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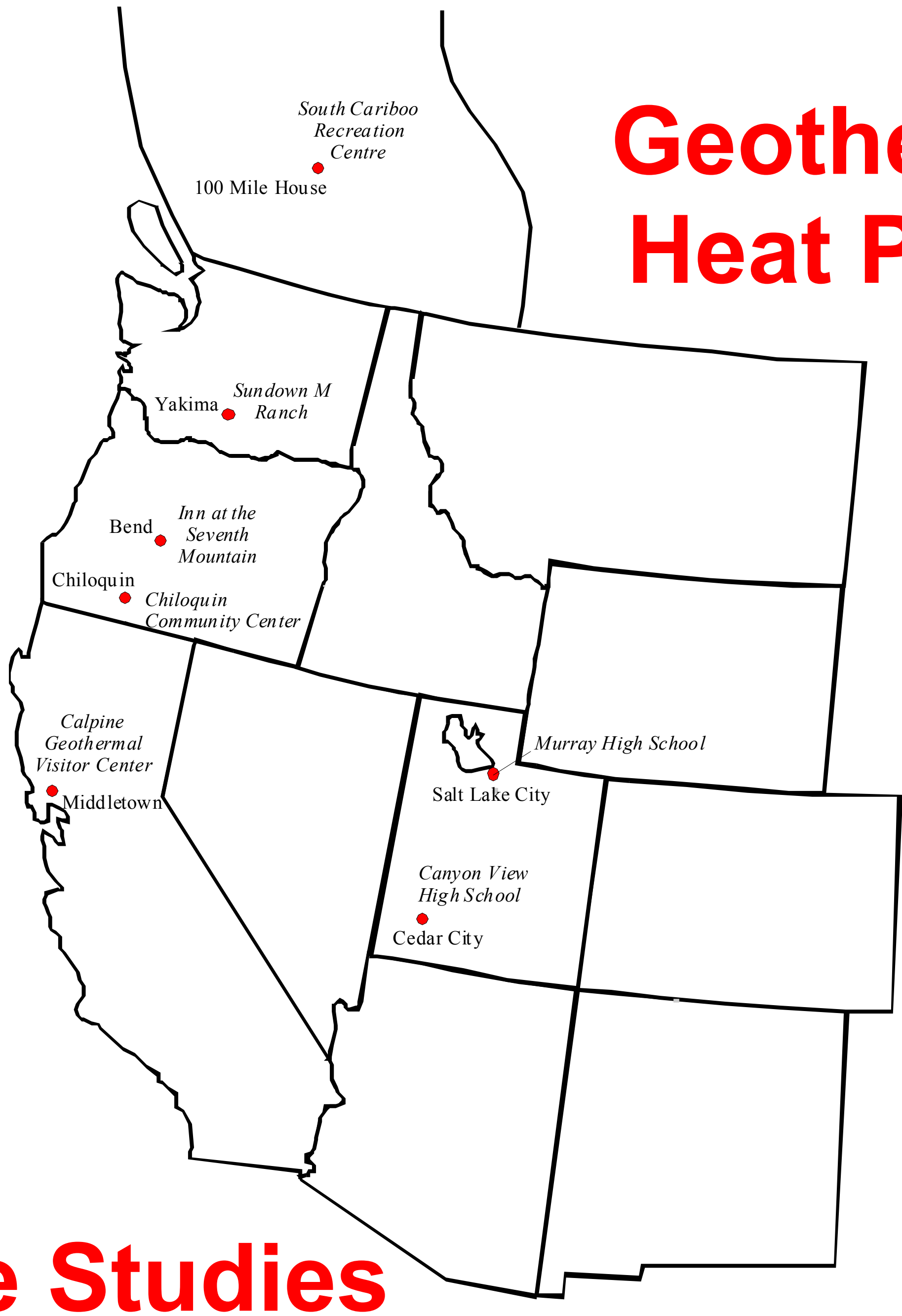
Geothermal Heat Pump



Case Studies of the West

Vol. 26, No. 3 September 2005

GEO-HEAT CENTER QUARTERLY BULLETIN

ISSN 0276-1084
A Quarterly Progress and Development Report
on the Direct Utilization of Geothermal Resources

CONTENTS

Cover: The following case studies were developed at the request of the USDOE National Renewable Energy Laboratory (NREL) to provide a thumb-nail description of a cross section of geothermal heat pump projects in the western U.S.

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GEOTHERMAL HEAT PUMP CASE STUDIES OF THE WEST

Geothermal (ground-source) heat pumps (GHPs) have become a major growth area of geothermal energy use in the United States, Canada and Europe. Within the United States; however, according to geothermal heat pump shipment tracking by the Energy Information Administration (EIA), the west only represents 9% of the total GHP shipments. Thus, this issue of the Geo-Heat Center *Quarterly Bulletin* is devoted to seven examples of GHPs in the western regions of Canada and the United States. Two are open-loop (groundwater) types and five are closed-loop (ground-coupled) types. We have attempted to include operating and maintenance experiences along with the associated costs.

The number of GHPs has steadily increased over the past 10 years with an estimated 600,000 to 800,000 equivalent 12 kW (3.4 ton) units installed in the United States and 36,000 in Canada. They have been reported installed in all the states in the U.S. and all the provinces in Canada. We estimated that 60,000 units were installed in the U.S. and over 3,000 in Canada this past year. The U.S. units are mainly found in the Midwestern and Eastern states, and the Canadian units in Ontario and Manitoba with considerable growth in British Columbia. Of the installed units, we estimate that 44% are vertical closed-loop, 36% are horizontal closed-loop and 20% are open-loop systems. Interest in open-loop systems appears to be increasing, accounting for 25% of the units shipped from manufacturers this past year.

Using an average unit size of 12 kW (3.4 tons), the installed capacity in the U.S. is between 7,200 and 9,600 MWt, and based on approximately 1,200 full-load equivalent operating hours per year and a coefficient of performance (COP) of 3.5, the annual energy removed from the ground is between 6,171 and 8,228 GWh (21,060 and 28,080 billion Btu). The corresponding figures for Canada are 396 MWt and 600 GWh/yr (2,048 billion Btu). World-wide, 33 countries report the use of GHPs (from the World Geothermal Congress 2005). It is estimated that there are 1.7 million units installed world-wide, accounting for an installed capacity of 15,384 MWt and annual energy use of 24,300 GWh (82,960 billion Btu). In the United States, most systems are designed for the cooling load, whereas in Europe they are designed to provide base-load heating, and average an equivalent 2,200 full-load operating hours annually. Cooling load cannot be considered geothermal, as heat is rejected to the ground or ground-water; however, cooling has a role in the substitution for fossil fuels and reduction of greenhouse gas emissions.

