2016

Building Energy Efficiency Assessment of Renewable and Cogeneration Energy Efficiency Technologies for the Canadian High Arctic

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ABSTRACT

This paper presents an energy analysis of the Polar Continental Shelf Program (PCSP) facility located in Resolute, NU. The study focuses on the evaluation of innovative energy efficiency strategies including on-site cogeneration and renewable technologies such as wind and solar. Developed energy models were validated using data collected from installed metering systems recording the electricity, heating fuel and hot water consumption of six buildings that make up the PCSP Resolute facility. A preliminary energy audit identified short term energy efficiency measures that could be implemented to reduce greenhouse gas (GHG) emissions by 15% and reduce utility costs by 12.5% annually. Proposed innovative strategies are designed to build upon the suggested short term energy efficiency measures to achieve significant utility cost savings. From simulations it is estimated that almost all electricity can be produced by on-site generation and the heat recovered from the generators can be used to meet close to 50% of the space heating loads, resulting in close to $600,000 (~50%) savings in annual utility costs from the proposed short term measures. The feasibility of sea water heat pump system is also evaluated to efficiently meet a portion of the building heating loads, while increasing the demand on the combined heat and power system. The use of a sea water heat pump would help save an additional $40,000 (~7.0%) in utility costs annually. In comparison, the use of wind and solar photovoltaic renewable energy technologies can achieve more savings. Sized to meet the base electrical load of the facility, the use of these technologies are estimated to save $175,000 annually.

1. INTRODUCTION

Arctic communities, challenged by the harsh climate and a lack of local energy resources, are often confronted with finding more sustainable solutions for power and energy. Due to their isolated nature, reductions in energy or fuel use can have important implications for operating costs, security, and energy independence. While high performance buildings have received significant attention in more populated areas, there has been less work done on the opportunities and challenges for these buildings in the Canadian North.

The Polar Continental Shelf Program (PCSP) facility in Resolute, NU, (74°70'N, 94°83'W), is one of 17 building groups identified under the Low Carbon Initiative (Low Carbon NRCan 2016) to reduce greenhouse gas (GHG) emissions by 17% from the 2005 levels. Through facility expansions and additional operational requirements, the PCSP facility has seen an increase of close to 500% in electricity use, fuel use and ultimately greenhouse gas (GHG) emissions in comparison to 2005/2006 levels. Combined with a doubling of electricity rates, annual utility costs have risen by 750% over this time period (Table 1). With future expansions planned to add more storage facilities as well as an on-site incinerator, energy consumption, utility costs and GHG emissions will continue to rise.

Table 1: Electricity and fuel consumption with associated utility costs for the PCSP facility

Fiscal Year	Purchased Electricity (kWh)	Heating Fuel (L)	Electricity Cost ($,CAD)	Heating Fuel Cost ($,CAD)	Total Utility Cost ($,CAD)	GHG Emissions (ton CO_2 eq.)
2005/2006	152,095	46,591	$98,007	$40,357	$138,364	243.5
2013/2014	839,516	250,361	$792,832	$300,121	$1,092,953	1324.4
2014/2015	867,031	271,321	$857,557	$338,341	$1,195,898	1403.7

In 1986, the PCSP experienced the first of 3 significant expansions. At this time, the PCSP facility consisted of three buildings, which are still in use today (XR-01, XR-02 and XR-03). In 2011 a second large expansion was undertaken, which nearly doubled the existing infrastructure to provide additional accommodation and living space (XR-12), and a research prep laboratory (XR-04). A third significant expansion was completed in 2013, resulting in two additional buildings (XR-15 accommodations and XR-14 an operations building) to meet the specific needs of the Canadian Armed Forces Arctic Training Centre (Figure 1).

