FINAL REPORT
LIFE-CYCLE COST STUDY OF A GEOTHERMAL HEAT PUMP SYSTEM BIA OFFICE BLDG., WINNEBAGO, NE

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DISCLAIMER STATEMENT

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EXECUTIVE SUMMARY

The Geo-Heat Center conducted a life-cycle cost analysis for various heating, ventilating, and air-conditioning (HVAC) systems for the proposed new office building on the Winnebago Reservation in northeastern Nebraska. Three HVAC systems were considered: (1) rooftop units with gas heat and direct expansion (DX) cooling (air-cooled condensers), (2) air-source heat pumps, and (3) geothermal heat pumps (GHPs). This work has been funded and completed under Midwest Research Institute, National Renewable Energy Laboratory (NREL) Task Order No. KLDJ-5-55052-01, "*Feasibility Studies and Life-Cycle Cost Analysis*", Task 2: Winnebago Life Cycle Cost Analysis.

The heating and cooling loads were estimated by using building energy simulation software. The peak cooling load is estimated at 264,000 Btu/hr (22 tons), and the peak heating load is estimated at about 178,000 Btu/hr. The annual energy demand of the building is 246 kBtu for heating and 479 kBtu for cooling.

To compare alternatives, the net present value (NPV) of 30-year life-cycle cost was computed for each alternative, as shown in the table below. The GHP system was found to have the lowest net present value of life-cycle cost, approximately 18% lower than the conventional alternatives, which have very similar life-cycle costs to each other. The GHP system, although more expensive to install, has considerably lower operating and maintenance costs than conventional alternatives.

HVAC System	Capital Cost	Annual Costs		Periodic Costs	Net Present Value of 30-yr Life-Cycle Cost
		Energy	Maint.		
1. Rooftop units w. gas heat & DX cooling	$114,610	$8,226	$4,476	$40,000 Year 17	**$299,020**
2. Air-source heat pumps	$139,824	$6,803	$4,069	$50,000 Year 17	**$301,922**
3. Geothermal heat pumps	$160,600	$3,852	$1,899	$30,000 Year 20	**$245,634**

In terms of simple annual cash flows, the GHP system has a simple payback period of 6.6 years and 4.1 years with respect to System 1 and System 2. Neglecting annual maintenance cost and only considering energy savings, the simple payback period is 10.5 years and 7.0 years for Systems 1 and 2, respectively.

A sensitivity analysis on the GHP cost items has shown that for all three HVAC systems to have a similar NPV of life-cycle cost, the capital cost for the GHP system assumed here would have to be about 30% greater, and the simulated energy costs would have to be doubled.

A greenhouse gas analysis was also conducted, and has shown that use of a GHP system can reduce annual greenhouse gas emissions by 15 tons of CO_2 equivalent over the use of rooftop units with gas heat, and by 33 tons of CO_2 equivalent over the use of air source heat pumps.

INTRODUCTION

This work has been funded and completed under Midwest Research Institute, National Renewable Energy Laboratory (NREL) Task Order No. KLDJ-5-55052-01, "*Feasibility Studies and Life-Cycle Cost Analysis*", Task 2: Winnebago Life Cycle Cost Analysis.

The motivation for conducting this project originated from interest by the Bureau of Indian Affairs (BIA) to increase the use of geothermal heat pumps (GHPs) in buildings on Tribal Lands. A new office building on the Winnebago Reservation in northeastern Nebraska is being planned, and a GHP system is under consideration for potential showcasing of GHP technology.

OBJECTIVE AND SCOPE

The objective of this project is to estimate the life-cycle cost of a geothermal heat pump (GHP) system for the proposed office building on the Winnebago Reservation in Nebraska, and compare it to the life-cycle costs of conventional heating, ventilating, and air-conditioning (HVAC) systems.

