Denali Commission

Emerging Energy Technology Grant

An Investigation of the Alaska SeaLife Center Seawater Heat Pump Demonstration

A Project by the Alaska SeaLife Center

Emerging Energy Technology Grant

Emerging energy technology is a critical phase in the development process of energy technology, linking research and development to the commercialization of energy solutions. Although the Arctic possesses bountiful energy resources, the Arctic also faces unique conditions in terms of climate, environment, population density, energy costs, logistics, and the isolated nature of electrical generation and transmission systems. These conditions, challenging under the best of circumstances, making the Arctic an ideal test bed for energy technology. Emerging energy technology provides a unique opportunity to meet Arctic energy needs, develop energy resources, and create global expertise.

In 2009 the Denali Commission, an independent federal agency in Alaska, released a public solicitation entitled the Emerging Energy Technology Grant (EETG). The EETG targeted (1) research, development, or demonstration projects designed to (a) test new energy technologies or methods of conserving energy or (b) improve an existing energy technology; and (2) applied research projects that employ energy technology with a reasonable expectation that the technology will be commercially viable in Alaska in not more than five years.

The following are the 9 projects funded under this solicitation:

Alaska SeaLife Center, Seawater Heat Pump Demonstration Project

Cordova Electric Cooperative, Psychrophiles for Generating Heating Gas

Kotzebue Electric Association, Feasibility of Solar Hot Water Systems

ORPC Alaska, Nenana Hydrokinetic Turbine

Sealaska Corporation, Commercial Scale Wood Pellet Boiler

Kotzebue Electric Association, Flow Battery Energy Storage Systems

Tanana Chiefs Conference, Organic Rankine Cycle Heat Recovery System

University of Alaska, Fairbanks, High Penetration Hybrid Power System

Kotzebue Electric Association, Wales Diesel-Off High Penetration Wind System

For further information, please visit the EETG program website at:

http://energy-alaska.wikidot.com/emerging-energy-technology-grant

Alaska SeaLife Center

The ASLC has been operating on the coast of Resurrection Bay in Seward since 1998 in pursuit of its four primary objectives: research, rehabilitation, education, and display of exhibits. The ASLC conducts research on marine animal populations and environmental changes; it provides care for sick and injured marine animals and is Alaska's only permanent marine mammal rehabilitation facility. ASLC seeks to educate people of all ages about Alaska's marine ecosystems through a variety of programs. The most well-known aspects of ASLC are the re-creations of these ecosystems in its aquarium exhibits which receive about 160,000 visitors each year.

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About the Author

The Alaska Center for Energy and Power (ACEP) is an applied energy research group housed under the Institute of Northern Engineering at the University of Alaska Fairbanks. ACEP is serving as the program manager of the EETG program on behalf of the Denali Commission.

A key deliverable for each EETG project is a lessons learned report by ACEP. As the projects deal with emerging energy technology, providing lessons learned and recommendations is critical for understanding the future of the technology in Alaska, and the next steps needed in developing energy solutions for Alaska.

ACEP's technical knowledge and objective academic management of the projects, specifically for data collection, analysis, and reporting, are vital components to the intent of the solicitation.

An Investigation of the Alaska SeaLife Center Seawater Heat Pump Demonstration

A Project by Alaska SeaLife Center

Recipient:

Alaska SeaLife Center

EETG Funding: $426,720

Total Project Budget: $881,265

Project Timeline:

May 2010—May 2013

Report Overview

This report investigates the demonstration of a seawater heat pump system at the Alaska SeaLife Center (ASLC); the project was funded by the Denali Commission Emerging Energy Technology Grant (EETG) program. Heat pumps, a technology with limited cold climate applications, have been successfully utilized in countries such as Canada, Norway and Sweden with seawater as a heat source. There is much interest in this technology for Alaska given these relative applications and the opportunity to displace expensive heating fuel in the state's coastal communities with access to (relatively) inexpensive electricity." This report includes an overview of the demonstration project, an analysis of performance and economic data, and a summary of the lessons learned, findings and recommendations relevant for potential future applications of heat pumps utilizing seawater in Alaska.

For comprehensive project information and report appendices, please visit the EETG program website at

http://energy-alaska.wikidot.com/emerging-energy-technology-grant.

Project Introduction

The goal of this project was to reduce expensive and rising heating costs at the ASLC. To meet this goal, the building was retrofitted with a heat pump system, taking advantage of existing seawater intake infrastructure to replace costly heating oil[i] with more affordable electricity.

Key project tasks and relevant activities included the following:

- Installation of two 90-ton[ii] heat pumps
- Installation of supporting infrastructure (heat exchangers, pumps, etc.)
- Commissioning of integrated monitoring and controls system
- Reconfiguration and integration of supporting mechanical and electrical systems
- Rehabilitation and integration of seawater intake system
- Demonstration of the technology

Project activities commenced in May 2010, with primary system installation and commissioning completed by June 2012 and final system commissioning completed by December 2012. The project underwent active performance monitoring through May 2013.

The following organizations were involved in this project:

Alaska SeaLife Center: Located on the shores of Resurrection Bay in Seward, ASLC is Alaska's only public aquarium and ocean wildlife rescue center. ASLC submitted this project to the Denali Commission for consideration under the EETG program. ASLC is the primary stakeholder of this project.

The City of Seward: The City of Seward owns the ASLC facility and supported the implementation of the project. The city is monitoring the success of the technology and investigating other relevant applications, such as a district heat system.

YourCleanEnergy LLC: YourCleanEnergy LCC (YCE) is a clean energy consultant based in Anchorage, Alaska. YCE conducted an energy audit of the ASLC facilities and recommended a seawater heat pump system as a solution to mitigating energy costs. YCE, in association with EDC, Inc., designed the final system and was instrumental in installing and commissioning it.

Trane: Trane is a global provider of chillers, heat pumps and other HVAC systems. Trane was the manufacturer of the heat pump and controls system and provided installation, commissioning and programming services for the project.

Alaska Energy Authority: The Alaska Energy Authority provided $286,580 in supplemental funding through the Renewable Energy Grant Fund.

Alaska Center for Energy and Power: The Alaska Center for

Energy and Power (ACEP), an applied energy research program based at the University of Alaska Fairbanks, provided technical support for data collection. In addition, ACEP provided independent project and performance analysis and reporting. This report is the final product of that effort.[iii]

Technology Overview

Heat pumps are a mature and widely used technology for both heating and cooling applications. There are several aspects to the ASLC demonstration that qualified the project for funding under the EETG program, which targets emerging energy technology that has the potential of widespread deployment in Alaska; these include the application of heat pumps in cold climates, the use of seawater as a heat source and the prospect of district heating applications. The following is an overview of key technical information relevant to this project.

Heat pumps

Heat pumps extract thermal energy from a low temperature reservoir and transfer it to a high temperature sink. The typical process begins by running a cold working fluid (typically a refrigerant that vaporizes at a low temperature) through a low temperature reservoir; the working fluid absorbs heat from the reservoir and becomes a vapor. The vapor is then compressed, which increases its temperature and pressure. The higher-pressure, hot vapor then passes through the high temperature sink (which is at a lower temperature than the hot vapor), releasing usable heat that cools and compresses the working fluid back to a liquid state. Finally, the working fluid passes through an expansion valve, which causes a drop in pressure and brings the temperature of the working fluid back down to its original cold state.

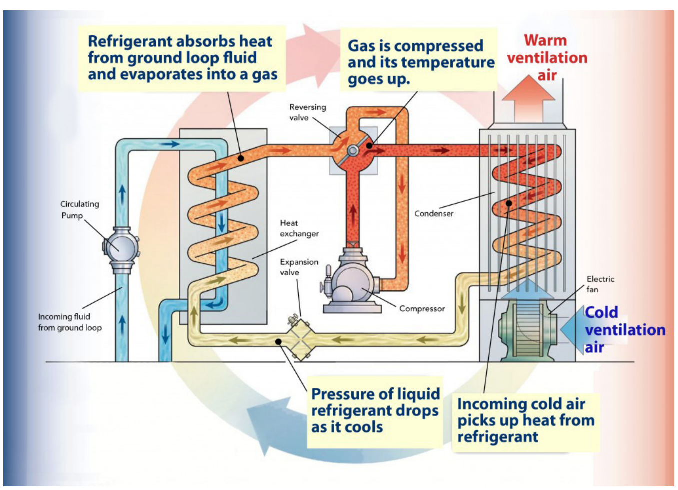

Figure 1. How a Heat Pump Works[iv]

This process is the same one used in refrigerators and air conditioners; heat is removed from inside the refrigerator (the low temperature reservoir) and transferred it to the kitchen (the high temperature sink), which cools the interior of the refrigerator. A heat pump moves heat from a source, such as Resurrection Bay, and transfers it to an application, such as the ASLC.

Heat pumps do not always come into direct thermal contact with the heat source; sometimes a fluid is used to transfer the heat from the source to the pump. Potable water can be used as the transfer fluid; if there is a risk of freezing, an antifreeze mixture or brine can be used instead. Heat exchangers are used to facilitate the heat transfer between mediums. The heat exchangers provide excellent thermal contact between different parts of the system without allowing fluids to mix.

Coefficient of Performance

The transfer of heat from a low temperature source to a high temperature sink requires some energy. Electricity is required to power the compressor (the primary energy use in the cycle) and pumps used to move the working fluids. The Coefficient of Performance (COP) is a measurement of performance of a heat pump system. Formally, COP is as follows:

$$COP = \frac{Q}{W}$$

Q is the heat supplied by the reservoir and W is the work performed by the heat pump system. Informally, the COP is the ratio of heating to electricity energy used.

When heat pumps have a COP greater than 1, the energy provided as heat is greater than the energy used. This is because the energy provided is used to move existing heat, rather than generating additional heat. As a comparison, electrical resistance heaters have a COP of 1 because all of the electrical energy is converted into heat and is not used to transfer heat from another source. The COP is dependent on the type of heat source (see discussion on heat sources below). Air has a lower heat capacity than ground or water, meaning there is less heat available to use in the air at equal temperatures. The difference in temperature between the heat source and the heat sink also greatly affects the COP. A larger temperature difference means a smaller COP because the pump must do more work to reach the desired temperature of the heat sink. Generally, heat pumps operate with a COP of approximately 2-6.5; however, in cold climates such as Alaska a lower COP of 2-3.[v] is more typical.[vi] For more information regarding COP calculations, see the section Performance Evaluation.

Categorization

Heat pump systems are loosely categorized by their heat source (air, ground or water) and how the source is utilized. Air-source heat pumps (ASHPs) transfer heat between air and either indoor air (air-to-air) or domestic hot water (DHW, air-to-water). Ground-source heat pumps (GSHPs) transfer heat between soil, rock or groundwater and an indoor application. Water-source heat pumps (WSHPs), such as the one at the ASLC, transfer heat between a body of water such as a lake, river or sea and an indoor application.[vii]

GSHPs (and some WSHPs) can be further categorized as horizontal or vertical systems. In a horizontal ground loop, the working fluid collects heat over a large area at or near the surface of the ground (the loop is spread out horizontally). In a vertical system, the loop extends vertically (like a water well) to collect heat where the temperature is more stable or to access a water source (see Figure 2).

