Alaska Energy Engineering LLC

25200 Amalga Harbor Road Tel/Fax: 907.789.1226
Juneau, Alaska 99801 alaskaenergy@earthlink.net

TECHNICAL MEMORANDUM

December 2007

to: **Dave Palmer, Airport Manager**
Catherine Fritz, Airport Architect

subject: **Ground Source Heat Pump Feasibility Study: Life Cycle Cost Analysis**

project: **JNU Terminal Renovation and Expansion**

INTRODUCTION

This report presents a life cycle cost analysis of a ground source heat pump (GSHP) system for the JNU Terminal. A GSHP system represents a significant change from the traditional heating, ventilating, and air-conditioning (HVAC) system that has been proposed for the JNU Terminal building. The intent of this report is to compare the life cycle cost of the two systems.

The terminal expansion and renovation will happen over several phases, including the complete replacement of the older commuter terminal. Since a timeframe and exact scope is presently unknown, the analysis has been simplified by assuming that renovation of the entire terminal building will be performed in 2009 in one project. It is believed that this approach will not significantly alter the findings.

The life cycle cost comparison presented in this analysis represents total life cycle costs over 25-years. The analysis assumptions that all construction costs occur in Year 0 and all maintenance and energy costs occur equally over 25-years presents valid cost comparison of the systems. Since the renovation will actually occur over two or more phases of construction, actual construction, maintenance, and energy costs are likely to be different than present in this report.

DESCRIPTION OF HVAC SYSTEMS

Proposed HVAC Scheme

The HVAC scheme that has been proposed for the JNU Terminal consists of variable air volume ventilation systems and a fuel-oil heating system using hydronic boilers. Domestic hot water is generated by indirect hot water tanks heated by the hydronic boiler system.

This scheme is similar to the existing terminal HVAC systems with the following features that providing greater energy efficiency:

- The proposed heating plant has three smaller boilers which can better match the heating load, improving seasonal efficiency. The existing plant has two large boilers.

- The proposed ventilation system uses a variable air volume system with supply air temperature reset control to reduce the energy required to reheat the supply air at each zone. The existing systems are constant air volume with no reset control.
- The proposed ventilating system uses a demand control ventilation (DCV) strategy to reduce ventilation air when the building occupancy is less than design. The highly variable occupancy of the building allows the DCV strategy to reduce the ventilation air by an average of over 50%, yet maintain adequate indoor air quality.

Ground Source Heat Pump Scheme

Ground source heat pump systems exchange heat with the ground to heat and cooling the building. The GSHP scheme has an array of closed-loop vertical well field connected to water-to-air heat pumps distributed throughout the terminal.

The vertical well field will require 215 wells, each 175' deep. The wells will be spaced 10' apart and each will contain a 3/4" HDPE pipe loop. The analysis assumes two well fields located within 200' of the terminal building. The well field was sized based on an industry standard of 300 feet of well per ton of heating load.

Water circulating through the well field gains heat from the ground. The heat pumps remove this heat from the water and, using a compressor/condenser cycle, distribute it via warm air to the rooms. The system will also provide cooling by rejecting heat to the ground, but for our heating-dominant climate this report will focus on heating operation.

Ventilation air is supplied by a dedicated outdoor air system (DOAS). The DOAS is a central heat recovery system that transfers heat from exhaust air to preheat ventilation air that is supplied to each heat pump. A DCV scheme is used to vary the amount of outside air delivered to each heat pump with building occupancy.

Domestic hot water is generated by domestic hot water heat pumps (DHWHPs) that are also coupled to the ground loop. The DHWHPs produce hot water which is stored in tanks.

<u>Other Ground Coupling Options</u>

The analysis is based on a closed-loop vertical well field ground couple that has been successfully used by AEL&P in their office building. It is a dependable, proven scheme that will work well for the terminal. Other ground coupling opportunities also exist at the site but were not pursued. These are:

- Open-loop Method (Pump and Dump): This method extracts heat from ground water and reinjects it into the ground or discharges it to surface flows. The site is likely to have sufficient ground water and obtaining a water right should not be a problem. It is used extensively in other regions because it has lower construction costs, which are partially offset by higher maintenance and pumping costs than a closed-loop system.
- Submerged Closed Loop System: This method would use the float plane pond as a ground couple for the system. Pipe loops would be placed in the pond to extract heat. There is an opportunity to integrate the loop installation with the pond dredging project that will occur in near future.