METHOD OF STUDY

The methods and approach conducted by the Geo-Heat Center to accomplish the project objectives are summarized as follows:
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- Obtained preliminary floor plans from the project architect, J.F. Griffith,

- Developed a computer model of the building using eQuest (J.J. Hirsch, 2005) graphical user interface,

- Computed peak hourly and annual heating and cooling loads of the building using the DOE-2 simulation engine (York and Cappiello, 1981),

- Simulated annual performance and energy consumption for two conventional HVAC systems using the DOE-2 building simulation software. The conventional HVAC systems chosen for comparison to the GHP system were:
    - Roof -top units with gas heat and direct expansion (DX) cooling (air-cooled condensers), *and*
    - Air-source heat pump units

  These conventional system selections were made for two main reasons. First, as suggested by the architect, and after review of the floor plans, the space allotted for HVAC equipment is minimal, making the choice of a boiler/chiller system impractical. Second, all-air roof-top units are generally the lowest capital cost HVAC systems.

- Simulated geothermal heat pump energy consumption and determined earth loop size using GLHEPro, Version 3 (Spitler, 2004), with the building loads computed by the DOE-2 program,

- Conducted a present worth analysis of life-cycle costs to compare alternatives, along with an associated sensitivity analysis of cost assumptions,

- Conducted a greenhouse gas analysis to estimate the possible reduction in greenhouse gas emissions by using geothermal heat pumps. This analysis was done using RetScreen software (NRC, 2005).

HEATING AND COOLING LOADS ANALYSIS

A two-story office building with a total floor area of 14,632 ft^2 (7,316 ft^2 each floor) was modeled with the eQuest/DOE-2 software using weather data for Sioux City, Iowa. Occupancy schedules for people, lighting, and equipment usage for a typical office building were assumed.

The peak cooling load for the building is estimated from the DOE-2 software at 264,000 Btu/hr (22 tons) and the peak heating load is estimated at 178,000 Btu/hr. The monthly heating and cooling energy demands are shown graphically in Figure 1. The annual energy demand of the building is 245,800 Btu for heating and 478,800 Btu for cooling.

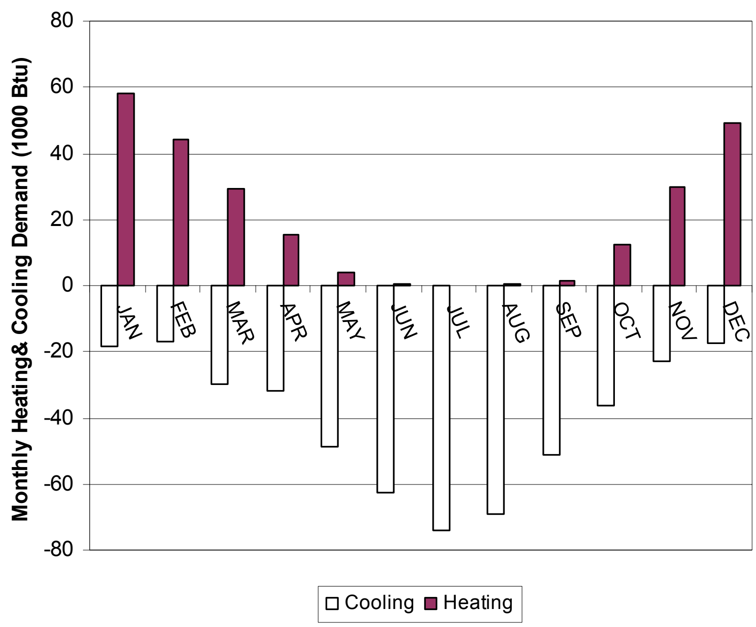

Figure 1*. Monthly heating and cooling energy demands for the proposed Winnebago Office Building.*

ANNUAL ENERGY CONSUMPTION AND COST OF THE HVAC SYSTEMS

From the DOE-2 simulation software, the annual energy consumption for the conventional HVAC systems is:

- System 1, rooftop units w. gas heat and DX cooling:
  - Heating Energy: 3,504 therms
  - Cooling Energy: 30,737 kWh
  - Fans: 17,662 kWh

- System 2, air-source heat pump units:
  - Heating Energy: 27,718 kWh
  - Supplemental Electric Heating: 34,644 kWh
  - Cooling Energy: 30,418 kWh
  - Fans: 17,662 kWh

From GLHEPro software, the annual energy consumption for the GHP system is:

- System 3, geothermal heat pumps:
  - Heat pumps, fans, pumping energy: 48,293 kWh

Utility rate schedules were obtained from utility companies that would serve the prospective building in order to estimate annual energy costs. The electric utility would be Nebraska Public Power District (NPPD), and the natural gas utility would be Aquila.