In addition, and particularly relevant to WSHPs, heat pump systems are also categorized as open loop or closed loop, depending on how the source is utilized. Informally, a closed-loop system never uses the source directly; rather, a loop containing a working fluid passes through the source and transfers heat. An open-loop system, by contrast, will pump the source water directly through a component of the system; water will enter at one end, transfer heat and discharge out the other end. An example of this is a system that extracts water from a well, exchanges the heat and discharges the water back to the original well or elsewhere.

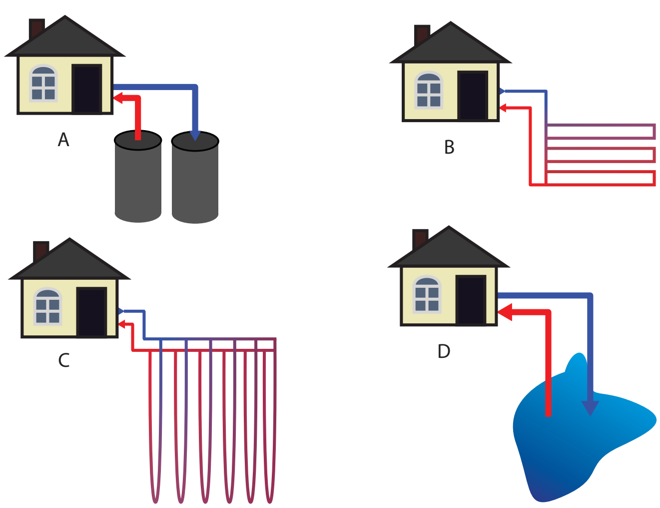

Figure 2. Ground-loop configurations: a) open-loop bore-hole, b)closed-loop horizontal, c) closed-loop vertical, d) open-loop pond

Both systems have drawbacks. In open loops especially, bio-fouling or hard water can cause an accumulation of debris over time, leading to higher maintenance costs and concerns. Closed loops are generally less efficient at transporting heat because of the intermediate heat exchangers and additional loops.

Seawater Heat Pumps: Seawater heat pump systems can be either closed loop or open loop. It is presumed, however, that a commercial-sale system would employ an open loop configuration.[viii] There are several technical items to note relative to the ASLC concerning seawater heat pump systems:

- Bio-fouling: In open loops, algae and invertebrates such as barnacles or mussels can accumulate in the seawater intake piping. Too much buildup can lead to clogged pipes and reduced flow. A strategy for cleaning the intake piping is a critical system consideration.
- System location: Pumping is an important consideration for the system COP since the demand for electricity increases as the need for pumping increases. Therefore, the distance and elevation of the facility is an important consideration in determining the feasibility of an application.
- Thermal reliability: In general, seawater is very thermally stable and predictable, which makes it a utility-grade resource — a critical consideration for commercial-scale applications.

Cold Climate Application

Historically, adoption of heat pumps in cold climates has been limited because of several fundamental issues affecting the process described in Figure 1:

- Reduced operation: In relatively temperate locations, heat pumps are used to cool in the summer and heat in the winter, maximizing system operation and minimizing the payback period. Use in cold climates is often limited to heating, or heating with limited cooling application. Limited use lessens the economic advantage of a heat pump system over other heating and cooling systems.
- Increased work: Typically, the high temperature sink of the heat pump remains constant but the low temperature source varies with the season. The compressor (the primary energy user in a heat pump system) works harder and uses more electricity as the temperature difference between source and sink increases.

- Source availability: If the source temperature is too extreme, it is possible that the heat pump will be incapable of providing sufficient heat. Frozen lakes and streams, permafrost and subzero air are all concerns common to WSHPs, GSHPs and ASHPs.

Recently there have been technological advancements in heat pump technology for cold climate application. ASHPs, for instance, have seen a recent surge in application in Southeast Alaska and can be used in temperatures below freezing.[ix] These technological advancements have increased the lower limit of practical application of WSHPs, GSHPs and ASHPs alike.

District Heating

District heating is a centralized method of providing heat to a large number of users. Similar to a commercial electric grid and utility, district heating connects many individual customers to a single heating facility. In a typical system, water is heated at a heating facility then piped through a central loop with connections to homes and businesses.

The central heating facility can be either a heat-only boiler system or a cogeneration (heat and electricity) facility. Energy sources range from traditional fossil fuels to nuclear, geothermal and even solar resources.[x] Heat pumps are a technology that can be integrated into district heating loops; there are several seawater heat pump systems used for district heating applications in Scandinavia (see discussion below), applications that are relevant to the system at the ASLC.

Relevant Projects

While seawater heat pump systems are not new, the technology is not widespread, particularly in North America. Following are several key seawater heat pump projects relevant to this report:

International Projects

Värtan Ropsten: Värtan Ropsten in Stockholm, Sweden, is the world's largest heat pump facility with a total heating capacity of 180 MW. It has been in operation since the mid-1980s under the energy distribution company Fortum and uses six Unitop 50FY heat pump units manufactured by Friotherm. The facility produces about 2,600 GWh of energy each year from district heating with a COP of 3.75. It provides approximately 60% of the heat produced for the greater Stockholm area heating districts. The plant takes in water as cold as 37°F and returns it at 33°F.[xi]

Bodø Air Station: Bodø Air Station in Norway is NATO's northernmost air base. Historically, the base was heated by oil-fired boilers, with a backup system of electric boilers. In 1992, a district heating system was installed, with a seawater heat pump as the primary source and the older oil-fired boilers as auxiliary sources. The system draws water at a constant temperature of 45°F into a holding basin and returns it at 37°F. The system has a heating capacity of approximately 2 MW and provides about 8 GWh for heating each year. The system COP is approximately 3.4.[xii]

Vancouver West Convention Centre: In 2009, construction for the Vancouver West Convention Centre in Vancouver, British Columbia, was completed. The convention center was designed to have low and sustainable energy usage. Part of its design incorporates a seawater heat pump to heat the building in the winter and cool it during the summer. The system draws in water from the Burrard Inlet and provides approximately 50% of the heating requirements for the building, 6.2 MW, with an estimated COP of around 3.[xiii]

Gulf Islands National Park Operations Centre: The Gulf Islands National Park Operations Centre, located in Sidney on Vancouver Island, British Columbia, houses park operations and administrative staff and is Canada's first LEED (Leadership in Energy and Environmental Design) Platinum building. Integral to the energy efficiency of the building is a seawater heat pump system that uses water from Tsehum Harbour and provides all heating needs for the facility. Lessons learned from this installation, such as best practices in seawater intake, informed the system design of the ASLC system.[xiv]

Alaska Projects

Ted Stevens Marine Research Institute: The Ted Stevens Marine Research Institute (TSMRI), located in Juneau, is managed by the National Marine Fisheries under the National Oceanic and Atmospheric Administration (NOAA). In March 2011, TSMRI installed a seawater heat pump system similar to the ASLC system; TSMRI had an existing seawater intake system for their marine research. Water is pumped from Auke Bay to wells near the shore. From there, the water is pumped to a 30,000-gallon holding tank next to the research facility, distributed to various laboratories, then sent to a 15,000-gallon waste water tank. The intake to the heat pump system is integrated at this point; the water is either sent back into the bay or run through the heat pump system. The heat pump cools the water by about 3° to 5°F from a starting temperature of 38° to 42°F. The extracted heat is transferred to air handlers and DHW preheating systems. It is estimated that the additional electricity needed to run the pump, 300,000 kWhr, costs about $36,000 per year (assuming $0.12/kWh). However, it is further estimated that approximately 60,000 gallons of heating oil are displaced annually, for a savings of $180,000 (assuming $3.00/gallon).[xv]

Kodiak Fisheries Research Center: The Kodiak Fisheries Research Center (KFRC), managed by the National Marine Fisheries and NOAA, has recently begun upgrading the facility to use heat from a seawater chilling system. Water is drawn from Trident Basin for use in research tanks. Previously, this water was fed to individual research tanks that were chilled separately. This was inefficient, in part because the chillers were in the same room as the tanks. Furthermore, the building was heated entirely with oil heaters, using 65,400 gallons per year on average. The new system is designed to chill the water to needed research temperatures in a central location and use the extracted heat for space heating. It is estimated the new system will displace about 25,000 gallons of oil using 500,000 kWh of electricity each year. It should be noted that while the KFRC system will use more electricity and displace less oil than the TSMRI system, the KFRC system is designed primarily as a water chiller with a secondary benefit of utilizing the extracted heat elsewhere in the building; the system will be working harder in the summer months to chill seawater when the extracted heat is not needed.[xvi]

ASLC Project Summary

Project Development

The ASLC has been operating on the shoreline of Resurrection Bay in Seward since 1998 in pursuit of its four primary objectives: research, rehabilitation, education and display of exhibits. The ASLC conducts research on marine animal populations and environmental changes; it provides care for sick and injured marine animals and is Alaska's only permanent marine mammal rehabilitation facility. ASLC seeks to educate people of all ages about Alaska's marine ecosystems through a variety of programs. The most well-known aspect of ASLC is the re-creation of these ecosystems in its aquarium exhibits, which receive about 160,000 visitors each year.

As a nonprofit organization, energy and operation costs represent a significant concern. The primary goal of ASLC during this project was to reduce monthly heating costs in the long term. Because ASLC is well aware of the impact excess amounts of carbon dioxide have on the climate, another

Figure 3. Alaska Sealife Center[xvii]

important objective of this project was to decrease the carbon footprint of its facilities.

Historic Heating System

Prior to 2009, the ASLC heated its facility with three Cleaver Brooks oil-fired boilers (two 80-hp units and one 125-hp unit). The boilers provided heat for an air-handling unit (AHU) system for primary building space heating,[xviii] a preheating system for DHW,[xix] a slab heating system used for exterior laboratory space, animal habitats, exhibits and sidewalks, and other heating units (duct coils, ceiling unit heaters, wall unit heaters, baseboard heaters, etc.). On average, the facility used nearly 130,000 gallons of fuel for heating each year. In an initial effort to reduce oil consumption, the ASLC replaced the 125-hp oil-fired boiler with a 500-kW Sussman electric boiler in 2009. The electric boiler supplied all necessary heating between April and October each year, when heating demand was relatively low. Oil usage was reduced during this time, although electrical usage increased. The resulting breakdown of ASLC maximum heating production and demands is as follows:

Heat Production Equipment	MBH	% of Total Capacity
Fuel Boiler #1	2911	38.6
Fuel Boiler #2	2911	38.6
Electric Boiler	1706	22.6
Electric Unit Heater	14	0.2
Total Heat Production	7542	100
Heating Demand Equipment	MBH	% of Total Demand
Slab Heating	1204	15.3
AHU Demand #1	3919	49.7
AHU Demand #2	810	10.3
Domestic Hot Water Tank	416	5.3
Other Unit Heater Demand	1534	19.4
Total Heat Demand	7883	100

Table 1. Representative Breakdown of ASLC Maximun Heat Production and Demand (2009 - 2012)[xx]

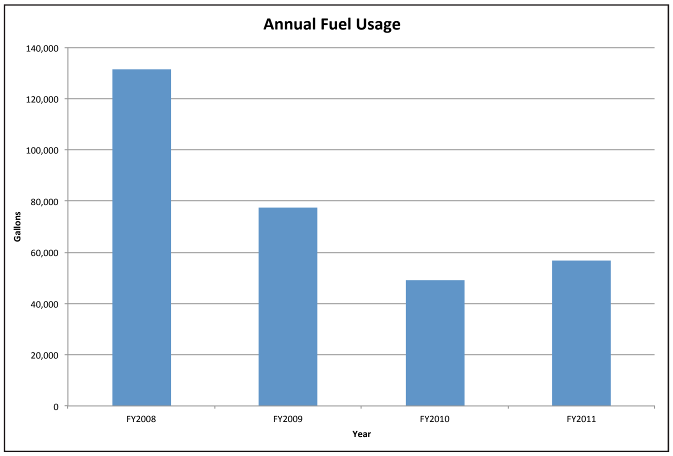

Figure 4. ASLC Historic Fuel Use

Figure 4 shows the estimated yearly fuel oil use of the ASLC boilers from 2008 to 2011.[xxi] Note that, as described above, the 125-hp boiler was replaced by an electrical boiler in 2009, resulting in a significant decrease in fuel oil consumption.[xxii]

Figure 5 shows the ASLC's monthly electric usage from September 2008 to September 2011. Again, as described above, the electric heater was installed in 2009 and provided heat for the facility during periods of low heating demand, primarily during warm months. This figure illustrates the strong relationship between electricity use and electric heating need; electricity use prior to 2009 was relatively stable, approximately 300,000 kWh per month, similar to the periods of low electrical usage in this figure.