While both of these methods are likely to have lower construction costs, they are not recommended because they bring higher risks to the project. The open-loop method has operational concerns with ground water quality and low ground water temperatures. The submerged system has concerns about whether to pond size is adequately sized given that our heating dominated climate. Other concerns include designing the pipe loops so they can be routinely cleaned of algae and other vegetative growth while maintaining flight operations.

HVAC Scheme Comparison

System	Proposed Scheme	GSHP Scheme
Ventilation System	Variable air volume air handling units (AHU)	Dedicated outdoor air system supplying each heat pump
Heating and Cooling	Fuel-oil fired boilers hydronic heating units	Water-to-air heat pumps (61); Closed loop vertical well field
	Electric chiller supplying AHU cooling coils	
Snowmelt System	Hydronic heat via boilers	Water-to-water heat pump
Domestic Hot Water System	Indirect HW tanks heated by the boilers	Domestic hot water heat pumps and HW storage tanks

ENERGY ANALYSIS

Energy Costs

Fuel Oil

Fuel oil currently costs the CBJ over $3.00 per gallon. On average, fuel oil prices have risen 31% per year for the past 2-years, 16% per year over the past 5-years, and 6.3% per year for the last 15-years. The analysis assumes fuel oil costs will inflate at 5% per year for the next 25 years, which is lower than recent history. This represents a deliberate decision to underestimate fuel oil inflation, lending conservatism to the analysis. The cost of fuel oil is predicted to be today’s cost of $3.00 per gallon inflated at 5% per year to $3.31 per gallon in 2009.

Electricity

The terminal is billed under Alaska Electric Light & Power (AEL&P) Schedule 25 – Large Commercial. It is assumed that a rate increase will not occur prior to 2009.

Electricity inflation has historically been under 1% per year but it is expected to be higher in the future as the community uses up its hydroelectric surplus and buys more expensive power from new hydroelectric sources and/or supplements with diesel power. The rising cost of fuel oil will also increase electric heating loads, placing more demand on the electric generation system. The analysis assumes these factors will cause electricity inflation to triple to an average of 3% per year over the next 25-years.

Economic and Energy Factors

Factor	Rate or Cost	Factor	Rate or Cost
Nominal Discount Rate	5.5%	Electricity Rate	Current AEL&P rates
General Inflation Rate	2.8%	Electricity Inflation	3.0%
Real Discount Rate	2.6%	Fuel Oil Cost (2009)	$3.31/gal
		Fuel Oil Inflation	5.0%

Findings

The GSHP scheme has considerably lower energy costs than the proposed scheme. As shown in the following table, heating costs are the largest difference.

Annual Energy Cost Comparison

Component	Proposed Scheme	GSHP Scheme
Heating	$135,000	$37,400
Fans	10,200	13,000
Pumps	2,300	9,000
Cooling	2,100	5,500
Total Cost	**$150,000**	**$64,900**

Heating costs are the primary difference between the two systems. This result has been carefully scrutinized, as the difference is remarkable. There following factors contribute the most to the findings:

- The GSHP scheme is much more efficient at converting purchased energy into heat. While the fuel oil boilers are 69% efficient at converting fuel oil to heat, the heat pumps are 260% efficient at converting electricity to heat. The 260% efficiency occurs because for each purchased BTU, the system extracts 1.6 BTUs from the ground and delivers 2.6 BTUs to the building.
- The GSHP scheme benefits from using a lower cost energy source. Fuel oil at $3.31 per gallon and a conversion efficiency of 69% costs 11.8¢ per kWh of delivered heat. Currently, the terminal is paying an effective electricity cost—combined energy and demand charges—of 6.7¢ per kWh. A GSHP system will cause an increase in the effective cost of electricity—due to higher demand charges—to 7.9¢ per kWh. This cost is 33% lower than the cost of fuel oil heat at 11.8¢ per kWh.
- The GSHP scheme is systemically more efficient than the proposed scheme. The proposed scheme is essentially a central cooling system that must reheat the air supplied to zones that do not require cooling. This reheat energy penalty is larger in our heating-dominated climate than in warmer climates. The distributed heat pump scheme adds heating and cooling as needed at each zone and does not have a reheat penalty.
- With the GSHP scheme, it is much easier to reduce ventilation air and turnoff the HVAC in areas that are unoccupied, such as offices during nights and weekends.