Commercial electric rates from NPPD used in this cost analysis included an $18.50 monthly customer charge plus winter and summer energy charges. In winter, these charges are $0.0756/kWh for the first 1,000 kWh per month, $0.0562/kWh for the next 2,000 kWh, and $0.0502/kWh for all additional use. In summer, the energy charges are $0.0972/kWh for the first 1,000 kWh per month, and $0.0775 for all additional use. Summer rates apply from June 1 through September 30.

Natural gas rates from Aquila have been quite variable over the past year (2005), ranging from $0.912/therm to $1.433/therm. As of January 2006, the rate is $1.251/therm. For this cost analysis, a natural gas rate of $1.20/therm was assumed. Aquila also has a monthly customer charge of $15, in addition to a monthly regulatory assessment fee, which is currently $0.09.

From the above, the annual energy costs of the three HVAC systems are estimated at:

- System 1, rooftop units w. gas heat and DX cooling: **$8,226**
- System 2, rooftop air-source heat pump units: **$6,803**
- System 3, geothermal heat pumps: **$3,852**

GREENHOUSE GAS ANALYSIS

Greenhouse gas emissions have been attributed to various negative impacts on air quality and global weather patterns. As a result, carbon emissions have become regulated in some locations throughout the world. Heating and cooling of buildings is responsible for greenhouse gas emissions through the use of electricity generated by fossil-fuel fired power plants, and by combustion of fossil-fuels directly for heat.

RetScreen software (NRC, 2005) was used to estimate the reduction (if any) in greenhouse gas emissions through the use of a GHP system at the Winnebago Office Building. The greenhouse gases considered included carbon dioxide (CO_2), methane (CH_4), and nitrous oxides (N_2O). Carbon emission factors from various electrical power generating methods, along with emission factors from natural gas combustion for heating are used in the software. For the Nebraska Public Power District, the electrical energy generation mix is reported on their website as: 61.16% coal, 24.48% nuclear, 10.81% purchases, 2.65% hydro, 0.88% oil/gas, and 0.02% wind (www.nppd.com/our_community/environmental). For this greenhouse gas analysis, the *purchases* were assumed to be divided proportionally amongst the other groups.

The reduction in greenhouse gas emissions is estimated at 15 tons of equivalent CO_2 per year in using a GHP system over rooftop units with natural gas heat and DX cooling, and 33 tons of equivalent CO_2 per year in using a GHP system over air-source heat pumps. Note that more greenhouse gas emissions are offset by avoiding air source heat pumps, due to the large amount of supplemental electric heat required in winter, and the fact that the majority of electricity supplied by the utility is generated by coal-fired power plants.

LIFE-CYCLE COST ANALYSIS

A net present value approach was chosen for comparing the HVAC system alternatives. Life-cycle costs that were considered included capital costs (or initial costs), annual costs (which include operating and maintenance costs), and periodic costs (such as replacement costs). As there is some obvious uncertainty in predicting these costs, a sensitivity analysis was conducted to quantify the effect of various cost items on the net present value.

Capital Costs

The capital costs for the conventional HVAC were taken from construction cost data compiled by R.S. Means (2006) for office buildings. For System 1 (rooftop units with natural gas heat and DX cooling), the installation cost is $7.85/sq. ft of floor space, and for System 2 (air source heat pumps) the installation cost is $9.58/sq. ft of floor space. For the proposed Winnebago Office Building, this translates into an installation cost $114,610 for System 1 and $139,868 for System 2.

The capital cost of a GHP system was taken from a study done by ASHRAE (1998). Documented installation costs of GHP systems at that time were found to range from $2.67/sq. ft to $16.35/sq. ft, with an average cost of $9.32/sq. ft. Assuming 2% annual inflation, today's average cost of GHP installation would be $10.91/sq. ft. For this cost analysis, $11.00/sq. ft installation cost was assumed for the GHP system, for a total installation cost of $160,600.

Annual Costs

The annual costs of the HVAC systems considered included energy costs and maintenance costs. Annual energy costs have been described above. Annual maintenance costs were taken from a study by Bloomquist (2001). These were $0.31/sq. ft for System 1 (rooftop units with natural gas heat and DX cooling), $0.28/sq. ft for System 2 (air source heat pumps), and $0.13/sq. ft for System 3 (geothermal heat pumps). Other studies (for example Martin et al., 1999) have also identified GHP systems to be the lowest maintenance cost HVAC system.