YourCleanEnergy Concept Design and Initial Economic Evaluation

The seawater heat pump project was intended to continue and expand the effort to reduce oil consumption, in particular through a more electrically efficient and stable method. Prior to receiving external funding or grants, ASLC contracted with YCE to develop a concept design for installation of seawater heat pumps, and conduct and economic evaluation of this design.[xxiii] The report analyzed existing heat production and demands for the facility, and then considered three possible scenarios: (1) Use one heat pump to supply heat to the AHU system, (2) use one heat pump to supply heat to the slab heating system or (3) use two heat pumps to supply heat to the AHU and the slab heating systems. For each of the scenarios, the report estimated the installation and upkeep costs as well as the potential heat produced and fuel displaced. It determined that despite costing the most, the scenario with two heat pumps would provide the best long-term economic benefit and the shortest payback period.

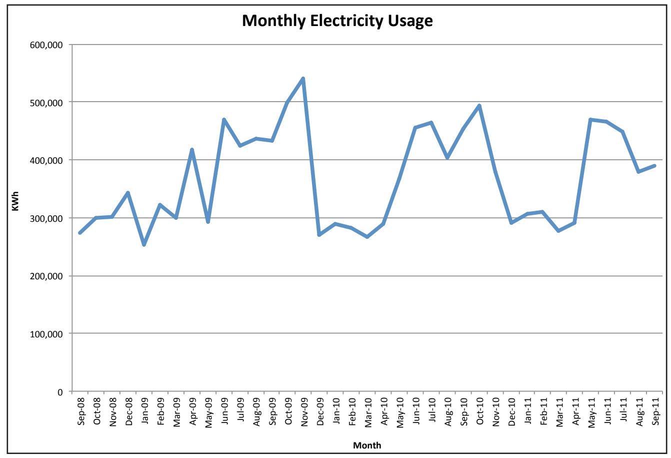

Figure 5. ASLC Historic Electricity Use

The ASLC was able to use seawater heat pumps because Resurrection Bay is a tremendous utility-grade heat resource (Figure 6). This is due to several factors:

- The bay has a very stable temperature because it is a relatively large body of water.
- There is no buildup of sea ice during the winter months.
- The bay is able to collect and store large amounts of solar heat because it is south-facing and light is unimpeded by mountains or trees.
- Because the shape of the bay reduces flow in and out of the Gulf of Alaska, solar energy stored in the water is not washed out to sea.

In addition, ASLC has two seawater intake pipes, 24 inches in diameter, providing the center with all of its seawater needs. The pipes draw in water by gravity siphon from a depth of 275 feet to a wet well within ASLC at a maximum rate of 5,000 gallons per minute.[xxiv] The seawater is pumped throughout the facility as needed, then sent to another wet well for purification (using ozone) and returned to Resurrection Bay.

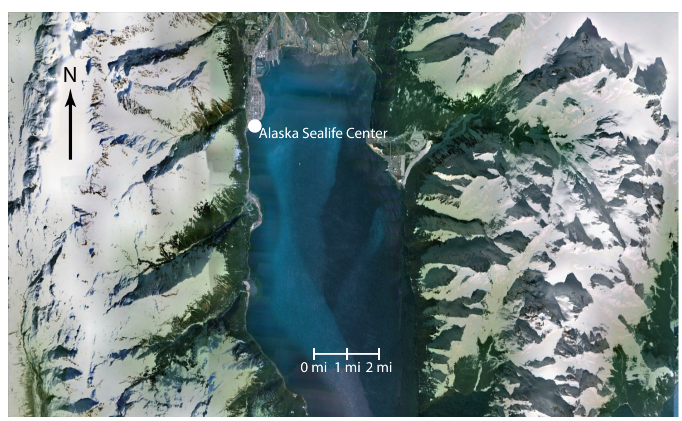

Figure 6. ASLC and Resurrection Bay

The capacity of the seawater wet well was determined to be sufficient for even the most demanding scenario proposed by YCE.[xxv]

The evaluation conducted by YCE found that from 2003 to 2008 the temperature of the bay at the ASLC seawater wet well ranged from 37°F to 56°F with a monthly average of 40°F to 48°F (Figure 7). It also found that the yearly heating demand profile of ASLC was as expected, with peak demand in January and lowest demand in July. However, the evaluation found slightly unexpected results when looking at the heating capacity of the bay — the maximum and minimum did not directly correlate with the lightest and darkest times of the year, respectively. The evaluation concluded that this is because of Resurrection Bay's ability to collect and store heat well into October and November.

Project Funding and Scope

Based on the findings of the YCE evaluation, ASLC pursued funding opportunities in support of the various scenarios proposed. The Denali Commission EETG program provided primary project funding in the amount of $426,720, which allowed for a scenario utilizing a single heat pump. Supplemental funding was received through the Alaska Energy Authority Renewable Energy Fund in the amount of $286,580, which allowed for the two heat pump scenario. In addition, ASLC provided $52,965 in matching funds for the EETG in cash and in-kind contributions, $115,000 in matching funds from the MJ. Murdoch Charitable Trust and other funding sources for a total project budget of $881,265. Match and supplemental funding was primarily utilized for installation (ASLC facilities staff played a significant role in installation of the heat pump system), the rehabilitation of the seawater intake system, and the inclusion of slab heating as a system load.

The overall goal of the project was to reduce expensive and rising heating costs at the ASLC. Specific to the EETG program

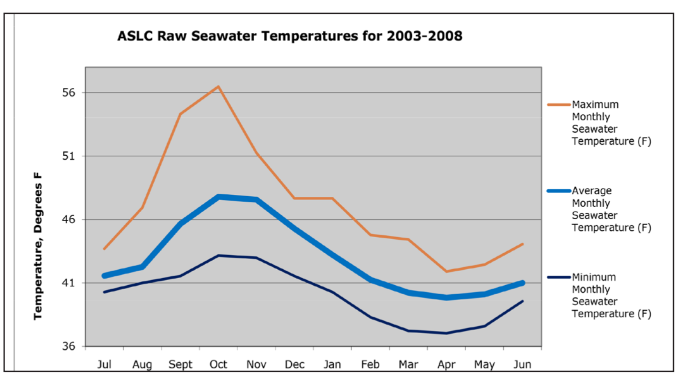

Figure 7. ASLC Raw Seawater Temperature for 2003-2008[xxvi]

(the subject of this report), the goal was to demonstrate a commercial-scale seawater heat pump system in an Alaska environment. To this end, data collection was a priority during design and installation of the system in order to provide enhanced system and performance monitoring as well as recommendations for future projects in Alaska.

Key project tasks and relevant activities included the following:

- Installation of two 90-ton heat pumps
- Installation of supporting infrastructure (heat exchangers, pumps, etc.)
- Commissioning of integrated monitoring and controls system
- Reconfiguration and integration of supporting mechanical and electrical systems
- Rehabilitation and integration of seawater intake system
- Demonstration of the technology

Project activities commenced in May 2010, final design was completed in November 2010, with primary system installation and commissioning completed by June 2012 and substantial system commissioning completed by February 2013. The project underwent active performance monitoring through May 2013.

Project Design and Installation

With final funding secured, ASLC contracted with YCE for design services for a two heat pump system as proposed by YCE. The system is composed of five general sections: the seawater loop (heat source), the evaporator loop, the heat pumps, the condenser loop and the heat loads. The following is a representation of the system:

Seawater Loop: Seawater is pumped from the existing wet well to a plate-and-frame heat exchanger. A custom filter/strainer is installed in this loop (prior to the heat exchanger) to extract as much particulate matter as possible and reduce maintenance requirements of the heat exchanger, which is a plate-and-frame unit specified with titanium plates to resist corrosion.

Evaporator Loop: The evaporator loop transfers the heat exchanged from the seawater to the heat pumps. A mixture of 20% propylene glycol and fresh water circulates through the loop.

Heat Pumps: Each heat pump is a high-efficiency, water-cooled, helical rotary chiller with a 90-ton (1080 MBH)

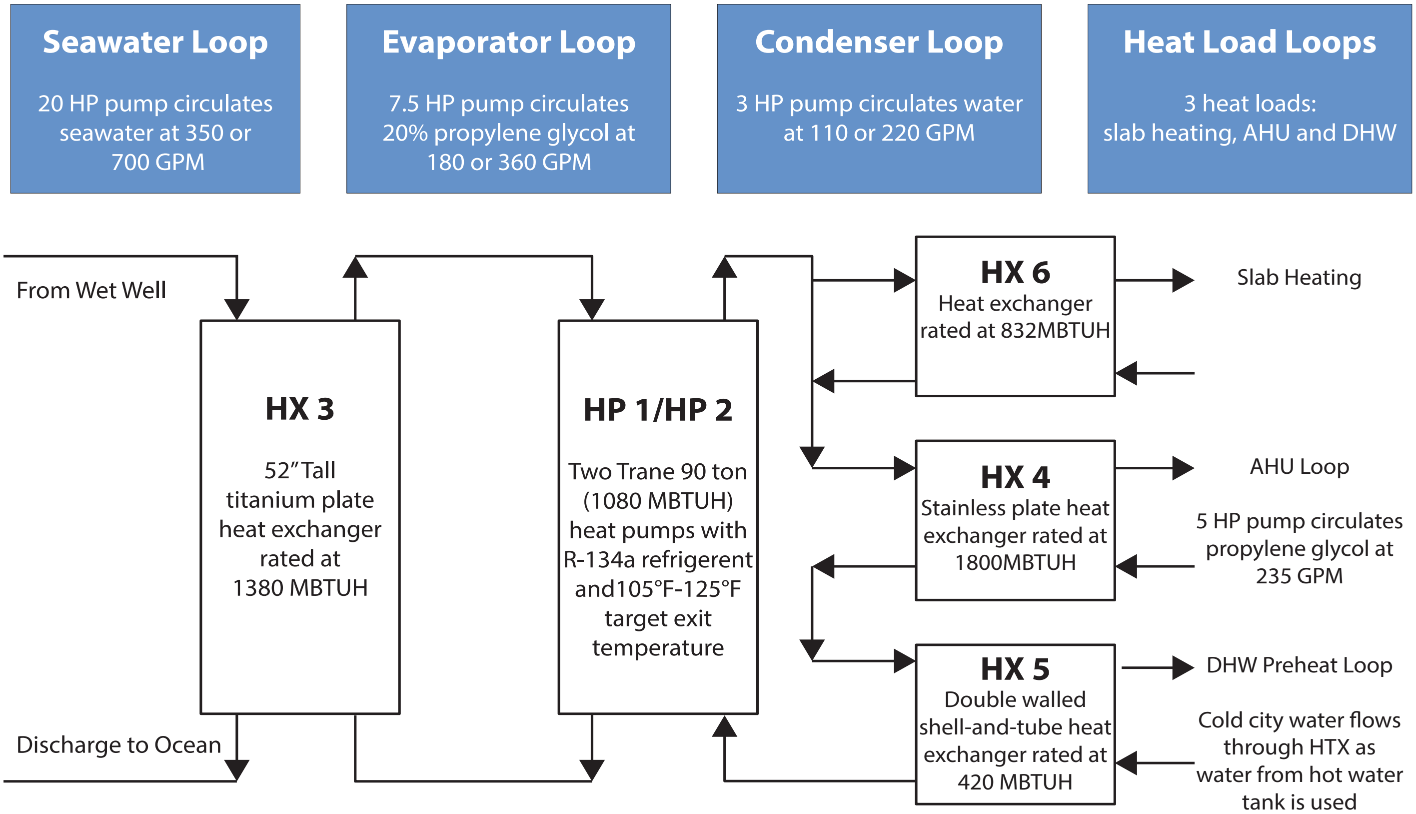

Figure 8. Block Diagram of ASLC System

capacity and is manufactured by Trane; the heat pumps use R-134a as a refrigerant. The compressors of the heat pumps are the primary energy load for the system.