As reported in our March 2001 (Vol. 22, No. 1) issue of the *Quarterly Bulletin*, President George W. Bush installed a geothermal heat pump on his Texas ranch. The unit is 49 kW (14 tons) broken into five separate systems with desuperheater. The vertical closed loop installation cuts his heating and cooling cost by 40%. On the other side of the Atlantic, the *Sunday Times* of London (August 21, 2005 by Lois Rogers), reports that the Queen of England is planning to install a GHP for heating and to cut energy bills at Buckingham Palace. A closed-loop system placed below the surface of a four-acre (1.6 ha) lake will provide heating to state rooms and the formal area of the palace. The heat will be provided through either radiators, or by venting hot air through underfloor heating. The system will cost approximately £50,000 (US$90,000) to install the outdoor equipment, and several hundred thousands additional Pounds (£) to make the system compatible with the existing palace heating system. This is estimated to reduce the heating and electricity bills by at least 70%. A trial system was installed in 2002 by drilling 400 feet into the chalk aquifer beneath the palace ground to run an air-conditioning system for a new art gallery, built at Buckingham Palace to mark the golden jubilee for the Queen. The results were impressive and led to the current project that will replace conventional heating sources for part of the palace.

Other famous persons from the United Kingdom who have installed GHPs are Sir Elton John, the pop star, Sir Richard Branson, the entrepreneur, Paul Allen, the billionaire co-founder of Microsoft, George Davies, the high street fashion guru, and Paul Lister, son of the found of the MFI furniture empire and owner of a vast Highlands nature reserve.

The Editor

CALPINE GEOTHERMAL VISITOR CENTER MIDDLETOWN, CALIFORNIA

Andrew Chiasson
Geo-Heat Center

LOCATION & BACKGROUND

The Calpine Geothermal Visitor Center is located in Middletown, California, about 70 miles (113 km) north of San Francisco. It is a single-story, 6,000 ft^2 (560 m^2) building and is the visitor center for The Geysers geothermal field, the largest geothermal power generating operation in the world. The visitor center building has incorporated a number of "green" features, one of which is a geothermal heat pump system. Completed in 2001, the building has a lobby area, an exhibit hall featuring geothermal power displays, small offices, a conference room, a kitchen, and a multipurpose room (Figure 1).

Average high temperatures in the area in July are about 92°F (33.3°C) and average low temperatures in January are about 35°F (1.7°C). There are approximately 2800 heating degree days and 800 cooling degree days per year [65 °F (18°C) base].

SYSTEM DESCRIPTION

Ground Source System

The ground source system (shown in Figure 1) is the vertical closed loop type consisting of 20 vertical boreholes, each 225 ft (69 m) deep, for a total length of 4500 ft (1372 m). The boreholes are installed in a 4 x 5 grid pattern with 20-ft (6.1-m) spacing. A single u-tube heat exchanger is installed in each borehole and the heat transfer fluid is pure water. The borehole field is piped in a reverse-return arrangement.

The mean annual ground temperature in this location is about 62°F (16.7°C). The loop field was installed in an alluvial fan deposit, consisting of cobbles and boulders.

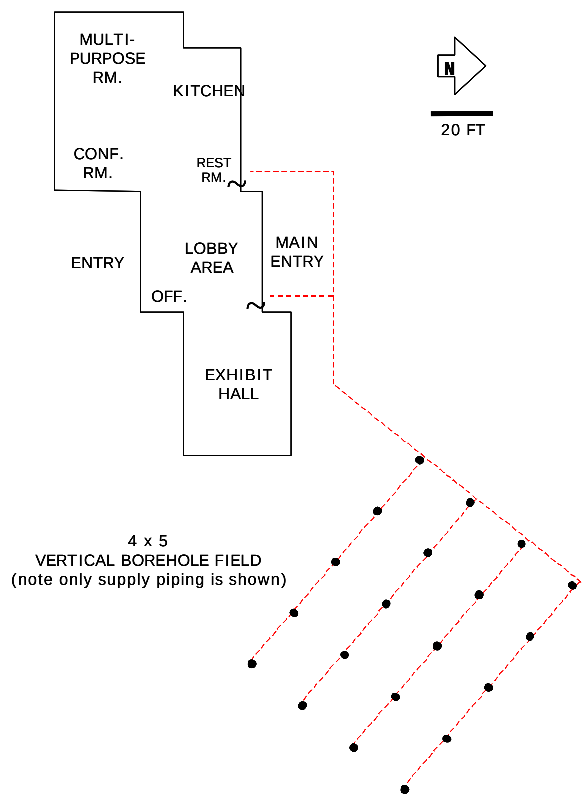

Figure 1. ***Calpine Visitor Center site sketch showing ground loop field.***

Interior System

The total installed heat pump capacity is approximately 25 tons (88 kW). As each room in the building has a different use and variable occupancy rate, the building was designed so that each room is a separate zone. Space conditioning for the lobby, offices, and exhibit hall is accomplished with vertical water-to-air heat pumps installed in closet spaces. Space conditioning for the other areas (conference rooms, hallways, restrooms, and kitchen) is done with horizontal water-to-air heat pumps hidden in the attic. Ventilation air is ducted through the attic space to individual heat pumps. A 1 ton water-to-water heat pump installed in the kitchen is used for domestic hot water heating. For energy efficient pumping, a separate water circulator is installed on each heat pump. A schematic of a typical heat pump layout is shown in Figure 2, and a photograph of the 6-ton (21 kW), vertical unit and flow center serving the exhibit hall is shown in Figure 3.

PROJECT COSTS

The total geothermal heat pump heating, ventilating, and air-conditioning (HVAC) system cost in 2001 was $78,000, or approximately $13/ft^2 ($140/m^2). From Means construction cost data (2000), the median HVAC system cost for a similar building (a community center) is $9/ft^2 ($97/m^2). Therefore, it is estimated that the geothermal heat pump system capital cost was about 44%, or $24,000 greater than a conventional system.