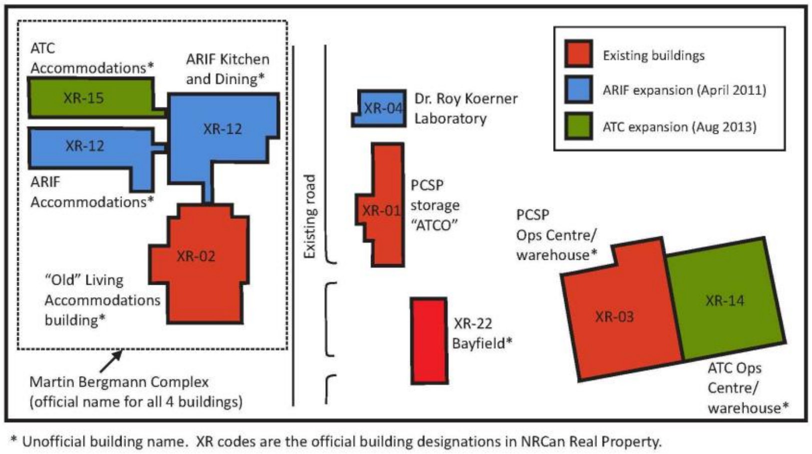

Figure 1: Layout of PCSP facility in Resolute, NU

2. METHODOLOGY

An energy audit conducted in March 2014 identified several easily implementable energy efficiency measures which could reduce GHG emissions by 15% and utility costs by 12.5%, annually. These measures focused primarily on increasing insulation levels in the utilidors, replacing inefficient light fixtures and installing new exterior doors, and are either currently being undertaken and/or planned for future implementation. However, it was evident that a more invasive energy efficiency strategy would be required to achieve significant impacts. In particular, high local electricity rates provided an important opportunity to focus on reducing facility purchased electricity. In order to properly assess opportunities for new energy efficiency measures, a three step methodology was employed:

1. Monitoring of on-site electricity, fuel, and hot water use.
2. Development and calibration of detailed energy models using monitored data.
3. Assessment of selected technologies using calibrated models with the assumption that the more easily implementable energy efficiency measures have already been implemented.

3. BUILDING ENERGY MODEL DEVELOPMENT

An extensive effort was undertaken to develop detailed building energy models of the PCSP facility in order to evaluate the various energy saving measures. TRNSYS v. 17 was selected due to its ability to accommodate non-standard HVAC systems, including renewable energy systems, in building energy models. While this required a detailed component-based approach, it was necessary to have an energy model capable of assessing both standard and innovative efficiency measures in the analysis.

Details and operating characteristics of the buildings were determined during site visits conducted from March 2014 to September 2015. Space temperatures, lighting and occupancy schedules were recorded during the site visits to gain 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 on-site personnel. Heating equipment details were gathered on-site, and manufacturer rated performance data was used in the energy models. Construction details were inspected in each building and compared with available architectural drawings. Key building characteristics are summarized in Table 2 and Table 3. XR-02, XR-03 and XR-04 are heated via indirect diesel furnaces and air handling units, with some electric unit heaters in the utilidor and entrances.

Currently, there is no central control system in XR-02 and XR-03, so all burners are controlled by local thermostats located throughout the building. XR-12, XR-14 and XR-15 are heated through hot water distribution systems, with diesel boilers in XR-12 being the only building controlled via a central system

Table 2: Summary of key building characteristics for XR-02, XR-03 and XR-04

	XR-02	XR-03	XR-04
Heating System	3 Diesel Fired Furnaces 84.0 % SSE 3 Diesel Fired AHU 80.0 % SSE	4 Diesel Fired Furnaces 86.0 % SSE 2 Diesel Fired AHU 81.0 % SSE	1 Diesel Fired Furnace 81.4 % SSE
DHW	2 Diesel Fired Conventional Tank	1 Electric Conventional Tank	1 Diesel Fired Conventional Tank
Lighting	Compact Fluorescents T12 Light Fixtures	Compact Fluorescents T12 Light Fixtures	Compact Fluorescents T8 Light Fixtures
Ventilation	No HRV	No HRV	No HRV
Heated Floor Area	1,427 m^2	2,693 m^2	191 m^2
Roof RSI	6.4 $(m^2{\cdot}°C)/W$	5.3 $(m^2{\cdot}°C)/W$	8.8 $(m^2{\cdot}°C)/W$
Wall RSI	5.8 $(m^2{\cdot}°C)/W$	4.3 $(m^2{\cdot}°C)/W$	5.0 $(m^2{\cdot}°C)/W$
Utilidor Wall/Floor RSI	3.3/3.1 $(m^2{\cdot}°C)/W$	-	3.3/3.1 $(m^2{\cdot}°C)/W$
Exposed Floor RSI	4.9 $(m^2{\cdot}°C)/W$	3.4 $(m^2{\cdot}°C)/W$	7.4 $(m^2{\cdot}°C)/W$
Infiltration	0.30 $L/s/m^2$	0.25 $L/s/m^2$	0.25 $L/s/m^2$
SSE: Steady State (Thermal) Efficiency AHU: Air Handling Unit			