Condenser Loop: The condenser loop transfers heat from the heat pumps to the heat loads of the system. Fresh water is the circulating fluid in the condenser loop; the target temperature exiting the heat pumps is between 105°F and 125°F, depending on seasonal requirements. The loop enters the AHU heat exchanger (with the option of entering the slab heating heat exchanger, depending on heating need) and then goes through the DHW heat exchanger before returning to the heat pumps.

Heat Loads: Three heat exchangers transfer heat from the condenser loop to the three heat load loops: AHU, DHW and slab heating. The AHU heat loop contains a mixture of 40% propylene glycol and water and is plumbed into two AHU fan rooms that supply forced-air heating to the building.[xxvii] The DHW loop preheats incoming fresh water from the municipal water utility for building DHW use. The slab heating loop contains a mixture of 40% propylene glycol and water, and provides heating to the exterior laboratory space, animal habitats, exhibits and sidewalks. The AHU loop is the largest heating load for the building, while the slab heating system only engages during very cold (below 37°F) periods for the health and safety of ASLC animals and personnel.

Construction, Installation, and Commissioning

Preconstruction activities began in summer 2010 with the removal of a water treatment system and a retired salmon research project to make room for the heat pumps, condenser and evaporator loops, and heat exchangers. Existing PVC piping was removed and replaced with steel piping to connect the heat pump to several AHUs located at roof level. Requests for proposals were issued for equipment bids on heat exchangers, closed loop circulation pumps, air separators, expansion tanks, control valves, non-motorized valves, the motor control center, and PVC and steel piping/fittings. In December 2010, the heat pumps were ordered from Trane. Much of the equipment was purchased and delivered in March 2011, the same month the heat pumps were installed and a concrete housekeeping pad for the motor control center was poured. In April, installation began for the piping and other components and by the end of June all mechanical and electrical installations were completed (except the slab heating system) and the existing seawater intake was connected to the evaporator loop.

The heat pumps for the AHU and DHW loads began preliminary operations in July and commissioning began shortly thereafter. In December 2012, the heat pump system was connected to the slab heating system, and full system commissioning was completed. Lingering instrumentation and controls issues (described below) were substantially resolved in February 2013[xxviii], at which time continuous data collection for the purposes of this report began and continued through May 2013.

There were several notable troubleshooting events during installation and commissioning of the system:

- In August 2011, one of the heat pumps was tripped and unable to be reset due to loss of oil in the compressor. This was caused by a controller ramping the pump motor variable frequency drive's (VFD's) down to low , causing the flow switches to show no flow. This caused the heat pump to shut down abruptly before the before oil could to be purged from the refrigerant and returned to the compressor. This required a service call by a Trane technician to manually purge the oil from the refrigerant in order to place the unit back in operation.
- Electronic flow meters were intended to measure the flow rate of the various heat pump loops. The glycol and temperature ranges exceeded the specifications of the flow meters, rendering the meters unreliable. An attempt to recalibrate the flow meters with help from the supplier was unsuccessful. The electronic meters were eventually replaced with mechanical paddle wheel meters on October 26, 2011. When tested in the glycol loop, the paddle wheels showed readings that correlated design flows and pump pressure curves.
- An issue discovered during initial system commissioning was a communication problem with the Smart Server, a ModBus to LonWorks converter. The Smart Server had not been programed before installation in the motor control center. The Smart Server was uninstalled and returned to Eaton, the company that supplied the motor control center. Eaton then contacted the Smart Server supplier, Echelon Corporation, to program it. After the Smart Server was reprogrammed, returned and installed in the motor control center, technicians from Trane Eaton, and Echelon were able to complete the Tracer SC program that operates the controller by spring 2012. Tracer SC training for ASLC staff was completed by the end of April. Additional difficulties remained and were not substantially resolved until February 2013. During the time in which the heat pumps were operating but before the Tracer SC controller programming issues were resolved, it was not possible to collect long-term data. Individual temperature, flow and pressure measurements were taken to verify successful operation of the heat pumps, but automated measurement and storage could not occur.
- There were several instrumentation errors (in particular. erroneous power readings), which resulted in incorrect system COP calculations. These errors were identified in December 2012 and corrected by ASLC and Trane in February 2013.

Economic Evaluation

The Institute of Social and Economic Research, University of Alaska Anchorage and ACEP completed a sensitivity analysis for the ASLC seawater heat pump system in order to review project economics and key cost drivers and calculate net present value (NPV), the benefit-cost ratio and project payback periods.[xxix] The following is a summary of this analysis. Because of delays in commissioning and instrumentation errors, as outlined above, this analysis was completed before performance data was available. The context of system performance in this analysis, based on the three months of monitored performance, can be found in the following section, Performance Evaluation.

Economic Assumptions

The analysis uses different electricity and fuel price projections and various estimates of social costs of carbon (SCC).[xxx] Table 2 is a summary of these economic assumptions. The costs driving the benefit-cost ratio of this 20-year project is calculated using data provided by ASLC. In

Summary of Economic Assumptions		
Full Year of Operation Begins		2013
Project Lifetime		20 Years
Discount Rate for Net Present Value (NPV)		3%
Electricity Price Rate Increment		3%, 4%, and 6%
Fuel Price Projection for Kenai		low, medium and high
Social Cost of Carbon	Low Cost	$5.42
	Medium Cost	$22.78
	High Cost	$37.97
	Very High Cost	$70.52

Table 2. Summary of Economic Assumptions

Net Present Value with SCC (in thousands of dollars)			
Electricity Cost Projection - low	Fuel Oil - low	SCC - low cost	($861)
		SCC - medium cost	($521)
		SCC - high cost	($223)
		SCC - very high cost	$414
	Fuel Oil - medium	SCC - low cost	$957
		SCC - medium cost	$1,297
		SCC - high cost	$1,595
		SCC - very high cost	$2,233
	Fuel Oil - high	SCC - low cost	$2,978
		SCC - medium cost	$3,318
		SCC - high cost	$3,616
		SCC - very high cost	$4,253
Electricity Cost Projection - medium	Fuel Oil - low	SCC - low cost	($1,440)
		SCC - medium cost	($1,100)
		SCC - high cost	($803)
		SCC - very high cost	($165)
	Fuel Oil - medium	SCC - low cost	$378
		SCC - medium cost	$718
		SCC - high cost	$1,016
		SCC - very high cost	$1,653
	Fuel Oil - high	SCC - low cost	$2,399
		SCC - medium cost	$2,739
		SCC - high cost	$3,036
		SCC - very high cost	$3,674
Electricity Cost Projection - high	Fuel Oil - low	SCC - low cost	($2,141)
		SCC - medium cost	($1,801)
		SCC - high cost	($1,503)
		SCC - very high cost	($866)
	Fuel Oil - medium	SCC - low cost	($323)
		SCC - medium cost	$18
		SCC - high cost	$315
		SCC - very high cost	$953
	Fuel Oil - high	SCC - low cost	$1,698
		SCC - medium cost	$2,038
		SCC - high cost	$2,336
		SCC - very high cost	$2,974

Table 3. Net Present value with SCC

order to conduct these analyses, some economic assumptions have been made. For comprehensive information on economic assumptions, please see the document *Assumptions and Addition Information for Economic Evaluation available at the project website.*[xxxi]

Net Present Value without SCC (in thousands of dollars)		
Electricity cost projection – low	Fuel Oil - low projection	($967)
	Fuel Oil - medium projection	$851
	Fuel Oil - high projection	$2,872
Electricity cost projection - medium	Fuel Oil - low projection	($1,547)
	Fuel Oil - medium projection	$272
	Fuel Oil - high projection	$2,292
Electricity cost projection - high	Fuel Oil - low projection	($2,247)
	Fuel Oil - medium projection	($429)
	Fuel Oil - high projection	$1,592

Table 4. Net Present Value without SCC

Based on these assumptions, net present value, benefit-cost ratios and project payback periods have been calculated for the potential levels of displaced fuel and electricity consumption of the new heating system. The new heating system is expected to use 1.35 million kWh of electricity annually and displace approximately 130,000 gallons of fuel oil annually, saving approximately $3.9 million if one assumes the low fuel oil price projection, $5.7 million if one assumes the medium fuel oil price projection or $7.8 million if one assumes the high fuel oil price projection for the project's lifetime.

Fuel displacement of 130,000 gallons would reduce the carbon emission by 1,300 metric ton annually.[xxxii] If one considers SCC, , the added savings for the project's lifetime would be approximately $0.12 million if one assumes the low SCC, $0.45 million if one assumes the medium SCC, $0.74 million if one assumes the high SCC, or $1.4 million if one assumes the higher-than-expected SCC.

Net-Present Value and Sensitivity Analysis

Because the net present value, benefit-cost ratio and payback period of the project depend on different electricity price projections, different fuel oil price projection, and different SCCs, this report shows the sensitivity analysis with three electricity price projections (low, medium, high), three fuel oil price projections (low, medium, high) and five SCCs (none, low, medium, high and higher-than-expected cost). For details on price and cost projects, please see Assumptions for Economic Evaluation at end of report.

Table 3 presents the net present value for different electricity price projections, different fuel oil price projections and different SCCs

Table 4 presents the net present value for different electricity price projections and different fuel oil price projections if one does not consider SCC as an additional benefit to the project

Benefit-Cost Ratio

Through the life of the project, electricity cost becomes an increasingly bigger share of the project costs. For example, when considering the capital cost and first year of operation (initial cost), 78% of the project's cost is capital cost and 18% is electricity cost. The figure below shows the distribution of the initial costs of the project.