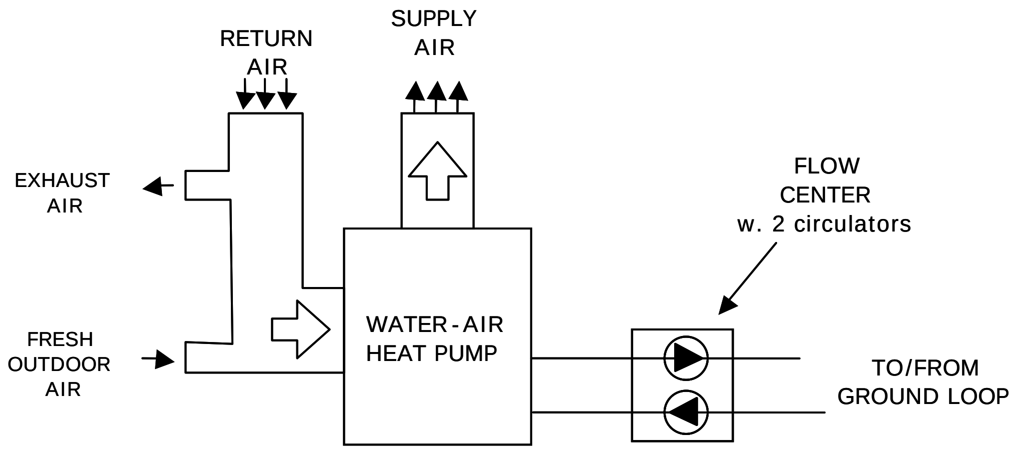

Figure 2. Schematic of a typical heat pump at the Calpine Visitor Center.

Figure 3. Photograph of a 6-ton, water-air, vertical heat pump and flow center.

SYSTEM PERFORMANCE AND OPERATING COST

Electrical energy consumption for the Calpine Visitor system for the year 2004 is shown in Figure 4. The data shown in Figure 4 represent the total electrical energy consumption for the building, and therefore the exact HVAC system energy use is not known. The total electrical energy consumption for 2004 was 80,120 kWh.

In order to compare performance of the geothermal heat pump system to a conventional HVAC system, the building performance was simulated using eQuest, which employs the DOE-2 building simulation engine. For this simulation, building use and occupancy profiles for a community center were chosen. The conventional HVAC system modeled was a multi-zone rooftop unit with forced-air natural gas heating and DX cooling.

Results of the simulated energy consumption of the conventional system are shown in Figure 5. A review of Figure 5 shows that a conventional HVAC system at the Calpine Visitor Center would consume a total of 86,400 kWh of electrical energy and a total of 597.65 million Btu (63 GJ) of natural gas.

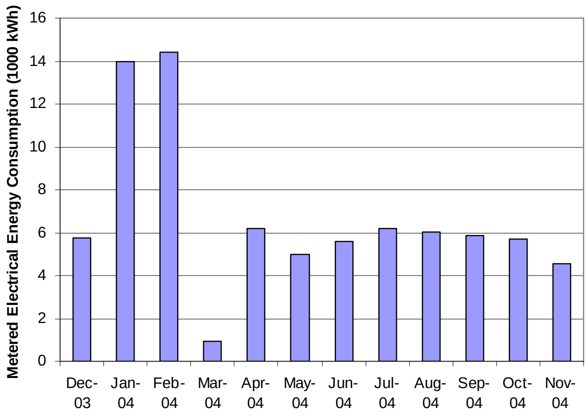

Figure 4. 2004 metered electrical energy consumption for the Calpine Visitor Center (note this is all electrical energy use for the building).

Assuming an average cost of electricity of \$0.10/kWh and an average natural gas cost of \$0.85/therm (\$0.3/m^3), the annual energy cost for the conventional system would be \$8,640 for electricity and \$5,080 for natural gas, giving a total annual cost of \$13,720. This is about 58% higher than the 2004 cost of \$8,640 from the metered use, giving an estimated annual savings of about \$5,080. Neglecting maintenance costs, this savings amounts to a simple payback period of 4.7 years.

OPERATING EXPERIENCES

Calpine reports that the drilling was more difficult than expected due to the presence of large cobbles and boulders underlying the site. This resulted in drilling costs in excess of original estimates.

The only operating difficulty to date is that not enough cooling was provided to the kitchen. This difficulty, however, is not attributable to the heat pump system, but to an oversight in the estimation of the kitchen cooling load.

OVERALL SUMMARY

Building Description:

Location: Middletown, California
Occupancy: Visitor Center
Gross Floor Area: 6,000 ft^2 (560 m^2)
Number of Floors: 1
Type of Construction: New
Completion Date: 2001
July Avg. High Temp.: 92°F (33.3°C)
Jan Avg. Low Temp.: 35°F (1.7°C)
Annual Heating Degree Days: 2800°F-day (1550°C-day)
Annual Cooling Degree Days: 800°F-day (444°C-day)

Interior System:

Total Installed Heat Pump Capacity: ~25 tons (88 kW)
No. of Heat Pump Units: 10
Heat Pump Capacities: 1 to 6 tons (3.5 to 21 kW)
Pumping System: Individual flow centers
Additional notes: Water-to-air heat pumps for space conditioning
Water-water heat pump for domestic water

Ground-Source System:

Geologic Materials: Alluvial sediments
Mean Ann. Ground Temp.: 62°F (16.7°C)
Type: Vertical closed loop, single U-tube
Configuration: 20 boreholes (4x5 grid pattern)
225 ft (69 m) deep,
20 ft (6.1 m) spacing
Borehole per ton: 180 ft/ton (15.6 m/kW)
Heat Transfer Fluid: Pure water

Economic Analysis:

Installed Geothermal HVAC Capital Cost:
\$78,000 (\$13.00/ft^2)(\$140/m^2)
Estimated Conventional HVAC Capital Cost:
\$54,000 (\$9.00/ft^2)(\$97/m^2)
Total Building Energy Use:
80,000 kWh
Simulated Conventional Building Electrical Use:
86,400 kWh
Simulated Conventional Building Gas Use:
598 million Btu (63 GJ)
Estimated Simple Payback Period:
<5 years