Table 3: Summary of key building characteristics for the XR-12, XR-14 and XR-15

	XR-12	XR-14	XR-15
Heating System	2 Two Stage Diesel Fired Boilers 85.6 % SSE	2 Single Stage Diesel Fired Boilers 85.0 % SSE	2 Single Stage Diesel Fired Boilers 83.2 % SSE
DHW	2 Indirect DHW Tanks Served From Boilers	1 Diesel Fired Storage Tank	2 Indirect DHW Tanks Served From Boilers
Lighting	Compact Fluorescents T8 Light Fixtures	Compact Fluorescents T8 Light Fixtures	Compact Fluorescents T8 Light Fixtures
Ventilation	Glycol HRV	Glycol HRV with solar Wall	HRV
Heated Floor Area	2,197 m^2	2,190 m^2	1,232 m^2
Roof RSI	8.8 $(m^2{\cdot}°C)/W$	8.4 $(m^2{\cdot}°C)/W$	8.0 $(m^2{\cdot}°C)/W$
Wall RSI	5.0 $(m^2{\cdot}°C)/W$	5.3 $(m^2{\cdot}°C)/W$	5.1 $(m^2{\cdot}°C)/W$
Utilidor Wall/Floor RSI	3.3/3.1 $(m^2{\cdot}°C)/W$	-	3.0/3.8 $(m^2{\cdot}°C)/W$
Exposed Floor/Slab RSI	7.4 $(m^2{\cdot}°C)/W$	4.7$(m^2{\cdot}°C)/W$	5.2 $(m^2{\cdot}°C)/W$
Infiltration	0.20 $L/s/m^2$	0.25 $L/s/m^2$	0.20 $L/s/m^2$
SSE: Steady State (Thermal) Efficiency			

4. ENERGY MODEL VALIDATION

Available utility bills were not able to provide an accurate description of each building's electricity and heating fuel consumption, as the electricity bills were given for multiple buildings and often adjusted for incorrectly billed consumption. For heating fuel, only the bulk fuel delivered to the entire facility was recorded. To gain better refinement and an improved understanding of the key energy flows of the PCSP facility, metering equipment was installed in each building to measure the:

- Electricity consumption
- Heating and DHW fuel consumption
- Hot water consumption
- Space temperatures

The electricity, heating fuel and DHW fuel consumption of each building has been recorded since September 2015 via the installed monitoring system and used to validate the simulation results for the complete facility. Figure 2 shows the predictions from the energy model for the electricity and heating fuel consumption for the complete facility. The predictions compare well with the monitored data, with simulations following the same trend in both electricity consumption and fuel consumption over the seven month monitoring period. Electricity consumption is typically within 1% of the measured electricity consumption, with larger differences in January and February attributed to assumed facility occupancy. Heating fuel consumption varies from close to 40,000 L in the colder winter months and to approximately 10,000 L in the warmer summer months for the complete facility. The predicted heating fuel consumption also closely follows the trend of the monitored data, with an average percent difference of 10% from the monitored data, primarily due to assumed infiltration rates.

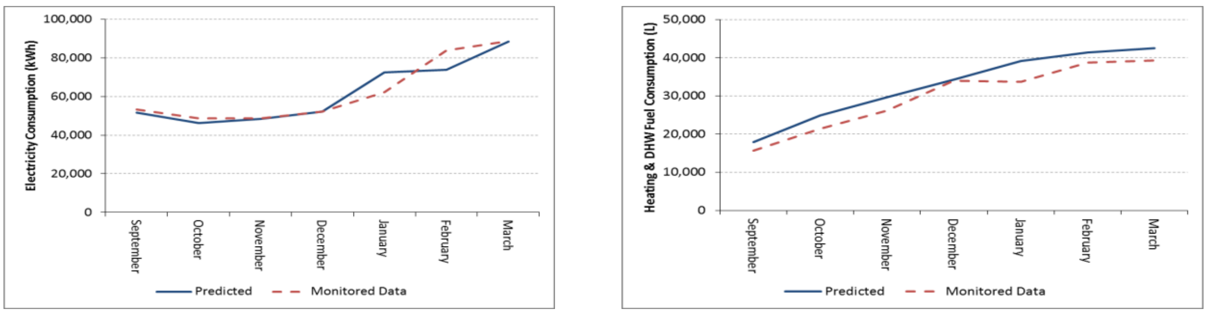

Figure 2: Comparison of simulated and recorded (a) electricity and (b) fuel consumption for the 2015/2016 FY

Using the calibrated energy models, the baseline energy consumption of the facility was estimated with the proposed shorter term energy efficiency measures. The facility energy end use distribution is shown in Figure 3, with 82% of the total energy consumption attributed to diesel fuel for space and hot water heating. Although electricity consumption represents only 18% of the total energy end use of the facility, the high electricity rates yields annual costs that are almost double the fuel costs (Table 4). Thus, efficiency measures targeting a reduction in electricity can have a substantial utility cost savings.