Periodic Costs

The periodic costs of the HVAC systems considered included replacement costs. Rooftop units and outdoor HVAC equipment have typical expected lifetimes of 15 to 20 years. For this cost analysis, it was assumed that the rooftop units of System 1 would need replacing after 17 years of operation at an estimated cost of $40,000 (R.S. Means, 2006). Outdoor air-source heat pump equipment associated with System 2 would also need replacing after 17 years at a cost of $50,000. It was also assumed that the geothermal heat pump compressors would need replacement after 20 years at an estimated cost of $30,000.

Net Present Value Comparison of Alternatives

For the net present value comparison, the following economic assumptions were made:

- Annual energy cost escalation rate = 2%
- Annual maintenance cost escalation rate = 2%
- Discount rate = 8%
- Project life = 30 years

The results of the life-cycle cost analysis are shown in Table 1.

TABLE 1.
NET PRESENT VALUE OF LIFE-CYCLE COST COMPARISONS FOR THE VARIOUS HVAC SYSTEM ALTERNATIVES

HVAC System	Capital Cost	Annual Costs		Periodic Costs		Net Present Value of 30-yr Life-Cycle Cost
		Energy	Maint.			
1. Rooftop units w. gas heat & DX cooling	$114,610	$8,226	$4,476	$40,000	Year 17	**$299,020**
2. Air-source heat pumps	$139,824	$6,803	$4,069	$50,000	Year 17	**$301,922**
3. Geothermal heat pumps	$160,600	$3,852	$1,899	$30,000	Year 20	**$245,634**

A review of the results presented in Table 1 shows that the GHP system has the lowest net present value of life-cycle cost, approximately 18% lower than the conventional alternatives, which have very similar life-cycle costs to each other. The GHP system, although more expensive to install, has considerably lower operating and maintenance costs than conventional alternatives. Air-source heat pumps are more expensive to install than rooftop units with gas heat, and their energy savings is not great enough to have a significantly lower present value. This is mainly due to the large amount of supplemental heat required with air-source heat pumps during the winter months in the project location.

In terms of simple annual cash flows, the GHP system has a simple payback period of 6.6 years and 4.1 years with respect to System 1 and System 2, respectively. Neglecting annual maintenance cost and only considering energy savings, the simple payback period is 10.5 years and 7.0 years for Systems 1 and 2, respectively.

Sensitivity Analysis

In order to quantify uncertainty in the GHP system cost estimates, a sensitivity analysis was conducted. The capital costs, annual costs, and periodic costs of the GHP system were varied from -30% to +30% of the base case (where the base case costs are those described above). The results of the sensitivity analysis are shown in Figure 2.