The following factors contribute to the other energy cost components:

- Fan Energy: The fan energy is about the same for both systems. The proposed fans are more efficient but they move air longer distances, resulting in nearly equal energy costs.
- Pumping Energy: The GSHP scheme has much higher pumping costs because more water flows through the well field. This cost partially offsets the energy cost savings.
- The proposed scheme is more efficient at cooling because it is capable of naturally cooling using outside air. The GSHP system must mechanically cool.

LIFE CYCLE COST ANALYSIS

The life cycle cost analysis determined that a GSHP system has the lowest life cycle cost. The proposed fuel oil system will cost $8,950K and the GSHP system $7,880K over 25-years. The following table shows the life cycle cost comparison.

Life Cycle Cost Comparison, $K

Heating System	Proposed System	GSHP System
Construction Cost	$5,230K	$6,050K
Maintenance Cost	270K	640K
Energy Cost	3,450K	1,190K
Total Cost	**$8,950K**	**$7,880K**

Discussion

The life cycle cost comparison of the two systems reveals that the GSHP system has a life cycle cost savings of $1.1M or 12%. The GSHP system has higher construction and maintenance costs, but these costs are more than offset by considerably lower energy costs. The following points are relevant to the findings.

Construction Costs

GSHP schemes typically require a larger upfront investment. The analysis has confirmed that this is the case for the JNU Terminal.

- The cost of coupling to the ground is highly dependent upon an experienced contractor willing to come to Juneau and install the well field. A Seattle-based company provided a preliminary estimate for the analysis. Their estimate was increased 33% to account for Alaska cost factors, working within an operating airport tarmac, and variations in subsurface conditions.
- Three separate ground loops are included in the costs for redundancy.
- A test well has been drilled at the airport site and indicates that the site is highly suited for a vertical well field.
- The heat pumps will be located above ceilings. This has a positive effect on construction costs as it reduces mechanical space and the length of duct runs for each zone. The heat pumps will generate noise above the ceilings. Locating them in non-sensitive areas can mitigate this issue.

- It is common in cold climates to supply heat along the building perimeter to improve occupant comfort. Since much of the terminal has a transient occupancy that is dressed for the weather, this is less of a concern. Modern buildings also have greatly improved thermal envelopes which also reduce the need for perimeter heat. If perimeter heat is desired in the office areas, the GSHP system can accommodate this need by supplying heating air along the perimeter during cold weather.
- GSHPs are supplied with standalone PLC controllers and do not require interface with a building automation system. However, it is desirable to have central control and monitoring of the HVAC systems. The analysis assumes a similar computer-based DDC monitoring and control interface for each system.

Maintenance Costs

A distributed HVAC scheme, such as the GSHP system, has more terminal components and moving parts located above ceilings. This increased number of moving parts coupled with their location above ceilings in occupied areas, increases maintenance efforts and costs. The analysis assumes airport maintenance staff will obtain the expertise to maintain and repair both systems without contracting for specialized technicians.

Energy Costs

Contributing to the annual energy cost difference of the two systems is that fuel oil is projected to inflate at 5% per year and electricity at 3% per year.

The energy analysis model is incapable of simulating the real-world variations in electric demand that are likely to occur with an electrically heated building. To account for this likely increase in electricity costs, building demand costs are increased by 50% in recognition that demand surges are likely.

RECOMMENDATION

While a GSHP scheme represents a notable departure from the existing HVAC scheme in the building, it is a viable, dependable system for heating, ventilating, and air-conditioning the JNU Terminal. The life cycle cost comparison shows the GSHP scheme has a much lower life cycle cost.

GSHP schemes have also been considered for the Juneau Police Station (1996) and Juneau's Thunder Mountain High School (2001). In those cases, the GSHP scheme did not have the lowest life cycle cost, primarily because the analysis was based on much lower projections of fuel oil prices and inflation. If actual fuel oil inflation was used, the findings are likely to have been different.