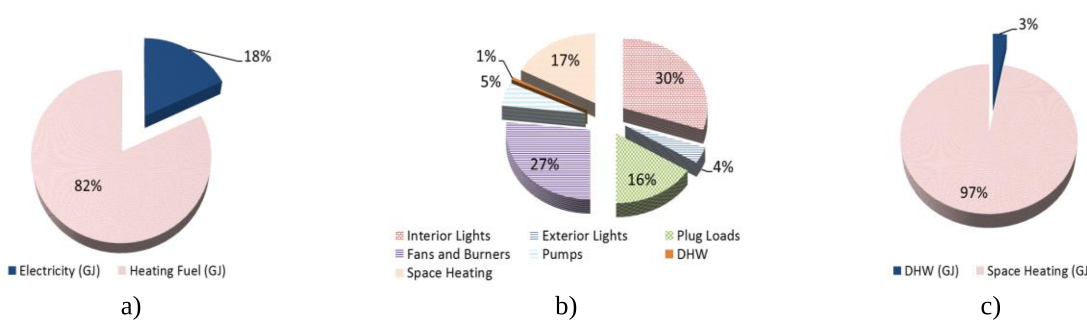

Figure 3: Distribution of a) Energy for the PCSP facility b) Electricity consumption by end-use c) Fuel use

Table 4: Baseline electricity and heating fuel consumption for the PCSP facility

Building	Purchased Electricity (kWh)	Heating Fuel Consumption (L)	Electricity Cost ($, CAD)	Heating Fuel Cost ($, CAD)	Utility Cost ($, CAD)
PCSP Facility	751,075	316,765	$743,773	$395,178	$1,138,951

5. ENERGY EFFICIENCY MEASURES AND ECONOMIC ANALYSIS

A three step process was employed to analyze various energy efficiency measures, as shown in Figure 4. Since electricity accounts for 65% of total utility costs, several on-site electricity generation scenarios were first examined as a means of achieving cost savings. Technologies examined include renewable wind and photovoltaic (PV) systems, and the use of on-site diesel generators. Next, the impact of upgrading the on-site generators to include cogeneration (combined heat and power, CHP) capabilities was examined to reduce on-site fuel use. Finally, to increase the amount of thermal energy available from the CHP units, the use of energy efficient space heating equipment was also investigated.

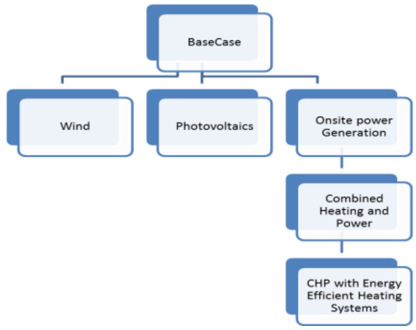

Figure 4: Framework for the energy efficiency measures

5.1 Integration of Renewables (Wind and PV)

Small scale wind turbines and PV systems can be used to reduce the electricity consumption and GHG emissions of each building examined. PV panels were added to the south-facing roof of each building at a tilt angle of 75°. Each PV system was limited to a single row of 240 W_P panels in order to avoid potential shading effects and the need to export excess generation to the Resolute, NU electricity grid. It is also important to note the community experiences 24 hour darkness from October through February, limiting the generating capabilities of the PV panels. Small scale wind turbine systems were sized to meet the minimum base electrical load of each building in multiple 2.5 kW rated systems. Table 5 summarizes the proposed renewable energy system for each building.

Table 5: Nominal system size for wind and PV for each building

Building	Nominal System Size (kW)	
	Wind	PV
XR-02	5	11
XR-03/XR-14	10	16
XR-04	5	-
XR-012/XR-15	15	19

5.2 On-site Power Generation

Electricity for the site is currently supplied via the local power plant, which uses five diesel generators to supply the complete electricity needs of PCSP and the neighboring community of Resolute Bay. A significant portion of the electricity demand of the facility could be met on-site by upgrading the currently installed standby generators to prime power units. This upgrade would effectively reduce the cost of electricity from $0.97/kWh from the local utility to an average of $0.37/kWh by producing the electricity on-site, while maintaining close to the same production of GHG emissions. The size of back-up generators available at the PCSP facility is shown in Table 6.

Table 6: Available on-site back-up generators

Building	Standby Power (kW)	Estimated Prime Power (kW)
XR-02	50	40
XR-03/XR-14	80	64
XR-04	42	34
XR-012/XR-15	100	80

5.3 On-site Combined Heating and Power (CHP)

Modifying the existing back-up generators to prime power units would require constant cooling of the engine jacket to avoid unit over-heating under constant use. With minimal additional investment, this waste heat could be recovered and used in the building, allowing the prime power units to become effective producers of both thermal and electrical energy. These modifications would improve system economics by significantly increasing the overall efficiency of the generators.

5.4 On-site Combined Heating and Power (CHP) with Efficient Heating Technologies

For cogeneration systems to be effective there must be a balance between the electrical loads on the generator, and the thermal loads served by the heat recovery system. In this paper, the potential of adding (1) cold climate air-source heat pumps, and (2) a sea-water heat pump system were examined. In both cases, by adding efficient electrically-driven heating systems, the electrical load on the generator is increased, resulting in more available heat recovery for use within the buildings.