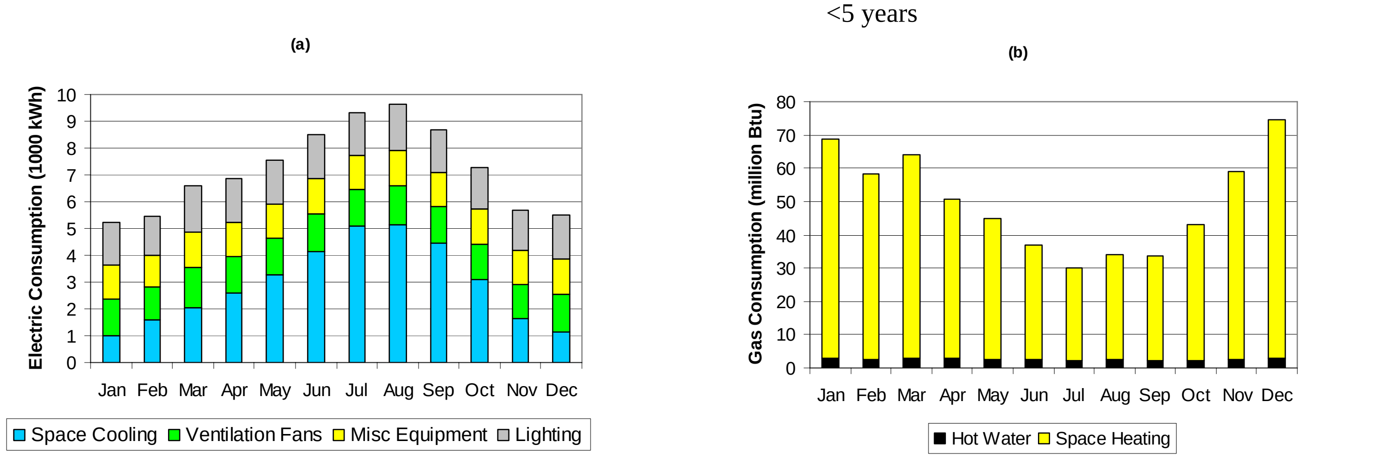

Figure 5. Simulated energy consumption of a conventional multi-zone rooftop unit with forced air natural gas heat and DX cooling: a) cooling with electricity, and b) heating with gas.

CANYON VIEW HIGH SCHOOL
CEDAR CITY, UTAH

Andrew Chiasson
Geo-Heat Center

LOCATION & BACKGROUND

The Canyon View High School is located in Cedar City, UT, about 90 miles (145 km) northeast of the point of intersection of Utah, Arizona, and Nevada. It is a two-story building with 233,199 ft^2 (21,665 m^2) of floor space, and construction was completed in 2001.

Average high temperatures in the region in July are about 93^{o}F (33.9^{o}C) and average low temperatures in January are about 15^{o}F (-9.4^{o}C). There are approximately 6100 (3390^{o}C-day) heating degree days and 700 (390^{o}C-day) cooling degree days per year [65 ^{o}F (18^{o}C) base].

The Canyon View ground-source heat pump system is considered the first "large" geoexchange system in the Central Rocky Mountain Region.

SYSTEM DESCRIPTION

Ground Source System

The ground source system (Figure 1) is the vertical closed loop type consisting of 300 vertical boreholes, each 300 ft (91.4 m) deep, for a total length of 90,000 ft (27,432 m). The boreholes, installed under the school playing field, are placed in a 15 x 20 grid pattern with a 20-ft (6.1-m) borehole spacing and 25-ft (7.6-m) spacing between run-outs. A single u-tube heat exchanger is installed in each borehole, and the borehole field is piped in a reverse-return arrangement.

The mean annual ground temperature in this location is approximately 53^{o}F (11.7^{o}C). An in-situ thermal conductivity test revealed that the average thermal conductivity of the soil to a depth of 300 ft (91.4 m) is 1.19 Btu/hr-ft-^{o}F (2.06 W/m-^{o}C). The loop field was installed in basin-fill type sediments, consisting of coarse sand and gravel with clay stringers and trace volcanics.

Interior System

The total installed heat pump capacity at the Canyon View High School is approximately 550 tons (1953 kW). Space conditioning is accomplished by over 100 water-air heat pumps, which are installed in ceiling spaces to serve individual classrooms and other zones. Outdoor air is introduced through heat recovery ventilator (HRV) units. The original design called for total energy recovery (ERV) units, but HRV's were installed due their to lower cost. There is little use of domestic hot water in the school, and thus it is generated partially by water-water heat pumps and natural-gas water heaters. The fluid distribution system consists of a central pumping system with a variable frequency drive.

A generalized schematic of the system is shown in Figure 2. Figure 3 is a photograph of the ground-loop headers in the mechanical room and Figure 4 is a photograph of a typical horizontal, ceiling-mounted water-air heat pump.

PROJECT COSTS

The Canyon View High School is an example of a building where a ground-source heat pump system was