For the JNU Terminal, fuel oil prices would have to be $2.20 per gallon in 2009 (instead of a cost of $3.31 per gallon that is used in the analysis)—with all other assumptions being equal—for both systems to have an equal life cycle cost. The high fuel oil inflation of the past 5 years has provided the financial incentive to invest in GSHP technology.

It is recommended that a GSHP scheme be used for the HVAC systems at the JNU Terminal. The following factors contribute to this recommendation:

- The site offers several options for coupling to the ground, including sufficient space for a vertical well field and favorable soil conditions.
- The GSHP scheme is more suited to reducing ventilation air when the building occupancy is below design levels (most of the time).

- The building operates 24/7, which offers the GSHP scheme the greatest opportunity to recoup the initial investment through annual energy savings.
- The system is capable of transferring heat from high heat gain areas to other areas where heating is needed. Since the population moves through the building in groups as planes arrive and depart, the system can more efficiently deal with the variations in load.
- The system allows for unoccupied spaces—offices, community meeting room, customs—to be turned off when not in use.

GSHP Scheme Design

The primary goal of any HVAC scheme is to provide adequate indoor air quality and maintain occupant comfort. For the GSHP scheme to achieve these goals at the lowest life cycle cost, it is recommended that the following issues be considered during design and construction of the system:

- Noise Mitigation: The heat pumps will generate fan and compressor noise above ceiling. The design should reduce noise concerns by located the units in non-noise sensitive areas or mechanical rooms and using materials that absorb sound.
- Maintenance Access: The heat pumps must be installed with adequate clearance for maintenance and eventual replacement of the unit.
- Perimeter Heat: In areas where perimeter heat is deemed necessary, heat pumps can be used to continuously supply warm air along the perimeter during cold weather. Another more expensive option is to use a water-to-water heat pump to provide perimeter hydronic heat.
- Hybrid System: A hybrid system uses a boiler (electric is preferred over fuel oil) to supply supplemental heat during cold weather. This allows the well field to be downsized, saving significantly on construction costs. Typically, the well field is sized for 70% of the design heating load, which is usually sufficient for heating the building when lights and equipment are operating.
- Water-side Economizers: GSHPs can be supplied with a water-side economizer feature which allows cooling with the ground source water rather than by using the compressor. This option is applicable to this site since ground water temperatures are likely to be cool enough during summer air-conditioning periods.
- Heat Pumps with Variable Speed Compressors: Variable speed compressors allow the heat pump to deliver air with less temperature swings than compressors that cycle on and off. This will improve the thermal comfort in areas such as offices where occupants are more sensitive to temperature variations.
- Heat Pump DOAS System: A variable speed heat pump can be used for the DOAS so that ventilation air is always supplying at the same temperature as the building. This will decrease temperature swings as heat pumps cycle on and off.

Conclusion

A GSHP scheme offers the financial incentive to move away from traditional fuel oil-based HVAC systems to a system that extracts heat from the environment and obtains most of its purchased energy from cleaner hydroelectric resources. As such, the GSHP scheme offers the JNU Terminal a lower cost HVAC system that is also more sustainable.

by: ....

Jim Rehfeldt, P.E.

Alaska Energy Engineering LLC

25200 Amalga Harbor Road Tel/Fax: 907.789.1226
Juneau, Alaska 99801 alaskaenergy@earthlink.net

Life Cycle Cost Analysis

December 14, 2007

JNU Terminal Renovation and Expansion

Alternative #1: Proposed HVAC Scheme

Basis

25	Study Period (years)	2.8%	General Inflation
5.5%	Nominal Discount Rate	5.0%	Fuel Inflation
2.6%	Real Discount Rate	3.0%	Electricity Inflation