Variable refrigerant flow (VRF) cold climate air-source heat pumps (CC ASHP) were first considered as an efficient heating option. These heat pumps are rated down to -25°C while maintaining 75-80% of their rated capacity (Mitsubishi electric, 2015). From preliminary calculations, it was determined that a heating COP of 1.35 would be required to break even in comparison to utility costs for the existing fuel fired equipment. For the CC ASHP system examined, achieving this COP would require ambient air temperatures above -15°C. However, in the cold Resolute climate, this limits beneficial use from May to October, when available heat recovery from the cogeneration units are capable of meeting the entire facility space heating load. As such, the benefits of this system were limited, and it was not examined further.

An additional option examined was the use of a sea-water heat pump. In this case, the heat pump would use the Arctic Ocean as a constant temperature thermal source for the heat pump system. With the PCSP facility located two kilometers from the Arctic Ocean, this represents a viable and effective option for the facility. At constant seawater temperature of 0°C (U.S. National Oceanographic Data Center 2014) a SWHP system would operate with a COP of 3.5, well above the estimated minimum required efficiency of 1.35.

5.5 Economic Analysis

A cost analysis is provided for the PCSP facility to prioritize efficiency measures and establish a budget. The economic analysis is based online sources and RSMeans with adjustments made based on experience of installing systems in the north (RSMeans 2013). Table 7 summarizes the estimated capital cost per kW of installed power for each efficiency measure. Simple payback periods were given by dividing the costs of the efficiency improvement strategy by the anticipated utility savings. A contingency of 50% was applied because of the remoteness of the facility and variation in design possibilities.

Table 7: Estimates capital costs per kW of installed power

Power Generation System	Costs ($, CAD)	Source
Wind Power	$15,000/kW per installed power	WINEUR 2006
Solar PV	$7.68/kW per installed power	Feldman *et al.*, 2014
On-site Diesel Generator*	$1,240/kW	Darrow *et al.*, 2015
Combined Heating and Power*	$1,665/kW	Darrow *et al.*, 2015
*For a 100 kW of installed generator power		

6. RESULTS

This section presents an analysis of the energy, GHG emissions, and economic performance of each energy efficiency measure outlined above. For all GHG calculations, values of 763 g CO_2 eq./kWh for electricity and 2,735 g CO_2 eq./L for on-site diesel were used. Table 8 outlines the baseline energy performance of the facility after the short term efficiency measures.

Table 8: Baseline electricity and heating fuel consumption for the PCSP facility

Building	Purchased Electricity (kWh)	Heating Fuel Consumption (L)	Electricity Cost ($, CAD)	Heating Fuel Cost ($, CAD)	Utility Cost ($, CAD)	GHG Emission (tons CO_2 eq.)
XR-02	101,194	53,77	$100,499	$66,872	$167,371	224
XR-03/14	269,168	120,170	$268,256	$150,212	$418,468	534
XR-04	78,730	9,481	$77,295	$11,823	$89,118	86
XR-12/15	301,983	133,337	$297,723	$166,271	$463,994	595
All Buildings	751,075	316,765	$743,773	$395,178	$1,138,951	1,439

6.1 Scenario # 1: Renewable Technologies (Wind and PV)

Wind turbine and photovoltaic systems were examined to determine the potential of renewable energy generation at the facility. Figure 5 compares the monthly electricity production of a 2.5 kW-rated wind turbine with a 2.4 kW_P PV array. Wind turbines offer greater annual electricity generation as these systems are able to operate year-round.

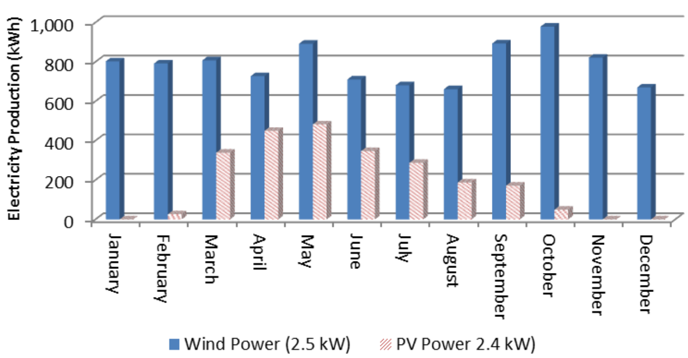

Figure 5: Monthly comparison of electricity production between a 2.5 kW wind turbine and a 2.4 kW PV array

Table 9 compares the annual performance of the wind turbine and PV systems on a facility-wide basis. Wind turbines sized to meet the base electrical loads offset 132,000 kWh of purchased electricity, with an estimated payback of 4 years. PV yields an offset of 46,000 kWh, with a simple payback period of 12 years. Future work will evaluate the life cycle cost of these systems taking into account maintenance requirements, which can be more costly for wind turbines in comparison to photo-voltaic arrays.