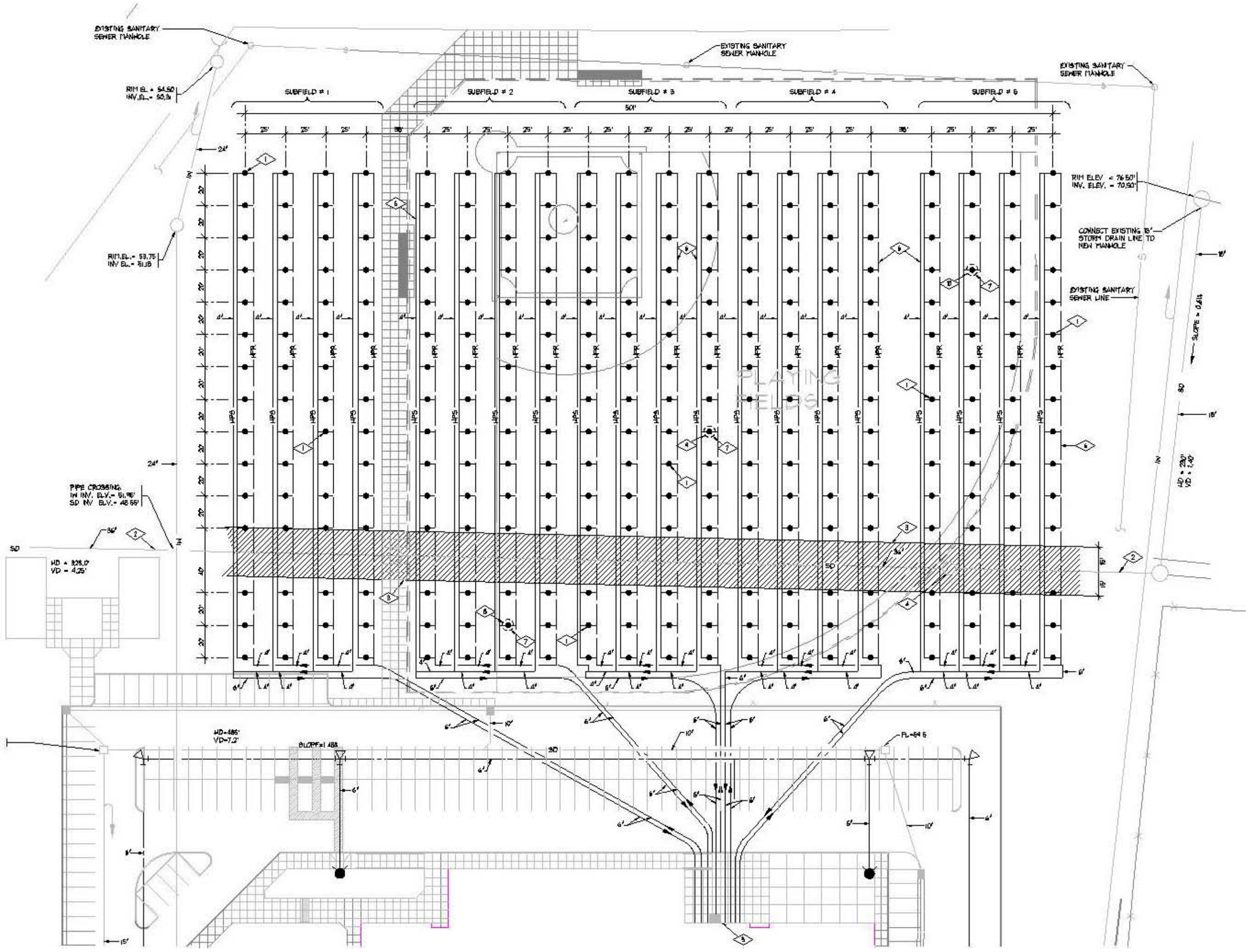

Figure 1. Canyon View High School ground loop field.

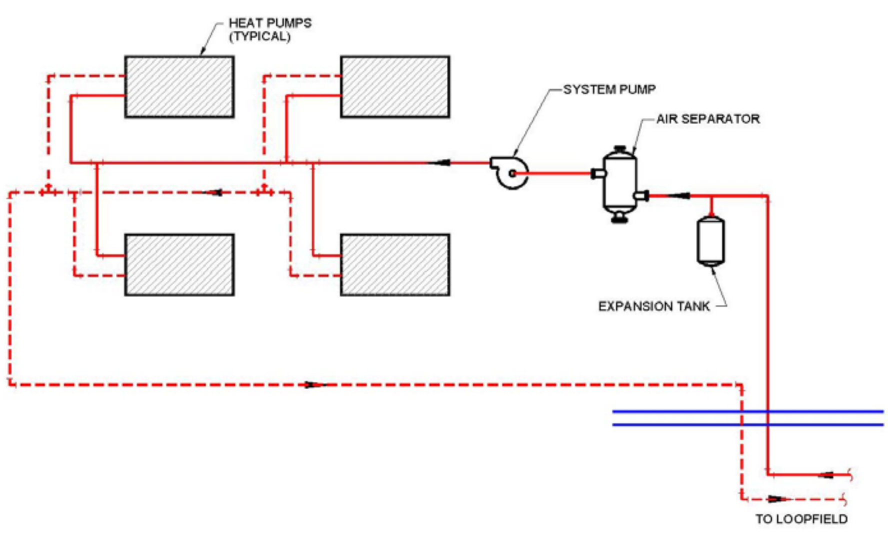

Figure 2. Schematic of the ground-source heat pump system at the Canyon View High School.

cheaper to install than a conventional boiler chiller system. The project costs are summarized as follows:

- Conventional Mechanical System Bid:
  $17.00/ft^2 ($183.00/m^2)
- Canyon View High School Ground Source System Bid:

Mechanical/Plumbing bid:	$2,457,000
Loop Field bid:	$778,000
Total Ground Source bid:	$3,235,000
Mechanical Cost/ft^2 (m^2):	**$13.87/ft^2 ($149.30/m^2)**

Cost Savings: $3.13/ ft^2 ($33.69/m^2) = **$729,000**

Additional cost savings may be realized if one considers architectural savings in the mechanical room floor space in the ground-source system over the conventional system. For the Canyon View High School, the mechanical room for the ground-source system is 2,680 ft^2 (249 m^2), or 1.15% of the total floor space. Comparing this value to 3.80% of mechanical room floor space to total floor space for average schools, and assuming $50/ft^2 ($538/m^2) cost of new construction, an additional savings of $309,000 may be realized.

Figure 3. Photograph of the mechanical room at the Canyon View High School, showing the ground loop field supply and return headers.

SYSTEM PERFORMANCE AND OPERATING COST

The system has performed as designed. Maximum ground loop temperatures observed in the summer are about 92^{o}F (33.3^{o}C) and minimum loop temperatures in the winter are 40-42^{o}F (4.4–5.5^{o}C). Annual utility costs for 2001-2002 are summarized as follows:

- Annual Utility Costs for Canyon View High School:

Electricity:	$135,886.54	(96%)
Natural Gas:	$5,446.87	(4%)
Total:	$141,333.41	
Cost/ft^2 (m^2):	$0.61/ft^2 ($6.57/m^2)	

- Utility Costs for a Comparable School:
  Cost/ft^2 (m^2): $0.86/ft^2 ($9.26/m^2) (77% electrical, 23% gas)
- Operating Cost Savings: $0.25/ ft^2 ($2.69/m^2)
  = $58,300 (or 29%)/year

Figure 4. Photograph of a typical horizontal, ceiling-mounted water-air heat pump.