Construction Costs	Year	Qty	Unit	Base Cost	Year 0 Cost
Commercial Terminal					
Demolition					
Per Schematic Cost Estimate	0	1	job	40,000.00	40,000
Fuel Oil System					
5,000 gallon buried tank complete with piping, monitoring		1	ea	42,750.00	42,750
50 gallon day tank, piping, connections	0	1	ea	8,225.00	8,225
Penthouse Mechanical Room					
Per Schematic Cost Estimate	0	1,820	sqft	320.00	582,400
Heating Plant					
Boilers - 750 MBH ea with controllers and chimneys	0	3	ea	21,000.00	63,000
Primary Loop - pumps, boiler header	0	3	ea	7,200.00	21,600
Secondary Loop - ex. tank, separator, pumps, piping	0	1	job	20,000.00	20,000
Snowmelt System					
Heat exchanger	0	1	ea	3,900.00	3,900
Boiler side piping	0	1	lot	10,000.00	10,000
Domestic Hot Water System					
300 gallon indirect HW heater, hw pump, piping, etc.	0	1	lot	12,225.00	12,225
Hydronic Heating System					
Unit heaters	0	7	ea	1,250.00	8,750
Terminal box reheat coil and valves	0	18	ea	745.00	13,410
Reheat coils	0	12	ea	660.00	7,920
Finned tube baseboards, valves, controls	0	362	lnft	59.00	21,358
Baseboard enclosure	0	480	lnft	21.00	10,080
Insulated hydronic piping (3/4" to 3"), supports, seismic	0	2,440	lnft	42.00	102,480
Ventilation					
AHU-1: 30,000 CFM supply fan, 23,000 CFM return fan, VFD s	0	30,000	cfm	5.25	157,500
3,000 CFM boiler room combustion air fan	0	3,000	cfm	5.50	16,500
2,500 CFM main exhaust fan	0	2,500	cfm	2.50	6,250
100 CFM janitor closet and small toilet exhaust fans	0	4	ea	415.00	1,660
VAV boxes	0	30	ea	675.00	20,250
Grilles and diffusers	0	184	ea	137.00	25,208
Sheetmetal ductwork, insulation, lining, hangers	0	18,550	lbs	8.75	162,313
Sound attenuators	0	1	lot	10,000.00	10,000
Outside air louver and damper	0	100	sqft	57.00	5,700
Miscellaneous dampers, etc.	0	1	lot	4,000.00	4,000
Cooling					
50 ton roof mounted chiller and circ pump	0	1	ea	65,820.00	65,820
Chilled water insulated piping (2" to 3/4"), glycol	0	800	lnft	36.50	29,200

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Juneau, Alaska 99801 alaskaenergy@earthlink.net

Life Cycle Cost Analysis

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JNU Terminal Renovation and Expansion

Alternative #1: Proposed HVAC Scheme

Construction Costs	Year	Qty	Unit	Base Cost	Year 0 Cost
Controls					
New DDC system	0	200	pts	1,625.00	325,000
Start up					
Test, balance and commission	0	325	hrs	150.00	48,750
Electrical					
3-phase circuits: pumps, ahu, rf	0	9	ea	2,500	22,500
1-phase circuits: boilers, fans	0	7	ea	1,500	10,500
Commuter Terminal					
Mechanical Room					
Fan Room	0	750	sqft	320.00	240,000
Hydronic Heating System					
Unit heaters	0	3	ea	1,250.00	3,750
Terminal box reheat coil and valves	0	12	ea	745.00	8,940
Reheat coils	0	8	ea	660.00	5,280
Finned tube baseboards, valves, controls	0	400	lnft	59.00	23,600
Baseboard enclosure	0	500	lnft	21.00	10,500
Insulated hydronic piping (3/4" to 3"), supports, seismic	0	3,400	lnft	42.00	142,800
Ventilation					
AHU-2: 20,000 CFM supply fan, 17,000 CFM return fan, VFD s	0	20,000	cfm	5.50	110,000
SF-1 Kitchen Makeup: 4,600 CFM	0	4,600	cfm	6.00	27,600
Kitchen hood exhaust fan	0	4,600	cfm	1.00	4,600
2,500 CFM main exhaust fan	0	2,500	cfm	2.50	6,250
100 CFM janitor closet and small toilet exhaust fans	0	2	ea	415.00	830
VAV boxes	0	20	ea	675.00	13,500
Grilles and diffusers	0	125	ea	137.00	17,125
Sheetmetal ductwork and hangers	0	23,000	lbs	8.75	201,250
Sound attenuators	0	1	lot	8,000.00	8,000
Outside air louver and damper	0	80	sqft	57.00	4,560
Miscellaneous dampers, etc.	0	1	lot	4,000.00	4,000
Cooling					
30 ton roof mounted chiller and circ pump	0	1	ea	52,000.00	52,000
Chilled water insulated piping (2" to 3/4"), glycol	0	800	lnft	36.50	29,200
Controls					
DDC system	0	100	pts	1,625.00	162,500
Start up					
Test, balance and commission	0	200	hrs	150.00	30,000
Electrical					
3-phase circuits: pumps, ahu, rf	0	5	ea	2,500	12,500
1-phase circuits: fans	0	2	ea	1,500	3,000
CONTINGENCIES					
Premium time	0	1,300	hrs	65.00	84,500
Subcontractors OH&P	0			15%	462,830
General Contractor OH&P	0			34%	1,206,444
Estimating contingency	0			10%	475,481
				Total Construction Costs	$5,230,000