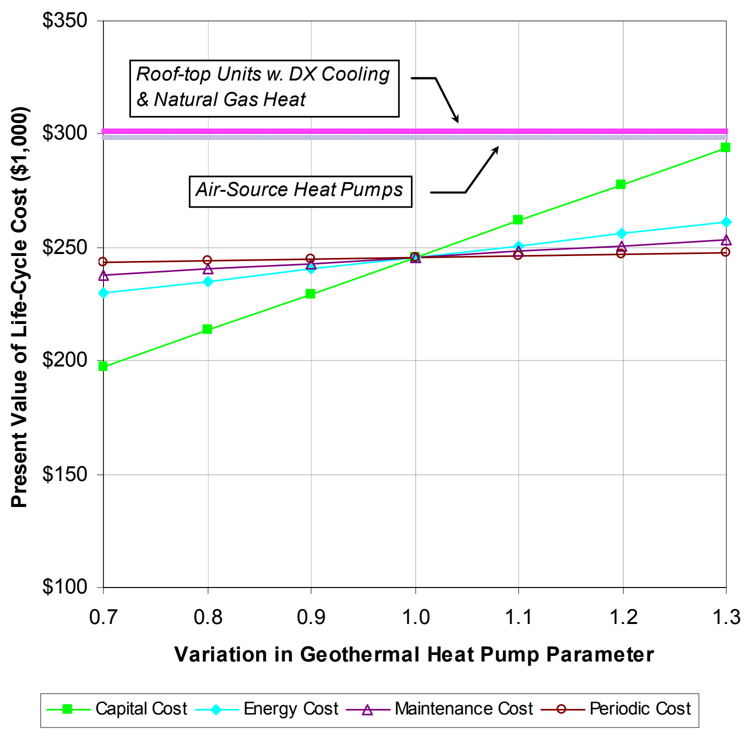

***Figure 2**. Sensitivity analysis of GHP cost items on the GHP system net present value of 30-year life cycle cost.*

A review of the graphs shown in Figure 2 reveals that the most sensitive cost item of the GHP system is the capital cost, followed by the energy cost, maintenance cost, and then the periodic costs. The capital cost of the GHP system would need to increase by 30% above the base case assumptions in order for its NPV of life-cycle cost to approach that of the conventional alternatives. A 30% increase in annual energy cost of the GHP system increases its NPV of life-cycle cost by only about 6.5%. Annual energy costs of the GHP system would have to double from the simulated results in order to approach the NPV of the conventional HVAC systems. Variations on the periodic cost have little effect on the NPV of life-cycle cost of the GHP system.

SUMMARY AND CONCLUSIONS

The Geo-Heat Center conducted a life-cycle cost analysis for various HVAC systems for the proposed new office building on the Winnebago Reservation in Nebraska. Three HVAC systems were considered: (1) rooftop units with gas heat and direct expansion (DX) cooling (air-cooled condensers), (2) air-source heat pumps, and (3) geothermal heat pumps (GHPs).

The GHP system is the most expensive to install, but the least expensive to operate and maintain. Rooftop units with gas heat and DX cooling are the least expensive to install, but the most expensive to operate and maintain. Air-source heat pumps have higher installation costs than gas roof top units, but do not save considerably in annual operating costs, mostly due to the significant amount of supplemental electric required in winter months.

A net present value (NPV) approach was used to compare alternatives. Net present values were computed for the 30-year life-cycle cost of each HVAC system. The GHP system was found to have the lowest NPV of life-cycle cost at $245,634, followed by rooftop units with gas heat at $299,020, and then by air-source heat pumps at $301,922. The latter two systems are quite similar in life-cycle cost, and the GHP system has an NPV of life-cycle cost about 18% lower than these conventional HVAC systems.

A sensitivity analysis on the GHP cost items has shown that for all HVAC systems to have a similar NPV of life-cycle cost, the capital cost for the GHP system assumed here would have to be about 30% greater, and the simulated energy costs would have to be doubled.

A greenhouse gas analysis has shown that use of a GHP system can reduce annual greenhouse gas emissions by 15 tons of CO_2 equivalent over the use of rooftop units with gas heat, and by 33 tons of CO_2 equivalent over the use of air source heat pumps. More greenhouse gas emissions are offset by avoiding air-source heat pumps than natural gas heat due to the large amount of supplemental electric heat required in winter with air-source heat pumps.

REFERENCES

ASHRAE, 1998. *Operating Experiences with Commercial Ground-Source Heat Pump Systems*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA.

Bloomquist, R.G., 2001. The Economics of Geothermal Heat Pump Systems for Commercial and Institutional Buildings, *Proceedings of the International Course on Geothermal Heat Pumps*, Bad Urach, Germany, September 2001.

Hirsch, J.J., 2005. *eQUEST Energy Simulation Tool*.

Martin, M.A., Durfee, D.J., and Hughes, P.J., 1999. Comparing Maintenance Costs of Geothermal Heat Pump Systems with Other HVAC Systems in Lincoln, NE Public Schools: Repair, Service, and Corrective Actions. *ASHRAE Transactions,* Vol. 105, No. 2.

Natural Resources Canada (NRC), 2005. Retscreen International, Clean Energy Project Analysis Software.

R.S. Means, 2006. *Assemblies Cost Data*, 31st Annual Edition.

Spitler, J.D., 2004. *GLHEPro Version 3.0, Ground Loop Heat Exchanger Design Software*, School of Mechanical and Aerospace Engineering, Oklahoma State University. Distributed by the International Ground Source Heat Pump Association (IGSHPA).

York, D.A. and Cappiello, C.C., 1981. *DOE-2 Engineers Manual (Version 2.1A)*, Lawrence Berkeley Laboratory and Los Alamos National Laboratory.