. 2012. Energy Conservation and Integration of Heat Pump Technologies in Arctic Communities, *7th International Cold Climate HVAC Conference*, November 2012, Calgary, Canada, 256 – 263.

Mitsubishi Electric 2012. Last Accessed March 2012. <http://www.mitsubishielectric.ca/en/hvac/zuba-central/index.html>.

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

National Research Council Canada (NRC) 2011. National Energy Code of Canada for Buildings, Ottawa Canada.

RSMeans 2012. Mechanical Cost Data, RSMeans, Kingston, USA.

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

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

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

Zhivov, A., Bailey, D., & Herron, D. 2011. Air Leakage Test Protocol for Building Envelopes Standard v2. Army Engineer Research and Development Center. Champaign, U.S.A.