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Life Cycle Cost Analysis

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JNU Terminal Renovation and Expansion

Alternative #1: Proposed HVAC Scheme

Annual Costs	Years	Qty	Unit	Base Cost	Present Value
Replacement Costs					
Pipe mounted pumps: one $1600 pump every eight years	1 - 25	1	ea	200.00	3,538
Base mounted pumps	12 - 12	2	ea	2,500.00	3,568
Indirect HW heaters	12 - 12	1	ea	8,000.00	5,709
Maintenance Costs					
Boiler maintenance: 3 @ 40hrs/ea	1 - 25	60	hrs	50.00	53,064
Pump maintenance: 5 @ 8 hrs/ea	1 - 25	40	hrs	50.00	35,376
Hot water tank maintenance	1 - 25	6	hrs	50.00	5,306
Hydronic system maintenance	1 - 25	30	hrs	50.00	26,532
Miscellaneous parts	1 - 25	1	lot	2,000.00	35,376
AHU maintenance (2 @ 10 hrs ea)	1 - 25	20	hrs	50.00	17,688
Chiller	1 - 25	10	hrs	100.00	17,688
Exhaust fans	1 - 25	4	hrs	50.00	3,538
DDC system	1 - 25	1	job	3,000.00	53,064
Fuel monitoring calibration	1 - 25	4	hrs	100.00	7,075
				Total Annual Costs	$268,000

Energy Costs	Years	Qty	Unit	Base Cost	Present Value
Fuel Oil	1 - 25	40,825	gals	3.31	3,176,412
Electricity	1 - 25	212,000	kWh	0.0697	274,416
				Total Energy Costs	$3,451,000

Present Worth	$8,949,000

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Life Cycle Cost Analysis

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JNU Terminal Renovation and Expansion

Closed Loop Ground Source Heat Pump System

Basis

25	Study Period (years)	2.8%	General Inflation
5.5%	Nominal Discount Rate	5.0%	Fuel Inflation
2.6%	Real Discount Rate	3.0%	Electricity Inflation