However, the distribution of costs changes significantly when all costs over the life of the project are included. Depending on the electricity price projections, the electricity cost is responsible for 76% to 80% of the total project cost whereas capital cost is responsible for only 12% to 14% of the total project cost. Labor and operations and maintenance cost is 1% to 2% of the total project cost and the other cost (i.e., general and administrative expense) is 7% to 8% of the total project cost. Figure 9, Figure 10, Figure 11 and Figure 12 show the total costs over the life of the project based on different electricity price projections.

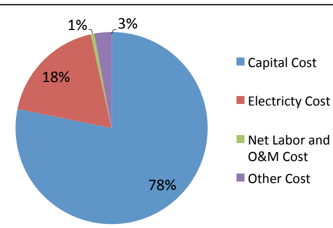

Figure 9. Initial Project Costs by Category

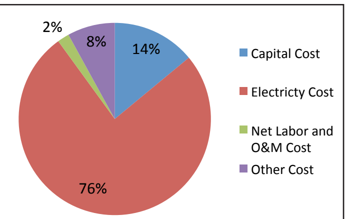

Figure 10. Total Project Costs by Category - Low electricity rate

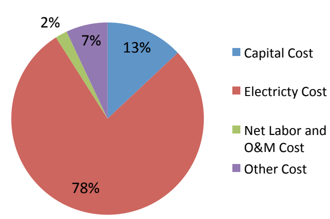

Figure 11. Total Project Costs by Category - Medium electricity rate

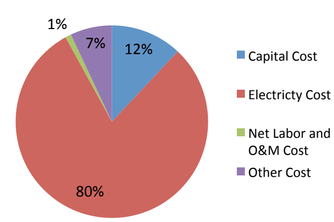

Figure 12. Total Project Costs by Category - High electricity rate

Benefit-Cost Ratios with SCC			
Electricity cost projection - low	Fuel Oil - low projection	SCC - low cost	0.82
		SCC - medium cost	0.89
		SCC - high cost	0.95
		SCC - higher-than-expected cost	1.08
	Fuel Oil - medium projection	SCC - low cost	1.19
		SCC - medium cost	1.26
		SCC - high cost	1.32
		SCC - higher-than-expected cost	1.45
	Fuel Oil - high projection	SCC - low cost	1.61
		SCC - medium cost	1.68
		SCC - high cost	1.74
		SCC - higher-than-expected cost	1.87
Electricity cost projection - medium	Fuel Oil - low projection	SCC - low cost	0.73
		SCC - medium cost	0.80
		SCC - high cost	0.85
		SCC - higher-than-expected cost	0.97
	Fuel Oil - medium projection	SCC - low cost	1.07
		SCC - medium cost	1.13
		SCC - high cost	1.18
		SCC - higher-than-expected cost	1.30
	Fuel Oil - high projection	SCC - low cost	1.44
		SCC - medium cost	1.50
		SCC - high cost	1.55
		SCC - higher-than-expected cost	1.67
Electricity cost projection - high	Fuel Oil - low projection	SCC - low cost	0.65
		SCC - medium cost	0.71
		SCC - high cost	0.75
		SCC - higher-than-expected cost	0.86
	Fuel Oil - medium projection	SCC - low cost	0.95
		SCC - medium cost	1.00
		SCC - high cost	1.05
		SCC - higher-than-expected cost	1.15
	Fuel Oil - high projection	SCC - low cost	1.27
		SCC - medium cost	1.33
		SCC - high cost	1.38
		SCC - higher-than-expected cost	1.48

Table 5. Project Benefit-Cost Ratios with SCC

Since the heat pumps consume electricity to operate the electric compressors, the operational cost of the project increases as the price of electricity increases, inversely affecting the benefit-cost ratios. For the evaluated scenarios, the benefit-cost ratios range from 0.65 to 1.87 depending on the electricity price projection, fuel oil price projection and SCC.

Table 5 shows the benefit-cost ratios for different electricity

Benefit-Cost Ratios without SCC		
Electricity cost projection - low	Fuel Oil - low projection	0.80
	Fuel Oil - medium projection	1.17
	Fuel Oil - high projection	1.58
Electricity cost projection - medium	Fuel Oil - low projection	0.72
	Fuel Oil - medium projection	1.05
	Fuel Oil - high projection	1.42
Electricity cost projection - high	Fuel Oil - low projection	0.63
	Fuel Oil - medium projection	0.93
	Fuel Oil - high projection	1.26

Table 6. Project Benefit-Cost Ratios without SCC

price projections and different fuel oil price projections if one does not consider SCC.

Table 6 presents the benefit-cost ratio for different electricity price projections, different fuel oil price projections and different SCCs.

Project Payback Period

Project payback periods vary depending on the electricity price projections, fuel oil price projections and SCCs. Since the new system uses electricity and displaces fuel oil, high electricity prices increase the payback periods. Conversely, high fuel oil prices and/or high SCCs lower the payback periods.

Figure 13 presents the payback periods for different electricity price projections, fuel oil price projections and SCCs.

Figure 14 presents the payback periods for different electricity price projections and different fuel oil price projections if one does not consider SCCs.

For scenario-specific payback period information for the above figures, please see the document *Assumptions and Addition Information for Economic Evaluation available at the project website*.

Economic Evaluation Findings

The economic viability of this project depends primarily on the price of the electricity, as 76% to 80% of the cost over the life of the project is electricity cost. Currently, the project has the potential of proving cost effective with benefit-cost ratios ranging from 0.65 to 1.87 and payback periods ranging from 3.3 years to longer than the project lifetime, depending on the future electricity price, displaced fuel oil price and SCC emissions. Higher electricity price negatively impacts the cost effectiveness of the project, while higher fuel oil and higher SCCs positively impact the cost effectiveness of the project.

As noted above, this analysis was completed before performance data was available. However, this analysis can serve as a framework for assessing the economic viability of the project once this information is available.

YCE has also completed an economic evaluation of this project as a component of their evaluation for ASLC, included in the proposal to the Denali Commission.[xxiii] According to their analysis, conducted before project construction, the project installation cost would be around $662,000, which is lower than our findings of around $906,000, and the present value of displaced fuel would be around $2,777,000, which is lower than our findings of around $3,913,000 with the low fuel price projection. Their analysis also shows that the payback period for the heating system would be 10.6 years, which is close to our finding of 10.0 years with the low electricity price projection and medium fuel oil price projection.

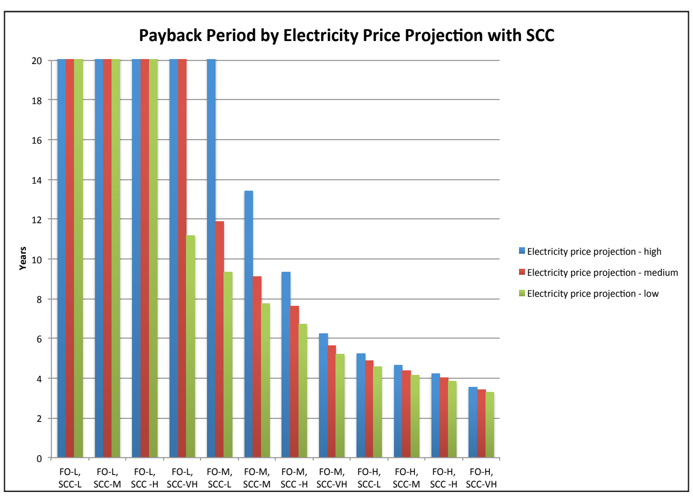

Figure 13. Payback Period by Electricity Price Projection with SCC (FO–Fuel Oil, SCC–Social Cost of Carbon, L–Low, M–Medium, H–High, VH–Very High)

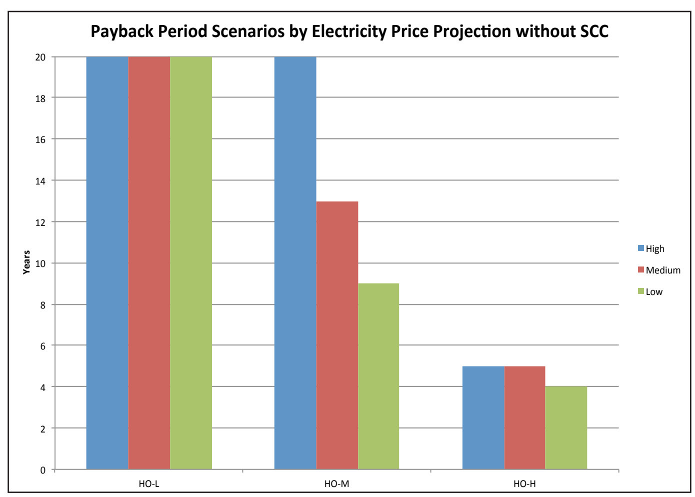

Figure 14. Payback Period Scenarios by Electricity Price Projection without SCC (FO–Fuel Oil, L–Low, M–Medium, H-High)

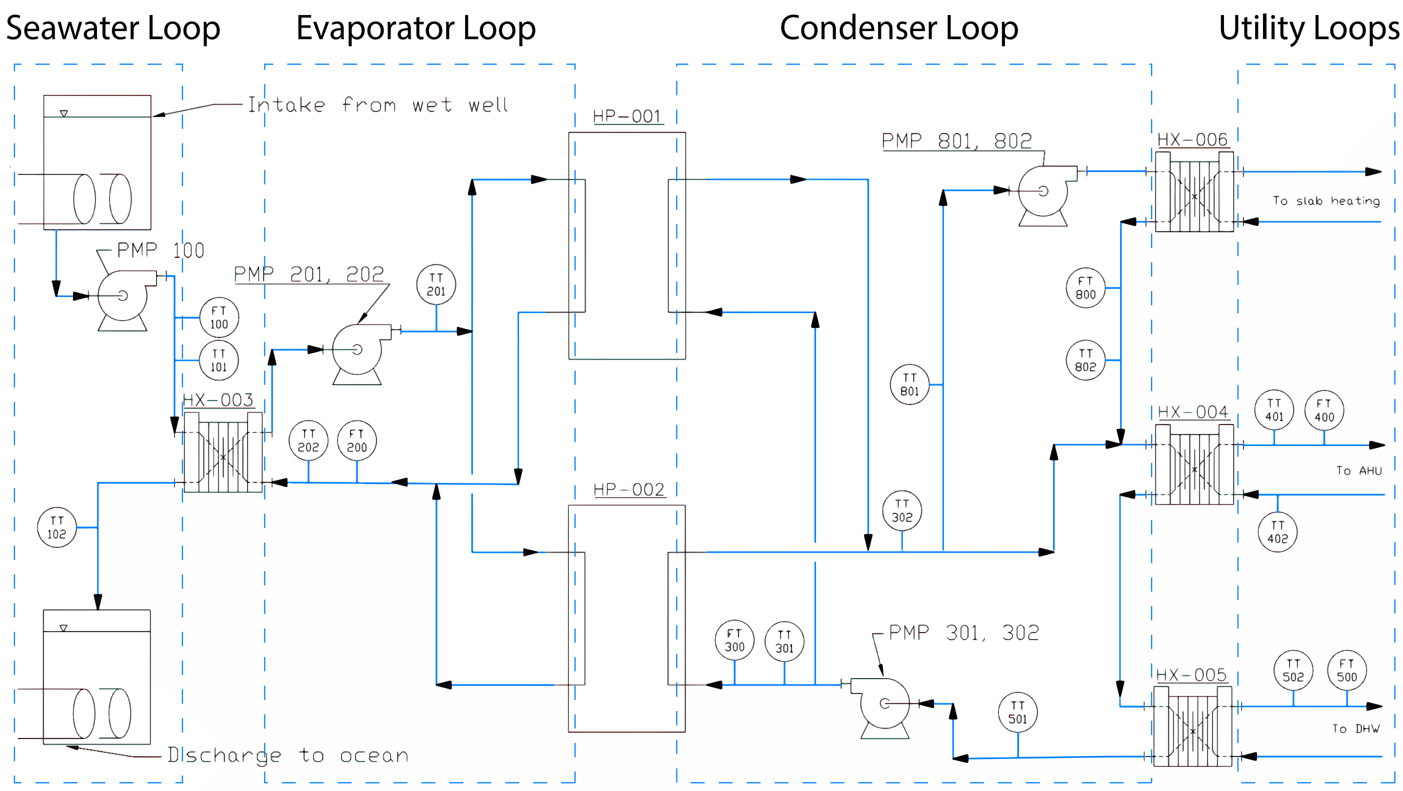

Figure 15. Simplified ASLC Seawater Heat Pump System Piping and Instrumentation Diagram

YEC's economic evaluation is only for the heat pumps and it does not consider the old heating system when calculating the net benefit. The analysis does not include the SCC. Some of the economic assumptions are also different from the economic assumptions of this report. In YEC's economic analysis, fuel price projection is assumed to be 4%, electricity price projection is assumed to be 4% and discount rate is assumed to be 4%.