Table 9: Electricity, fuel and utility cost savings for small scale wind turbines and PV modules

Building	Purchased Electricity Savings (kWh)	Utility Cost Savings ($, CAD)	GHG Emission Reductions (tons CO_2 eq.)	Estimated Cost ($, CAD)	Simple Payback Period (Years)
Wind Turbines	131,567	$127,370	100	$525,000	4.1
Solar Modules	45,448	$43,998	35	$529,920	12.0

6.2 Scenario # 2: On-site Electricity Production from Diesel Generator

Table 10 summarizes the impact of implementing on-site electricity production from a diesel generator in each building. Adding this on-site generation capability would save nearly $470,000 in annual utility costs, with a payback period of less than one year. These strong cost savings are possible because producing electricity on-site would cost approximately one third of the price of purchased electricity from the local utility. The PCSP facility would produce approximately 750,000 kWh on-site from the upgraded backup generators while consuming close to 210,000 L of fuel. As the associated electricity GHG emission factor is calculated from diesel power generation, minimal reductions are achieved through on-site electricity generation using diesel generators.

Table 10: Electricity, fuel and utility cost savings for on-site electricity generation

Building	Purchased Electricity Savings (kWh)	Generator Fuel Consumption (L)	Utility Cost Savings ($, CAD)	GHG Emission Reductions (tons CO_2 eq.)	Estimated Cost ($, CAD)	Simple Payback Period (Years)
XR-02	101,194	29,002	$64,334	-2	$62,017	<1
XR-03/14	266,037	73,388	$166,419	2	$99,228	<1
XR-04	78,370	22,747	$48,188	-2	$49,930	1.0
XR-12/15	301,983	81,987	$190,458	7	$124,035	<1
All Buildings	747,584	207,124	$469,399	5	$335,210	<1

Currently PCSP receives a fuel delivery approximately every three days during the colder winter months. Converting the generators to prime power units will increase on-site fuel use, with an average daily increase of 40% estimated during the winter. As such, new fuel tanks would likely be required to facilitate this increased fuel use. Alternatively, if the backup generators are kept to maintain emergency power, new generators could be installed to supply the complete electricity consumption of the facility, with a total estimated cost of $1,900,000 and a simple payback period of approximately 4 years.

6.3 Scenario # 3: Combined Heating and Power (CHP)

Table 11 summarizes the energy performance of the proposed cogeneration option. Results are shown based on the implementation of on-site electricity production from diesel generators, as outlined in Scenario #2 above. Incremental savings demonstrate the strong fuel and utility costs savings that this option provides. For the larger buildings (XR-12/15 and XR03/14) there are significant benefits to upgrading the generators to CHP units, with simple payback periods of less than one year. For XR-12 some of the utility cost savings are obtained from being able to operate the boilers on low fire because of the hydronic return loop preheat. For smaller buildings such as XR-02 and XR-04, savings are also achieved. However the simple payback periods are closer to 4 and 5 years, respectively due to the associated cost of installing a hydronic heating system. On a site-wide basis, adding cogeneration capabilities would decrease fuel use by approximately 83,000 L, while reducing GHG emissions by 225 tons CO_2 eq. Economic performance is also strong, with annual utility cost savings of $109,000.

Table 11: Incremental electricity, fuel and utility cost savings for upgrading to on-site CHP from scenario #2

Building	Purchased Electricity Savings (kWh)	Generator Fuel Consumption (L)	Heating Fuel Savings (L)	Utility Cost Savings ($, CAD)	GHG Emission Reductions (tons CO_2 eq.)	Estimated Cost ($, CAD)	Simple Payback Period (Years)
XR-02	0	0	6,796	$8,474	19	$34,035	4.0
XR-03/14	0	0	42,277	$58,863	116	$39,103	<1
XR-04	0	0	5,276	$6,579	14	$32,346	4.9
XR-12/15	0	0	28,736	$35,834	79	$42,481	1.2
All Buildings	0	0	83,085	$109,750	228	$147,965	1.3

6.4 Scenario # 4: Combined Heating and Power with Efficient Heating Technologies

Figure 6 compares available heat recovery and heating loads by building. Results show an imbalance between the two sets of values, suggesting that each building could benefit from the use of an efficient electrically-driven space heating system during the winter months. In particular, heat pumps represent an attractive option because of their high efficiencies and ability to facilitate the integration of renewable energy sources into the building.

Sea water heat pumps (SWHP) represent an interesting option to efficiently meet building space heating loads. Table 12 summarizes the electricity, fuel and utility costs for each building with a SWHP. Estimated costs for each building include the heat pump and associated (heating demand weighted) distribution network costs for the system. For XR-03, new electrical demands with the SWHP exceeded the generating capacity of the previously examined CHP unit. As such, a new 125 kW CHP unit is also included in the costs for this building.