Construction Costs	Year	Qty	Unit	Base Cost	Year 0 Cost
SITE WORK					
Demolition					
Remove paving	0	25,600	sqft	0.75	19,200
Closed loop vertical well field					
Vertical ground exchange wells					
Mob/Demob to/from barge lines	0	2	RT	4,000.00	8,000
Shipping	0	1	LOT	10,000.00	10,000
Drill rig transportation and down time	0	10	days	5,000.00	50,000
Per Diem; 3 people, 60 days	0	180	days	175.00	31,500
Drill cased hole, install 3/4" HDPE loop, remove casing, backfill	0	37,505	lnft	20.00	750,100
Grout plug between aquifers	0	215	holes	100.00	21,500
Exterior piping					
Excavate and backfill trench and wells	0	870	cuyd	11.00	9,570
Install 4" HDPE, SDR 11 mains in trench	0	2,520	lnft	15.00	37,800
Install 2-1/2" HDPE, SDR 11 in trench	0	360	lnft	12.00	4,320
Install 2" HDPE, SDR 11 in trench	0	720	lnft	10.00	7,200
Install 1-1/2" HDPE, SDR 11 in trench	0	720	lnft	7.60	5,472
Install 3/4" HDPE, SDR 11 in trench	0	4,500	lnft	6.10	27,450
Connect supply and return to well	0	216	ea	125.00	27,000
Sub base and leveling course	0	630	cuyd	30.00	18,900
Paving	0	25,600	sqft	5.00	128,000
COMMERCIAL TERMINAL					
Demolition					
Per Schematic Cost Estimate	0	1	job	40,000.00	40,000
Additional hydronic heating system demo	0	1	job	20,000.00	20,000
Additional duct system demo	0	1	job	40,000.00	40,000
Additional domestic hot water system demo	0	1	job	5,000.00	5,000
Penthouse Mechanical Room					
Mech space for DOAS, water-to-water HPs, DHWHP	0	800	sqft	320.00	256,000
Hydronic Ground Source System					
Source manifold					
6" HDPE SDR 11 manifold	0	40	lnft	55.70	2,228
4" HDPE SDR 11 ground loop piping	0	50	lnft	37.20	1,860
Manifold valves, gauges, appurtenances	0	1	ea	3,500.00	3,500
Source pumps, 225 gpm @ 150' head, 15 HP, VFD	0	3	ea	6,500.00	19,500
Expansion tank, separator, glycol mixing tank	0	1	job	6,000.00	6,000
Insulated hydronic HDPE piping (3/4" to 6"), supports, seismic	0	1,800	lnft	25.00	45,000
Snowmelt System					
120 MBH water-to-water heat pump	0	1	ea	20,000.00	20,000
Source side					
3" HDPE WWHP piping	0	60	lnft	37.20	2,232
Manifold piping, valves and gauges	0	1	ea	2,750.00	2,750

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JNU Terminal Renovation and Expansion

Closed Loop Ground Source Heat Pump System

Construction Costs	Year	Qty	Unit	Base Cost	Year 0 Cost
Domestic Hot Water System					
120 MBH water-to-water heat pump	0	2	ea	20,000.00	40,000
Source side					
3" HDPE WWHP piping	0	90	lnft	37.20	3,348
Manifold piping, valves and gauges	0	2	ea	2,750.00	5,500
300 gallon HW tank	0	2	lot	7,500.00	15,000
Ventilation					
Dedicated Outdoor Air Systems					
DOAS-1: 7,000 CFM HP with HRU, VFD s	0	7,000	cfm	4.00	28,000
DOAS ductwork to each HP	0	12,000	lbs	8.75	105,000
Outside air louver and damper	0	50	sqft	57.00	2,850
Miscellaneous dampers, etc.	0	1	lot	2,000.00	2,000
100 CFM janitor closet and small toilet exhaust fans	0	4	ea	415.00	1,660
Water-to-air heat pump, 0.5 ton, ductwork, loop and elect conn.	0	2	ea	5,000.00	10,000
Water-to-air heat pump, 1 ton, ductwork, loop and elect conn.	0	6	ea	5,500.00	33,000
Water-to-air heat pump, 1.5 ton, ductwork, loop and elect conn.	0	5	ea	6,000.00	30,000
Water-to-air heat pump, 2 ton, ductwork, loop and elect conn.	0	1	ea	6,500.00	6,500
Water-to-air heat pump, 2.5 ton, ductwork, loop and elect conn.	0	11	ea	7,000.00	77,000
Water-to-air heat pump, 3 ton, ductwork, loop and elect conn.	0	2	ea	7,500.00	15,000
Water-to-air heat pump, 5 ton, ductwork, loop and elect conn.	0	2	ea	9,000.00	18,000
Grilles and diffusers	0	184	ea	137.00	25,208
Controls					
Heat pump DDC interface (29 HP @ 8 pts ea)	0	232	pts	1,100.00	255,200
Ground loop pumps, DOAS, EF, etc.	0	25	pts	1,625.00	40,625
Start up					
Test, balance and commission	0	500	hrs	150.00	75,000
Electrical					
Additional electrical panels and feeds	0	2	ea	18,000	36,000
3-phase circuits: HP and DOAS	0	18	ea	2,500	45,000
1-phase circuits: boilers, fans	0	13	ea	1,500	19,500
COMMUTER TERMINAL	0				
Mechanical Room					
For DOAS, DHWHP	0	400	sqft	320.00	128,000
Hydronic Ground Source System					
Insulated hydronic HDPE piping (3/4" to 6"), supports, seismic	0	2,500	lnft	25.00	62,500
Ventilation					
Dedicated Outdoor Air Systems					
DOAS-2: 3,000 CFM HP with HRU, VFD s	0	3,000	cfm	4.00	12,000
DOAS ductwork to each HP		8,000	lbs	8.75	70,000
100 CFM janitor closet and small toilet exhaust fans	0	4	ea	415.00	1,660
Water-to-air heat pump, 1 ton, ductwork, loop and elect conn.	0	20	ea	5,500.00	110,000
Water-to-air heat pump, 1.5 ton, ductwork, loop and elect conn.	0	2	ea	6,000.00	12,000
Water-to-air heat pump, 2 ton, ductwork, loop and elect conn.	0	1	ea	6,500.00	6,500
Water-to-air heat pump, 2.5 ton, ductwork, loop and elect conn.	0	3	ea	7,000.00	21,000
Water-to-air heat pump, 3 ton, ductwork, loop and elect conn.	0	3	ea	7,500.00	22,500
Water-to-air heat pump, 6 ton, ductwork, loop and elect conn.	0	1	ea	10,000.00	10,000
Water-to-air heat pump, 12.5 ton, ductwork, loop and elect conn.	0	2	ea	15,000.00	30,000
Grilles and diffusers	0	184	ea	137.00	25,208