OPERATING EXPERIENCES

Although the geoexchange system at the Canyon View High School is performing well, it is a large system, and the designer admits that there are ways that the pumping system could have been designed to optimize energy consumption. For example, systems of similar size are being designed with primary/secondary pumping, multiple loop pumps to utilize only as much of the ground loop as necessary, and distributed pumping in the building.

Most heat pumps are installed in ceiling spaces, and access has been a bit tight. Dirt and sand was a problem in the system for about 6 months after start-up, which was attributed to a damaged header pipe, likely caused by landscaping work.

ACKNOWLEDGEMENTS
The Geo-Heat Center wishes to thank Cary Smith of Sound Geothermal for providing the data and information for this case study

OVERALL SUMMARY

Building Description:
Location: Cedar City, Utah
Occupancy: School
Gross Floor Area: 233,199 ft^2 (21,665 m^2)
Number of Floors: 2
Type of Construction: New
Completion Date: 2001
July Avg. High Temp.: 93^{o}F (33.9^{o}C)
Jan Avg. Low Temp.: 15^{o}F (-9.9^{o}C)
Annual Heating Degree Days: 6100^{o}F-day (3390^{o}C-day)

Annual Cooling Degree Days: 700°F-day (390°C-day)
Interior System:
Total Installed Heat Pump Capacity: ~550 tons (1,935 kW)
No. of Heat Pump Units: 100+
Pumping System: Central with VFD
Ground-Source System:
Geologic Materials: Basin-fill sediments
Mean Ann. Ground Temp.: 53°F (11.7°C)
Type: Vertical closed loop, single U-tube
Configuration: 300 boreholes (15x20 grid pattern)
300 ft (91.4 m) deep,
20 to 25 ft (6.1 to 7.6 m) spacing
Borehole per ton: ~164 ft/ton (14.2 m/kW)

Economic Analysis:
Installed Geothermal HVAC Capital Cost:
$3,235,000 ($13.87/ft^2)($149.30/m^2)
Conventional HVAC Capital Cost Bid:
$3,963,363 ($17.00/ft^2)($183.00/m^2)
Annual HVAC Energy Cost (2001-2002):
$141,333 ($0.61/ft^2)($6.57/m^2)
Annual HVAC Energy Cost of Comparable Conventional School:
$200,500 ($0.86/ft^2) ($9.26/m^2)
Annual HVAC Energy Savings:
29%
Estimated Simple Payback Period:
Immediate

MURRAY HIGH SCHOOL
SALT LAKE CITY, UTAH

Andrew Chiasson
Geo-Heat Center

LOCATION & BACKGROUND

The Murray High School is located in Murray, UT, which is part of the Salt Lake City metropolitan area. It is a two-story building with 267,256 ft^2 (24,829m^2) of floor space, and construction was completed in 2003.

Average high temperatures in the region in July are about 91°F (32.8°C) and average low temperatures in January are about 21°F (-6.1°C). There are approximately 5600 heating degree days (3110°C-day) and 1100 cooling degree days (610°C-day) per year [65 °F (18°C) base].

SYSTEM DESCRIPTION

Ground Source System

The ground source system (Figure 1) is a "hybrid system", consisting of vertical, closed-loop ground heat exchangers and a supplementary fluid cooler to balance the annual ground loads (since summer occupancy of the school was expected). The ground loop is comprised of 316 vertical boreholes, each 300 ft (91.4 m) deep, for a total length of 94,800 ft (28,895 m). It is installed under the north parking lot of the school, and the boreholes are placed in a grid-like pattern consisting of 5 sub-fields for easier flushing and purging. A single u-tube heat exchanger is installed in each borehole, and the borehole sub-fields are piped in a reverse-return arrangement. A photograph of the supplementary fluid cooler is shown in Figure 2. The fluid cooler capacity is 125 tons (440 kW).

The mean annual ground temperature in this location is approximately 53°F (11.7°C). An in-situ thermal conductivity test revealed that the average thermal conductivity of the soil to a depth of 300 ft (91.4 m) is 1.13 Btu/(hr-ft-°F)(1.95 W/m-°C). The loop field was installed in basin-fill type sediments, consisting of clay, sand, and gravel with cobble stringers.

Interior System

The total installed heat pump capacity at the Murray High School is approximately 650 tons (2286 kW). Space conditioning is accomplished by over 100 water-air heat pumps, which are installed in ceiling spaces to serve individual classrooms and other zones. Outdoor air is introduced through heat recovery ventilator (HRV) units. The original design called for total energy recovery (ERV) units, but HRV's were installed due their to lower cost. There is little use of domestic hot water in the school, and thus it is generated partially by water-water heat pumps and natural-gas water heaters. The fluid distribution system consists of a central pumping system with a variable frequency drive. Figure 3 is a photograph of the ground-loop headers in the main mechanical room.

PROJECT COSTS

The Murray High School is an example of a building where a ground-source heat pump system was cheaper to install than a conventional boiler chiller system. The project costs are summarized as follows:

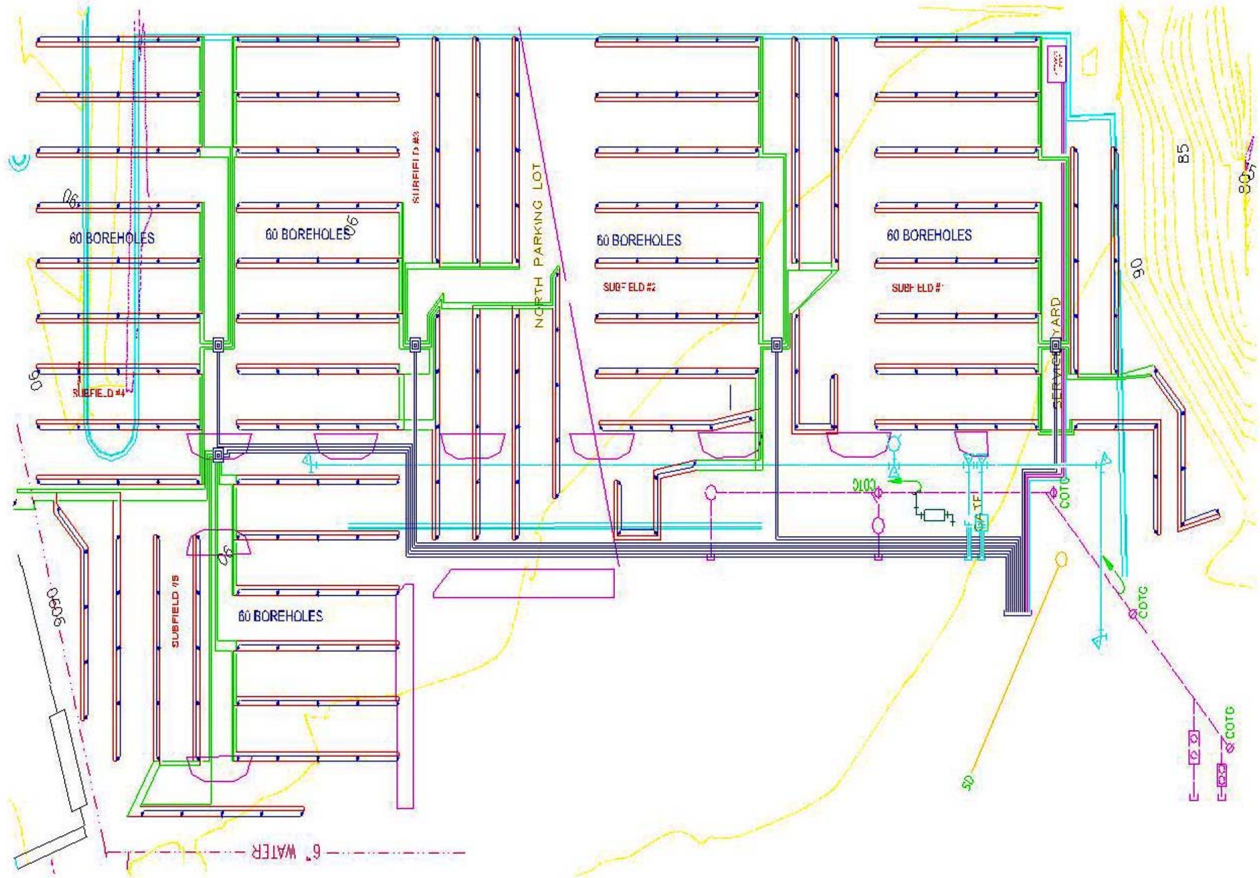

Figure 1. Murray High School ground loop field.

• Conventional Mechanical System Bid:
$19.00/ft^2 ($204.50/m^2)

• Murray High School Ground Source System Bid:

Mechanical/Plumbing bid:	$3,065,161
Loop Field bid:	$930,784
Total Ground Source bid:	$3,995,945
Mechanical Cost/ft^2 (m^2):	**$14.95/ft^2 ($160.92/m^2)**

Cost Savings: 4.05/ ft^2 ($43.59/m^2) = **$1,082,387**

Additional cost savings may be realized if one considers architectural savings in the mechanical room floor space in the ground-source system over the conventional system. For the Murray High School, the mechanical room for the ground-source system is 2,160 ft^2 (200.7 m^2), or 0.8% of the total floor space. Comparing this value to 3.80% of mechanical room floor space to total floor space for average schools, and assuming $50/ft^2 ($538.20/m^2) cost of new construction, an additional savings of $405,000 may be realized

SYSTEM PERFORMANCE AND OPERATING COST

Maximum ground loop temperatures observed in the summer are about 92^{o}F (33.3^{o}C), and minimum loop temperatures in the winter are 40-42^{o}F (4.4-5.5^{o}C). According to the designers of the system, to their knowledge, the fluid cooler has not yet been needed. Annual utility costs for 2003-2004 are summarized as follows:

Figure 2. Photograph of the fluid cooler at the Murray High School.

• Annual Utility Costs for Canyon View High School:

Electricity:	\$156,505	(96%)
Natural Gas:	\$6,521	(4%)
Total:	\$163,026	
Cost/ft^2 (m^2):	\$0.61/ft^2 (\$6.57/m^2)	

• Utility Costs for a Comparable School:

Cost/ft^2 (m^2): \$0.86/ft^2 (\$9.26/m^2)
(77% electrical, 23% gas)

• Operating Cost Savings:

\$0.25/ ft^2 (\$2.69/m^2) = **\$58,300 (or 29%)/year**

Figure 3. Photograph of the main mechanical room at the Murray High School, showing the ground loop field supply and return headers.

OPERATING EXPERIENCES

Thus far, the system has operated well, with the only difficulties being those typical at start-up, such as trapped air and some mud in the ground loop.

ACKNOWLEDGEMENTS

The Geo-Heat Center wishes to thank Cary Smith of Sound Geothermal for providing the data and information for this case study.

OVERALL SUMMARY

Building Description:

Location: Salt Lake City, Utah
Occupancy: School
Gross Floor Area: 267,256 ft^2 (24,829 m^2)
Number of Floors: 2
Type of Construction: New
Completion Date: 2003
July Avg. High Temp.: 91°F (32.8°C)
Jan Avg. Low Temp.: 21°F (-6.1°C)
Annual Heating Degree Days: 5600°F-day (3110°C-day)
Annual Cooling Degree Days: 1100°F-day (610°C-day)

Interior System:

Total Installed Heat Pump Capacity: 650 tons (2,286 kW)
No. of Heat Pump Units: 100+
Pumping System: Central with VFD

Ground-Source System:

Geologic Materials: Basin-fill sediments
Mean Ann. Ground Temp.: 53°F (11.7°C)
Type: Hybrid, vertical closed loop, single U-tube
Configuration: 316 boreholes (grid-like pattern in 5 sub-fields),
300 ft (91.4 m) deep + fluid cooler
Borehole per ton: 146 ft/ton (12.6 m/kW)

Economic Analysis:

Installed Geothermal HVAC Capital Cost:
\$3,995,945 (\$14.95/ft^2)(\$160.92/m^2)
Conventional HVAC Capital Cost Bid:
\$5,077,864 (\$19.00/ft^2)(\$204.50/m^2)
Annual HVAC Energy Cost (2003-2004):
\$163,026 (\$0.61/ft^2)
Annual HVAC Energy Cost of Comparable Conventional School: \$229,840 (\$0.86/ft^2) (\$9.26/m^2)
Annual HVAC Energy Savings:
29%
Estimated Simple Payback Period:
Immediate

CHILOQUIN COMMUNITY CENTER
CHILOQUIN, OREGON

Andrew Chiasson
Geo-Heat Center

LOCATION & BACKGROUND

The Chiloquin Community Center is located in Chiloquin, Oregon, which is in southern Oregon, about 30 miles (48 km) north of Klamath Falls, and about 250 miles (402 km) south of Portland. It is a single-level, 13,000 ft^2 (1,210 m^2) structure that provides space for the Chiloquin Public Library, the Two Rivers Art Gallery, public arts and crafts work-rooms, a large public meeting room with full kitchen, and also leases offices to the local Sheriff's Department. Portions of the building are in use 7 days per week, year round. A sketch of the building footprint and borefield are shown in Figure 1.