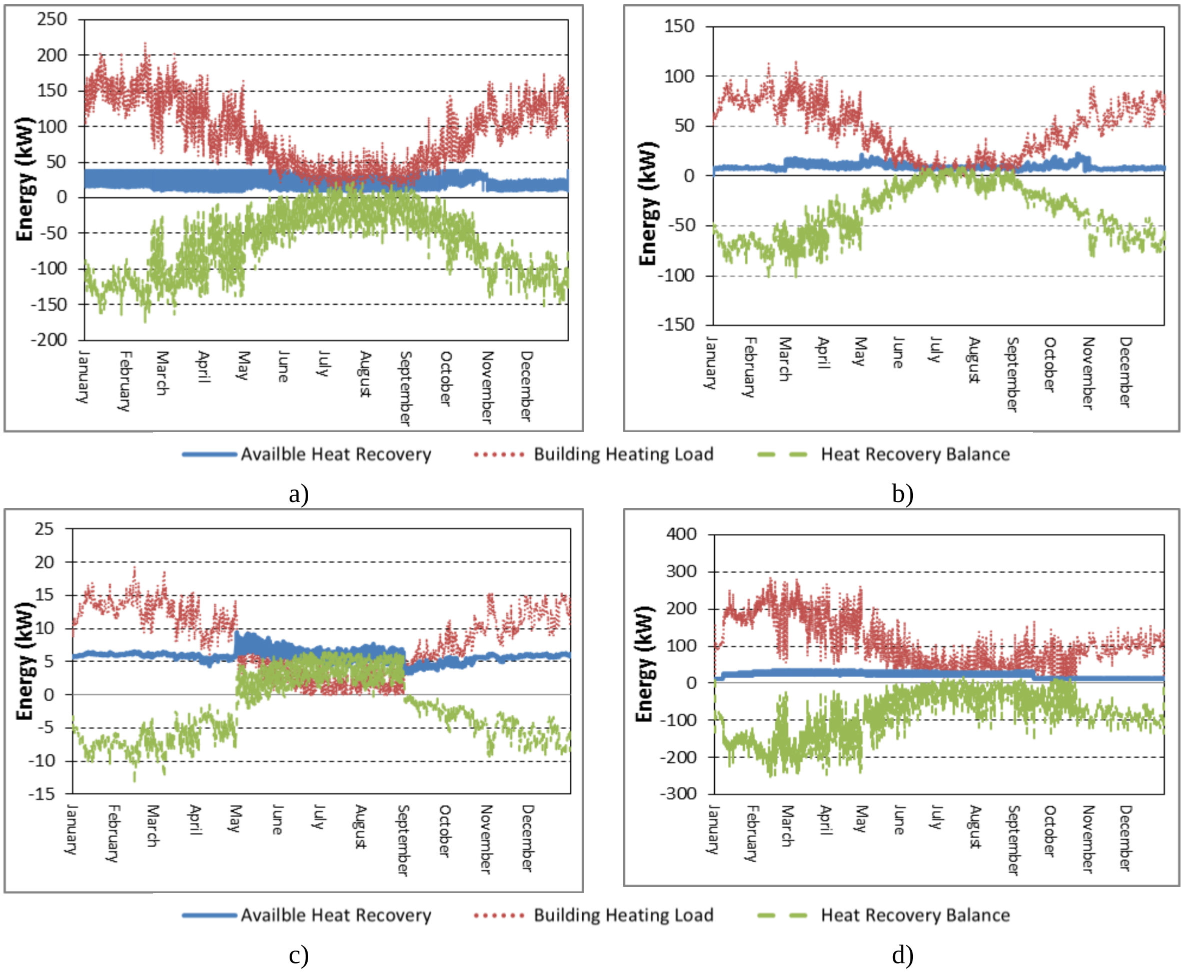

Figure 6: Required heat recovery and availability heat recovery for a) XR-02 b) XR-03/14 c) XR-04 d) XR-12/15

Table 12: Incremental electricity, fuel and utility cost savings for adding SWHP to scenario # 3

Building	Purchased Electricity Savings (kWh)	Increase in Generator Fuel Consumption (L)	Heating Fuel Savings (L)	Utility Cost Savings ($, CAD)	GHG Emission Reductions (tons CO_2 eq.)	Estimated Cost ($, CAD)	Simple Payback Period (Years)
XR-02	-59	18,875	29,484	$13,123	29	$336,808	>20
XR-03/14*	3131	40,393	48,918	$14,809	27	$898,365	>20
XR-12/15	0	11,798	22,484	$13,325	29	$615,308	>20
All Buildings	3072	71,066	100,836	$41,636	85	$1,850,482	>20
*XR-03/14 require a new 125 kW generator to be able to provide savings with the SWHP Scenario							

Adding a SWHP system increases facility fuel consumption by 71,000L. However, the facility space heating fuel consumption is reduced by approximately 100,000 L, resulting in an annual utility cost savings of $42,000. High infrastructure costs associated with the required piping network limit payback periods to over 20 years, which are likely too long for this particular project. However, for communities where the infrastructure is closer to the Arctic Ocean, a SWHP system could represent a viable energy efficiency measure.