Alaska Energy Engineering LLC
25200 Amalga Harbor Road Tel/Fax: 907-789-1226
Juneau, Alaska 99801 alaskaenergy@earthlink.net

Life Cycle Cost Analysis

December 14, 2007

JNU Terminal Renovation and Expansion

Closed Loop Ground Source Heat Pump System

Construction Costs	Year	Qty	Unit	Base Cost	Year 0 Cost
Outside air louver and damper	0	40	sqft	57.00	2,280
Miscellaneous dampers, etc.	0	1	lot	2,000.00	2,000
Controls					
Heat pump DDC interface (32 HP @ 8 pts ea)	0	256	pts	1,100.00	281,600
Ground loop pumps, DOAS, EF, etc.	0	18	pts	1,625.00	29,250
Start up					
Test, balance and commission	0	250	hrs	150.00	37,500
Electrical					
Additional electrical panels and feeds	0	2	ea	18,000	36,000
3-phase circuits: HP and DOAS	0	12	ea	2,500	30,000
1-phase circuits: boilers, fans	0	22	ea	1,500	33,000
CONTINGENCIES					
Premium time	0	1,500	hrs	65.00	97,500
Subcontractors OH&P	0			15%	535,496
General Contractor OH&P	0			34%	1,395,859
Estimating contingency	0			10%	550,133
				Total Construction Costs	$6,051,000

Annual Costs	Years	Qty	Unit	Base Cost	Present Value
Replacement Costs					
Test, balance and commission	0	2	ea	7,000.00	14,000
Water-to-air heat pump	1 - 25	3.0	ea	1,500.00	79,597
DHWHP	15 - 15	2	ea	20,000.00	26,404
Ground loop pumps	12 - 12	2	ea	6,500.00	9,276
Maintenance and Repair Costs					
Water-to-air heat pump (61 @ 6 hrs ea)	1 - 25	366	hrs	55.00	356,063
Water-to-water heat pumps (3 @ 2 hrs ea)	1 - 25	6	hrs	55.00	5,837
DOAS HRU (2 @ 10 hrs ea)	1 - 25	20	hrs	55.00	19,457
Ground loop system: pumps, glycol, gages	1 - 25	10	hrs	55.00	9,728
DDC system	1 - 25	1	job	2,000.00	35,376
Miscellaneous parts	1 - 25	1	lot	5,000.00	88,441
				Total Annual Costs	$644,000

Energy Costs	Years	Qty	Unit	Base Cost	Present Value
Fuel Oil	1 - 25		gal	3.31	0
Electricity	1 - 25	656,000	kWh	0.070	852,791
Increased demand charges (50% greater than prediction)	1 - 25	1,650	kW	11.00	337,068
				Total Energy Costs	$1,190,000

Present Worth	$7,885,000