Performance Evaluation

The seawater heat pump system was monitored for three months, from February 9 through May 9 of 2013.[xxxiv] The original monitoring period was to be for one year; however, commissioning delays and instrumentation errors, as identified above, limited this period. The intent of monitoring was to provide independent review of system performance, specifically system COP. Performance of the heat pump was examined using data collected from the heating and cooling loops. This section discusses how these calculations were performed and reviews some of the key findings.

Of note, three months is insufficient time to make a confident statement about performance; for this type of installation, a minimum of one year of data would be required to adequately assess performance and the relationship of COP to various factors such as seawater temperature. While insufficient, three months' data is still preliminarily informative. In addition, these three months did capture an interesting time frame – winter to spring, when outside air temperatures swing from cold to warm and seawater temperatures are at their lowest.

Instrumentation and Data Points Collected

Flow rates and temperatures were captured at five-minute intervals at the input and output of the different heating and cooling loops:

- Seawater loop
- Evaporator loop
- Condenser loop
- AHU loop
- DHW loop
- Slab heating loop

In addition, outside air temperature and incoming and outgoing seawater temperatures were taken at the same time points, and power consumption was measured at two points; this pro-

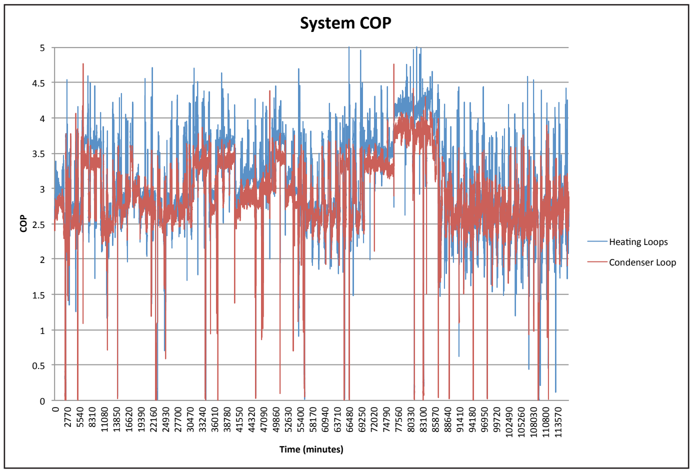

Figure 16. System COP

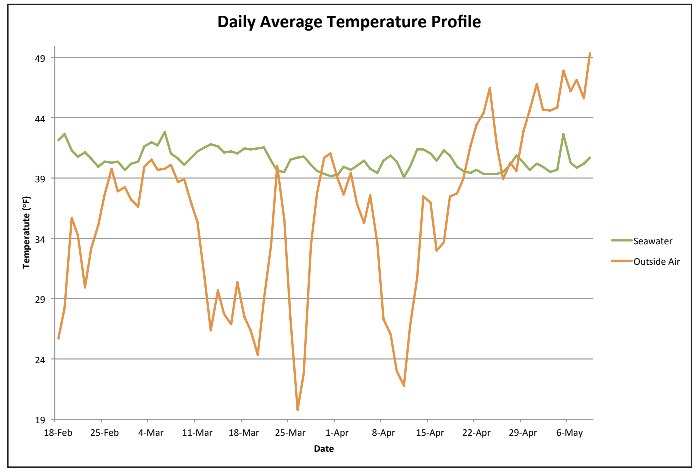

Figure 17. Daily Average Temperature Profiles

vided data for overall power consumption of the entire heat pump system and data for power consumption from the pump that pulls in the seawater. From these data points, performance data could be monitored and a COP could be calculated.

Figure 15 is a simplified piping and instrumentation diagram of the system, with data collection points highlighted.

Calculation of Coefficient of Performance

As introduced above, the COP for a heat pump is defined as the ratio of the thermal energy moved to the desired location to the electrical energy input. In the case of the ASLC seawater heat pump system, it is the ratio of thermal energy input to the heating loops to the electrical power consumed. The COP can be calculated from measurements such as temperature and flow rate from any of three options — the evaporator loop, the condenser loop or the sum of the three heating loops. For this review, the system COP is calculated from the condenser loop, and for comparative purposes, the heating loops.

COP is calculated from the condenser loop as:

$$COP = \frac{E_{gained\ in\ condenser\ loop}}{(electricity\ used)}$$

COP is calculated from the three heating loops as:

$$COP = \frac{E_{space\ heating} + E_{domestic\ hot\ water} + E_{slab\ heat}}{(electricity\ used)}$$

The energy transferred in a heating loop (or condenser loop) is:

$$E_{heating} = C_p \Delta T m$$

Where C_p is the specific heat of the fluid used to move the heat, ΔT is the temperature difference between the hot side and the cold side and m is the mass of the heat transfer fluid. These calculations are for determining performance over time, so units of power (energy per time) are used:

$$E_{heating}/time = C_p \Delta T \times (mass\ flow\ rate)$$

The denominator of the COP calculation is then the electricity used per time, which is a simple conversion from kWh on the meter to Btu per minute.

Coefficient of Performance Results

Figure 16 shows the resulting system COP (including transient data spikes) from calculations for both the condenser and heating loops. This figure indicates that the two resulting COPs are correlated, but not equal. There are several possible reasons for this difference, including the proximity of the condenser loop to the heat pumps within the system (which increases accuracy) and the increased amount of instrumentation on the heating loops (which potentially introduces more margins of error in calculations). For these reasons and others,[xxxv] this analysis uses the COP calculated from the condenser loop.

Of 23,238 data points representing 1,900 hours of system operation,[xxxvi] the average COP was 2.90, with a standard deviation of 0.53.[xxxvii]

The COP should depend on factors from both the heating and cooling sides, the most predominant of which are, respectively, the incoming seawater temperature and the heating load (demand). The temperature profile in Resurrection Bay lags the outside air temperature by about three months, so the correlation between air temperature and seawater temperature is not immediately evident in three months' worth of data. Indeed, one of the premises of the heat pump project was that thermal energy of the seawater would be captured from a warmer season for use during the coldest months of December through February. Figure 17 shows the daily average outside air temperature and the incoming seawater temperature profiles.

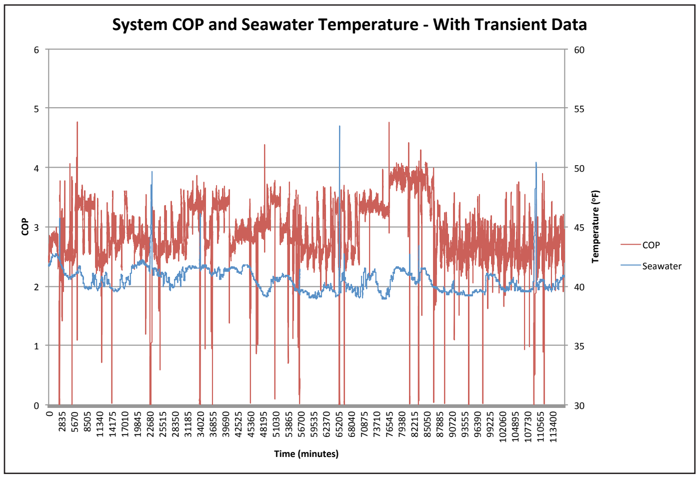

Figure 18. System COP and Seawater Temperature with Transient Data

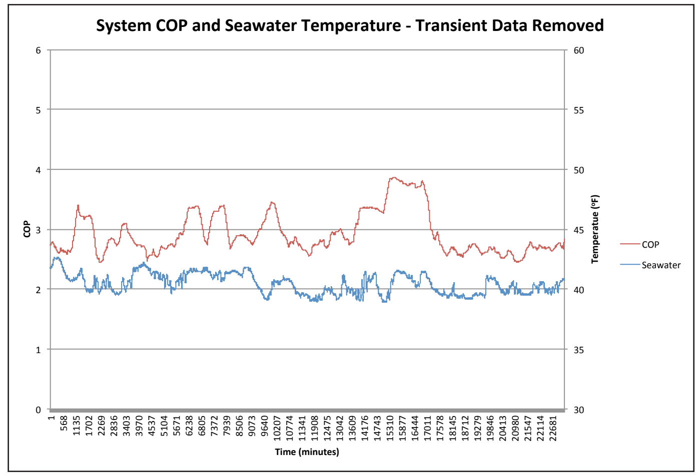

Figure 19. System COP and Seawater Temperature with Transient Data Removed

On the supply side, the COP should have a strong correlation with incoming seawater temperature; a comparison is shown in Figure 18.

Transient spikes were observed, during which incoming seawater temperature rose and COP dropped. These spikes could not be correlated with the power consumption, so their exact cause is unknown. With those spikes removed, and with a moving average of COP taken over 288 points (24 hours), COP alongside intake seawater temperature is as shown in Figure 19. No correlation could be seen between COP and seawater temperature over this short time period.

On the demand side, there are two binary factors that both greatly affect COP. First, there is significant change in heating demand depending on outside air temperature. Slab heating, a significant load when in use, is engaged only when the outside air temperature is below approximately 37 °F. Second, the system can have either one heat pump or two heat pumps engaged, depending on operational strategy and heating demand.[xxxviii] Typically, when demand is low (below approximately 20,000 BTU/min), only one heat pump is used; when the demand is high, the second heat pump powers up. Figure 20 shows the relationships among the outside air temperature, the incoming seawater temperature and the demands of the different heating loops.