7. FUTURE WORK

Future work will explore other innovative efficiency measures to further reduce the heating fuel consumption of the PCSP facility. These efficiency measures will include efficient heating technologies such as ground source heat pumps using advanced refrigerants like CO_2 incorporating the injection of solar thermal energy to reduce borefield sizes. Using solar thermal panels for domestic hot water, building integrated photovoltaic-thermal systems for ventilation preheat, and a facility wide district heating loop incorporating heat recovery from a future incinerator will also be explored. Future work will provide PCSP with a life cycle cost analysis including shipping costs, maintenance costs, additional operational costs, and projected utility cost escalation rates.

8. CONCLUSIONS

A series of long term energy efficiency measures have been assessed for the PCSP facility in Resolute using developed energy models. Proposed measures have been made based on a three step methodology that included (i) extensive monitoring of on-site electricity, fuel, and water use, (ii) development and calibration of detailed energy models using monitored data, and (iii) assessment of selected technologies using calibrated models.

Longer term measures require more planning and initial investment, but yield deep energy, GHG, and utility cost reductions. From monitoring of the energy flows of the facility, the electricity consumption represents only 18% of the total energy end use for the facility. Because of the high local electricity rates, reducing facility electricity consumption became the main target for these more complex measures, as it represents 65% of the total utility costs. To reduce the utility costs related to electricity consumption, renewable technologies such as wind and PV systems, and on-site power generation were first assessed to offset purchased electricity. The second step investigated efficiency strategies to reduce the total diesel consumption by upgrading the on-site power generation to a CHP system using the recovered heat to meet a portion of each buildings heating load. Thirdly, to increase the amount of energy available from the CHP systems, the use of energy efficient space heating equipment was investigated to shift the heating load from diesel fuel to electricity

Based on an extensive analysis of building energy performance, energy efficiency measures targeting electricity consumption were found to yield utility cost savings between $44,000 and $470,000, with simple payback periods ranging from under 1 year to 12 years. On-site power generation produced the greatest amount of annual utility cost savings with a simple payback periods less than 1 year. The second analysis phase targeted reductions in heating fuel consumption by recovering heat from on-site generators. These measures can further decrease utility costs by $109,000, with a simple payback period of 1.3 years The last analysis phase examined efficient heating technologies such as sea water heat pumps, which can be used to boost the heat recovery. Implementing these technologies can provide large reductions in heating fuel of up to 100,000 L and utility cost savings of close to $42,000. However, the high initial cost of the system results in a payback period greater than 20 years.

REFERENCES

Darrow, K., Tidball, R., Wang, J., & Hampson, A. (2015). *Catalog of CHP technologies*, U.S. Environmental Protection Agency Combined Heat and Power Partnership.

Feldman, D., Barbose, G., Margolis, R., James, T., Weaver, S., Darghouth, N., Wiser, R. (2014). Photovoltaic system pricing trends., (No. NREL/PR-6A20-62558).

Klein, S.A. et al. (2010). TRNSYS 17: A Transient System Simulation Program, Solar Energy Laboratory, University of Wisconsin, Madison, USA, http://sel.me.wisc.edu/trnsys.

Low Carbon NRCan (2016). NRCan website, <http://www.nrcan.gc.ca/energy/efficiency/buildings/eefb/leadership/4133> [Accessed Mar. 2016]

Mitsubishi Electric (2015). City Multi H2i™ Y-Series Hyper-Heating Inverter. <http://meus1.mylinkdrive.com/files/02_H2i_-Hyper-heat_Inverter_Unit_Section.pdf >. [Accessed Feb. 2016]

NREL (2016). Distributed Generation Renewable Energy Estimate of Costs. <http://www.nrel.gov/analysis/tech_lcoe_re_cost_est.html> [Accessed Feb. 2016]

RSMeans (2013). Mechanical Cost Data, RSMeans, Kingston, USA.

U.S. National Oceanographic Data Center: Global Temperature–Salinity Profile Programme. (2014). U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Oceanographic Data Center, Silver Spring, Maryland, 20910, <http://www.nodc.noaa.gov/GTSPP/>.

WINEUR (2006). Wind Energy Integration in the Urban Environment, Techno Economic Report, January 2006.