During the three-month monitoring period, slab heating made up 26% of the total system energy demand, while the AHU system made up 73% and DHW made up 1%. This profile will shift over the course of a year, presumably toward the historic energy demand profiles found by YCE during evaluation of the original system (see Table 1).[xxxix]

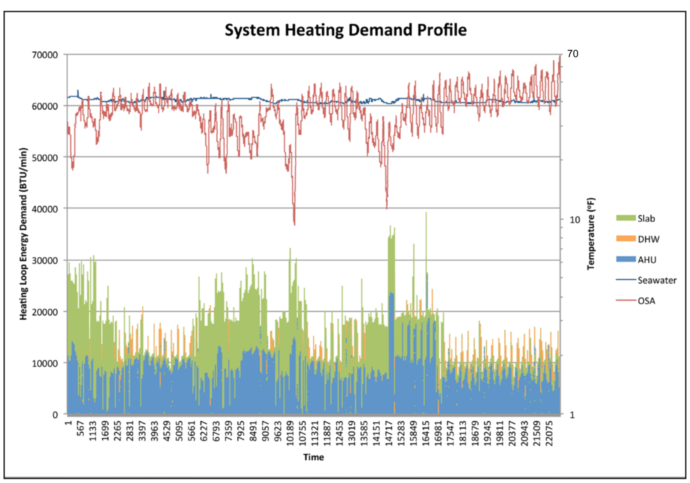

Figure 20. System Heating Demand Profile (Temperature is plotted on a logarithmic axis to highlight low temperature trends.)

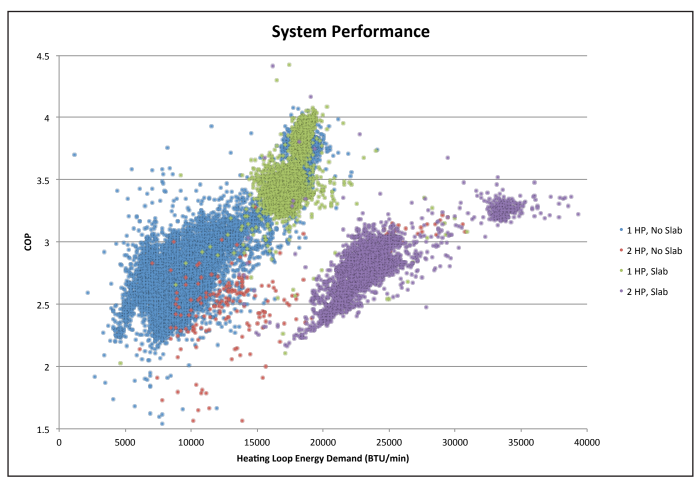

Figure 21. System Performance

As noted above, COP should be strongly correlated to demand in addition to seawater temperature. Figure 21 shows the system COP as a function of energy demand under the two binary scenarios (slab heating on or off and one or two heat pumps engaged, four scenarios total).

There are several notable trends shown in this figure. In general, whether one or two heat pumps are engaged, COP increases as their use increases (e.g., it is more efficient to use the heat pumps when they are fully loaded). However, the rate of increase in COP per increase in use (increased demand) is less when two heat pumps are being used. In addition, there is a significant drop in COP when the system transitions from one fully loaded heat pump to two partially loaded heat pumps.

Figure 22 indicates the operational mode of the system during the three months of monitoring:

Of note, the system was operating with two heat pumps only 38% of the time when slab heating was engaged, or 15% of total time.[xl] Figures 21 and 22 indicate that the system may be well-sized to optimize the use of one heat pump with the second heat pump providing additional heat when the need arises. Adequate analysis of the one or two heat pump scenarios and optimization of system operation, however, require significantly more monitoring data and operational information beyond the scope of this report.[xli]

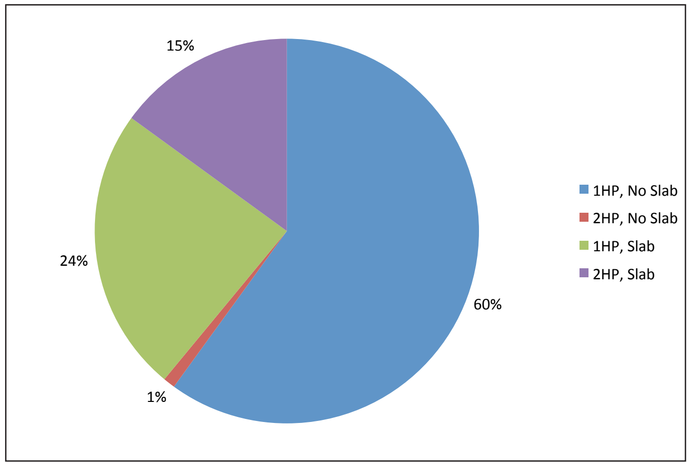

Figure 22. System Operation Modes

Table 7 summarizes the relationship of system COP to key factors as determined by this evaluation.

During the three months of monitoring, the total equivalent amount of heating oil displaced was 20,000 gallons, or approximately 125 gallons per day.[xlii] The electricity consumed was 300,000 kWhrs, or approximately 1,900 kWhrs per day. This represents $75,000 of avoided heating oil purchases (assuming $3.75/gallon) with an electricity cost of $31,500 (assuming $0.105/kWh) for a net savings of $43,500 during the monitoring period.

Parameters	How it's measured	Theoretical Effect	Actual Effect
Outside air temperature	Direct measurement	Higher outside air temperature creates lower energy demand and should decrease COP.	Preliminary indication through effect on slab heating usage; insufficient time period to determine overall effect.
Incoming seawater temperature	Direct measurement	Higher incoming seawater temperature makes more available heat and should increase COP.	Insufficient time period to determine.
Heating loop energy demand	Calculated from summing heating demand in each loop	Higher heating demand should increase COP.	Approximately linear; one line for when 1 heat pump is running; a separate line for when 2 heat pumps are running.
Slab heating	Proxy direct measurement; flow rate of slab heat loop	When slab heating is on, heating demand increases and COP should increase.	Correlation is good, specific to use of one heat pump or two heat pumps.
1 or 2 heat pumps running	Proxy direct measurement; flow rate of evaporator loop	The rate of increase in COP per utilization increase (increased demand), is less when two heat pumps are being utilized.	Correlation is good.

Table 7. Summary of Key Determinants of System COP

Findings

The ASLC successfully met original project objectives, particularly the installation of a seawater heat pump system and supporting infrastructure, controls and instrumentation. The project did experience some delays in commissioning as a result of minor instrumentation and controls issues, which were successfully addressed by February 2013. Over the course of three months of monitoring since that time (1,900 hours of system operation), the average COP was 2.90, displacing a total equivalent of 20,000 gallons of heating oil while consuming 300,000 kWh of electricity. Of note, it was reported by the ASLC that the existing fuel boilers were turned off on December 9, 2012 and have not been used for heating needs since.

Full demonstration of the technology will require a minimum of one year of monitoring data to adequately assess system performance and to inform future project considerations such as heat pump sizing, operation and system performance as a function of seawater temperature. The ASLC currently includes a video describing the project in their exit theater, and has made public presentations regarding the project. The ASLC will need to continue education and information dissemination, including lessons learned and information on system operation and performance, to supplement monitored data and to fulfill the demonstration component of the project.

A preliminary assessment shows that the economic viability of this project depends primarily on the price of electricity since 76% to 80% of the cost over the life of the project is electricity. It is projected that the project can potentially prove cost-effective with benefit-cost ratios ranging from 0.65 to 1.87 and payback periods ranging from 3.3 years to longer than the project lifetime depending on the future price of electricity, the price of displaced fuel oil and social cost of carbon (SCC). Higher electricity price negatively impacts the cost effectiveness of the project, while higher fuel oil and higher SCC positively impact the cost effectiveness of the project. More data monitoring, along with updated electricity and fuel oil pricing information, is needed to refine project viability projections.

Findings for Future Projects

This review indicates that facilities with high fuel oil costs that have access to (relatively) inexpensive electricity and an ocean resource may benefit from a seawater heat pump project. There are many factors, however, to consider.

Fundamental to the viability of a seawater heat pump project is the temperature profile of the ocean resource. In Alaska, one of the primary concerns is the minimum temperature of the seawater. While the monitoring period for this project was not sufficient to assess system performance as a function of seawater temperature, it did include the coldest annual temperatures. The system was able to supply sufficient heat to the ASLC during this period, even during several notable cold outside air events. For future projects, an understanding of the resource — in particular, annual temperature profiles — is critical to project viability and system design and sizing. While investigating the viability of the project, ASLC utilized extensive historical temperature data of incoming seawater from the intake pipes, set at a static depth and location. Depending on future project location, the local seawater temperature profile can be a function of depth, tides or even the presence of rivers or other thermal mixing sources.

A vital component of the technology is the seawater intake system. It is critical to develop a system that manages bio-fouling to ensure proper flow rates over the life of the project. In the case of the ASLC project, a pigging station was installed and modifications were made to the intake line to allow for periodic cleaning of the system. These modifications, while costly, proved effective in removing cumulated bio-fouling and restoring flow rates to original specifications.[xliii] A future project would need to integrate such management of intake bio-fouling into the system design and operations.

The ASLC (and other projects such as the TSMRI and KFRC) had existing seawater intake infrastructure that provided significant reductions to overall project costs and positively influenced overall project economics. Future projects without this existing infrastructure will have to account for its cost, design and implementation

Other seawater intake considerations include placement (avoiding anchors, fishing lines, etc.), resource access (factors such as elevation, distance and piping configuration can affect pumping needs and system COP) and contamination (turbidity, sedimentation, etc.). In the case of the ASLC project, a specialized basket filter was designed and integrated into the seawater supply line, since sedimentation, organic matter and particulates could increase the need for maintenance on the heat exchanger and potentially reduce its operational life. In addition, the ASLC project monitors the turbidity of the incoming seawater, since local river flooding events can lead to high sedimentation levels and turbidity in Resurrection Bay.

The ASLC emphasizes the importance of the availability of servicing and support. Seawater heat pump systems can be fairly complex in terms of controls and operations, especially when integrated into existing mechanical and electrical infrastructure, as was the case with the ASLC project. Thorough commissioning and a strong relationship with the vendor to ensure that issues related to the project are addressed effectively and in a timely manner are critical to a successful project.

If a facility is considering a project such as a retrofit to an existing infrastructure, special consideration must be made regarding system design and integration. Piping lengths and configuration, for instance, can affect pumping requirements and, ultimately, system COP. Seawater intake integration and the management of bio-fouling need particular attention. Existing building controls and instrumentation must be reviewed and assessed for compatibility with the heat pump system. While this report highlights system COP, demand-side energy management is equally critical in reducing overall energy costs. Adequate controls and instrumentation will help a facility optimize not only the heat pump performance but also overall building energy use.

The ASLC has a well-designed and spacious utility area, with (relatively) easy access to the various mechanical, electrical and plumbing systems of the facility. This was a tremendous asset when installing and integrating the new heat pump system, and it should be a key consideration for future retrofit projects. The ASLC also has a dedicated and talented facilities team that used its significant operational experience while developing and installing the system. Because the facilities team provides long-term operation and maintenance of the system, including them in future projects would greatly benefit the practical development of the project and long-term operation of the system.

In addition to assessing demand needs and resource availability, future projects need to carefully consider operational goals and strategy. The performance evaluation of this report indicates that designing around an operational strategy that optimizes loading on the heat pumps plays a critical role in overall system performance. In the case of the ASLC project, two identical 90-ton units were installed, with the need to operate only one unit for a majority of the time. This should increase the overall operational life of the units, since the units can be used interchangeably, and provide system redundancy during periodic maintenance or downtime. Other systems may explore the installation of heat pumps of varying size, to provide a staged approach to maximize system loading and COP.

Findings for Future Research

One area that could benefit from further investigation is the effect on system of seawater temperature colder the 37°F on system COP. The ASLC system has a minimum allowable temperature of 37°F, which is equivalent to the historical minimum of Resurrection Bay since 2003. Over the course of the monitoring period for the project (the coldest period for seawater temperatures in the bay), the minimum temperature reached was 38.9°F. While the system operated successfully at this temperature, deployability of the technology in cooler temperatures, or the scope of suitable resources juxtaposed to suitable project sites, warrants further investigation.

As mentioned above, this project and others in Alaska capitalized on existing seawater intake infrastructure. Presumably, the number of facilities with such existing infrastructure and the opportunity to implement a seawater heat pump system is limited. It is unclear how expensive such intake systems can be, but they could potentially add a significant capital and operational cost to a project. The ASLC system utilizes a wet well and gravity siphon system, which reduces the need for pumping. This system could reduce costs for other projects. YCE has recognized the need to develop a cost-effective intake system and has even applied to such programs as the AEA Emerging Energy Technology Fund for funds to investigate and develop low-cost wet wells. This is an area that needs to be researched further in terms of costs, best practices in current designs, innovations in design, replicability and scalability.

Finally, one promising application for this technology is district heating. Seawater is a utility-grade heat source and, as mentioned previously, has been successfully utilized for district heating in Sweden and Norway. Coastal communities that have access to (relatively) inexpensive electricity, but are dependent on high-cost fossil fuels for heating, and have higher-density commercial, business or residential districts close to a viable ocean resource are likely candidates for this scenario. District heating, however, can be expensive. Potential barriers to implementation include the cost of seawater intake infrastructure and distribution piping and pumping equipment, and the need to retrofit customer heating systems. The City of Seward has expressed interest in this concept since there is a business district in close proximity to the ASLC that may be a potential candidate for a district heating loop. However, the true potential of district heating in Alaska is unknown; economics, public support and interest in the technology, and business models for operating a heat utility all warrant further investigation.

References and Notes

i. For the purpose of this report heating oil, heating fuel, fuel, oil and diesel are used interchangeably.

ii. One ton of cooling (or heating) is defined as 12,000 Btu/h (3.5 kW). A 90-ton heat pump equates, therefore, to 1080 MBH (thousands of Btu per hour). One ton is approximately equivalent to and derived from the cooling capability of 1 ton (2000 lb) of ice.

iii. While ASLC was responsible for installation, maintenance, operation and instrumentation of the systems, ACEP was responsible for performance data analysis as well as independent economic and performance reviews.

iv. This graphic was adapted from the article "Is a heat pump right for you?" by S. Gibson in the 2010 Fine Homebuilding magazine.

v. Iain Staffell, "A Review of Domestic Heat Pump Coefficient of Performance", April 2009. wogone.com/science/review_of_domestic_heat_pump_cop.pdf

vi. Jason Meyer, Dominique Pride, Jonathan O'Toole, Colin Craven and Vanessa Spencer. "Ground-Source Heat Pumps in Cold Climates," Denali Commission, May 2011. www.uaf.edu/files/acep/Ground-Source-Heat-Pumps-in-Cold-Climates.pdf

vii. It is important to note that there is no formal system of categorizing heat pump systems. In particular, there is overlap between WSHP and GSHP categorization. Many systems that utilize a lake or pond as a heat source are known as a GSHP or WSHP, interchangeably. This report uses an informal, working definition of WSHP. Formally, WSHPs use flowing water as a heat source or heat sink and can be in either single pass (open loop) or recirculation (closed loop) configuration.

viii. Due to the quantity of heat needed for a commercial-scale application, a closed-loop system may not be practical because of considerations such as pipe length, increased pumping needs, deployment and maintenance logistics, and placement in a shared marine environment (fishing, boating, and anchoring considerations, etc.).

ix. Vanessa Stevens, Colin Craven and Robbin Garber-Slaght. "Air Source Heat Pumps in Southeast Alaska: A review of literature, a market assessment, and preliminary modeling on residential air source heat pumps in Southeast Alaska," Cold Climate Housing Research Center, April 2013. cchrc.org/docs/reports/ASHP_final.pdf

x. As an example, the University of Alaska Fairbanks utilizes a steam loop for heating needs around campus, sourced from a co-generation coal plant.

xi. For more project information, please visit www.friotherm.com/webautor-data/41/vaertan_e008_uk.pdf.

xii. For more project information, please visit geoheat.oit.edu/bulletin/bull25-3/art3.pdf.

xiii. COP estimation from www2.aiatopten.org/hpb/energy.cfm?ProjectID=1970. For more project information, please visit lmnarchitects.com/assets/work/vancouver_convention_centre_west/pdfs/2011%20VCECE%20Press%20Kit.pdf.

xiv. For more project information, please visit www.cwc.ca/documents/case_studies/Operations_Centre-GulfIslands.pdf.

xv. There is limited instrumentation on the system, so costs and savings are estimated. Information gathered in person during a staff site visit (August 2012) and from the TSMRI page on the NOAA Alaska Fisheries Science Center website: www.afsc.noaa.gov/abl/TSMRI.htm

xvi. "Economic Evaluation of Seawater Chilling System to Provide Chilled Filtered Seawater for Seawater Tank Laboratory for Kodiak Fisheries Research Center." Completed on January 12, 2010 by Andy Baker and Lee Bolling of YourCleanEnergy LLC. Received via email on December 10, 2012 from Bob Tucker, Kodiak Island Borough Maintenance Coordinator.

xvii. Image from www.alaskasealife.org

xviii. Additionally, there are several duct coils and ceiling, wall and tube heaters that disperse heat throughout the building, although these require a significantly smaller demand.

xix. The municipal water enters the building cold, and, to improve efficiency, it is warmed before being fed to the DHW boilers.

xx. Findings from "Economic Evaluation of Sea Water Heat Pumps to Provide Supplemental Heat for Make Up Air Units AHU-5 & AHU-6 and Outdoor Pavement Heating for Alaska SeaLife Center." Completed on March 28, 2009 by Andy Baker and Lee Bolling of YourCleanEnergy LLC. http://energy-alaska.wdfiles.com/local--files/seawater-heat-pump-demonstration-project/Appendix%20A,%20Exhibit%201%20-%20Final%20Seawater%20Heat%20Pump%20Report%20-%20ASLC%20-%20March%2028,%202009.pdf. Of note, the heat pump project provides heat to a majority, but not all, air handling units. AHU #1 represents the units supplied by the heat pump system.

xxi. This data is given by ASLC fiscal year, October 1 – September 30.

xxii. In 2008, 32,560 gallons of fuel were consumed for heating a salmon research project in addition to normal facility needs. The salmon research project commenced on October 1, 2007 and ended on June 3 2008.

xxiii. "Economic Evaluation of Sea Water Heat Pumps to Provide Supplemental Heat for Make Up Air Units AHU-5 & AHU-6 and Outdoor Pavement Heating for Alaska SeaLife Center." Completed on March 28, 2009 by Andy Baker and Lee Bolling of YourCleanEnergy LLC. energy-alaska.wdfiles.com/local--files/seawater-heat-pump-demonstration-project/Appendix%20A,%20Exhibit%201%20-%20Final%20Seawa-

ter%20Heat%20Pump%20Report%20-%20ASLC%20-%20March%2028,%202009.pdf

xxiv. The actual intake rate was impeded due to bio-fouling. Alternate funding was found to clean one of the pipes through the installation of a pigging system (a large cylinder called a pig was forced through the pipe and dislodged much of the blockage) and retrofit of the intake pipe opening. This activity would eventually need to be pursued by ASLC due to the gradual decline in flow rate, but was realized under this project.

xxv. Assuming the system was rehabilitated, as described above.

xxvi. Image from "Economic Evaluation of Sea Water Heat Pumps to Provide Supplemental Heat for Make Up Air Units AHU-5 & AHU-6 and Outdoor Pavement Heating for Alaska SeaLife Center." Completed on March 28, 2009 by Andy Baker and Lee Bolling of YourCleanEnergy LLC. *energy-alaska.wdfiles.com/local--files/seawater-heat-pump-demonstration-project/Appendix%20A,%20Exhibit%201%20-%20Final%20Seawater%20Heat%20Pump%20Report%20-%20ASLC%20-%20March%2028,%202009.pdf*

xxvii. As noted above, the heat pump system provides heat to a majority of the air handling units, but not all.

xxviii. Additional controls and instrumentations fixes were made by Trane in June 2013.

xxix. Sohrab Pathan and Alejandra Villalobos Meléndez of Institute of Social and Economic Research, University of Alaska Anchorage and Alaska Center for Energy and Power, University of Alaska Fairbanks. Any findings and conclusions of this paper are those of the authors. For any further inquiry please contact Sohrab Pathan, *ahpathan@uaa.alaska.edu.*

xxx. Social cost of carbon (SCC) is an attempt to monetize the value of the damages caused by the CO_2 emissions in the environment. Heating oil emits CO_2 in the environment when it is used to generate heat. If the alternative energy source (e.g., heat pump) is used to generate heat, then CO_2 emission will go down, which will be beneficial for the environment; SCC estimates the monetary value of that added benefit for the reduced CO_2.

xxxi. *http://energy-alaska.wikidot.com/emerging-energy-technology-grant*

xxxii. According to U.S. Energy Information Administration, the CO_2 emission factor or coefficient is 73.15 kg CO2/MMBtu. U.S. Energy Information Administration. January 31, 2011. Voluntary reporting of greenhouse gases program: fuel emission coefficients . Retrieved from *www.eia.gov/oiaf/1605/coefficients.html*

xxxiii. Page 3, "Economic Evaluation of Sea Water Heat Pumps to Provide Supplemental Heat for Make Up Air Units AHU-5 & AHU-6 and Outdoor Pavement Heating for Alaska Sea-Life Center." Completed on March 28, 2009 by Andy Baker and Lee Bolling of YourCleanEnergy LLC. *energy-alaska.wdfiles.com/local--files/seawater-heat-pump-demonstration-project/Appendix%20A,%20Exhibit%201%20-%20Final%20Seawater%20Heat%20Pump%20Report%20-%20ASLC%20-%20March%2028,%202009.pdf*

xxxiv. Issues with data precluded the calculation of results from February 9 through February 18.

xxxv. It was observed that the flow rate sensor in the AHU loop maxed out at 252 gallons per minute, resulting in "clipped" data (flow rates above this were simply recorded as 252).

xxxvi. Issues with data precluded the calculation of results from February 9 through February 18.

xxxvii. Standard deviation is a measure of variation in a sample; for a normal distribution, about 70% of data points are within one standard deviation of the mean (between 2.37 and 3.42), and about 95% of data points are within two standard deviations (between 1.84 and 3.95).

xxxviii. Additionally, each heat pump has two stages that can be deployed as needed. The impact of this operational scenario was not explored by this report but is a factor in optimizing system operation and COP.

xxxix. Specific to the heating demand supplied by the heat pump system, the historic percentages are 70.6% for AHU, 21.6% for slab heating, and 7.8% for DHW.

xl. Of note, this result was substantially influenced by mild winter weather with below-average snowfall during the monitoring period.

xli. ASLC has plans to connect additional slab heating loads from its four animal habitat observation decks as well as connect other heating demands in the summer months so the heat pumps can be more fully loaded in winter and summer months.

xlii. Assumes that heating oil contains 138,700 Btu per gallon and that the oil would have been used by a comparative fuel oil boiler at 87% efficiency.

xliii. During the original installation of intakes for the ASLC, it was believed that the deep depth and low seawater temperatures would prohibit bio-fouling.

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Alaska Center for Energy and Power

UAF University of Alaska Fairbanks