The building is constructed of insulated concrete form (ICF) walls and a conventional wood frame roof. As a consequence of using ICF with fixed windows, the building is extremely well insulated and air-tight. The entire slab is insulated using 1-inch polystyrene board to reduce downward heat loss in winter.

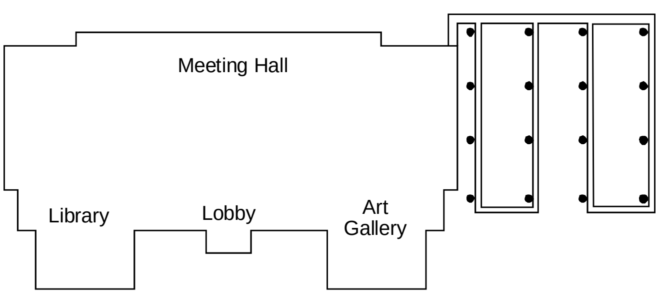

Figure 1. Chiloquin Community Center site sketch showing ground loop field.

The building was constructed in 2003-2004, and formally opened in the Spring of 2004. The ground-source heat pump system installation began prior to the commencement of the main building with the drilling of the network of vertical bores comprising the earth heat exchanger for the facility.

Average high temperatures in the area in July are about 85^{o}F (29.4^{o}C) and average low temperatures in January are about 22^{o}F (-5.6^{o}C). There are approximately 7000 (3890^{o}C-day) heating degree days and 200 (110^{o}C-day) cooling degree days per year (65 ^{o}F (18^{o}C) base).

SYSTEM DESCRIPTION

Ground Source System

The ground source system (shown in Figure 1) is a vertical network of 16 bores, each 6-inch (152-mm) diameter and 320 ft (98 m) deep, and arranged in a rectangular grid with a bore-to-bore spacing of 20 ft (6.1 m). The u-tube assemblies were fabricated using 1" (25.4 mm) diameter high-density polyethylene pipe (HDPE). Following insertion of the u-tubes, a bentonite/silica sand grout was pumped into the bores to achieve a nominal grout thermal conductivity of 1.0 Btu/hr-ft-^{o}F (1.7 W/m-^{o}C).

To aid in the design of the borefield, an in-situ thermal conductivity analysis was performed on a test bore. The resulting test data were used to determine that the average thermal conductivity of the earth surrounding the bore is approximately 0.62 Btu/hr-ft-^{o}F (1.07 W/m-^{o}C). The mean earth temperature was measured at 56^{o}F (13.3^{o}C).

The geology at the site, based on the drilling logs, consists of sands and gravels to a depth of approximately 16 ft (4.9 m), with the remainder of the bore depths consisting of gray clay deposits interspersed with occasional sandstone layers. The drilling was accomplished using air-rotary methods (Figure 2).

Figure 2. Photograph of drilling activities

Interior System

A highly unusual integrated system design was conceived for the project that addressed the energy efficiency goals of the building owners, and built on the very high thermal integrity of the shell. A crucial initial step in this process was agreement on design criteria that allowed for a wider range of indoor air temperatures than is typical for a building of this type. This determination facilitated the choice to use radiant floor heating as the primary means of thermal distribution, and this concept was then extended to include radiant floor cooling.

The building's 15 control zones are connected by a hydronic piping system to a central plant that has only one heat pump. The heat pump is a water-to-water unit (Figure 3) with a nominal rating of 15 tons (53 kW), and is equipped with a single compressor and refrigerant circuit. To prevent short-cycling, a thermal energy storage tank (Figure 4) is employed on the building side of the heat pump a significant buffer volume and de-coupling the control of building water distribution from the operation of the heat pump.

Because the building has no operable windows, all ventilation air is provided by mechanical means. A heat-wheel type air handling unit with a nominal capacity of 4000 cubic feet per minute (cfm) (6,800 m^3/hr) is installed in the attic space, together with ducting to distribute the air to each zone. At the zonal level, occupancy sensors operate a damper in the ventilation duct to minimizing the air handled by the fan system. These occupancy sensors also control lighting in the individual zones. The fan speed is modulated by means of variable frequency drives.

Figure 3. Photograph of the 15 ton water-water heat pump serving the entire building. Note the storage tank on the right.

The building's hydronic circulation pumps are in-line centrifugal types, with variable frequency drives that are controlled based on pressure in the supply pipe. At the heat pump, the ground loop pump is also controlled with a variable frequency drive. The tank circulation pump between heat pump and thermal storage tank is constant speed.

Figure 4. Photograph of the mechanical room, showing the distribution piping and storage tank.

To allow the programming of desired control sequences, a direct-digital control (DDC) system was installed. The system uses ASHRAE's BACnet communications protocol set over TCP/IP. It is therefore possible to use conventional internet browser software to access and interact with the control system, and a dedicated server is located in the building to accomplish this task.

PROJECT COSTS

The installed cost of the interior HVAC system was \$189,400 or \$14.57/ft^2 (156.83/m^2) and the cost of the ground loop was approximately \$48,000 or \$9.38/ft

($30.77/m) of vertical borehole. Thus, the total installed cost of the entire ground-source heat pump system was $237,400 or $18.26/ft^2 (196.55/m^2).

PacifiCorp provided incentives to the owners, underwriting the costs of pre-design analysis and construction. Additional efficiency incentives were provided through the State of Oregon's Business Energy Tax Credit (BETC) program. Together these incentives totaled approximately $80,000.

SYSTEM PERFORMANCE AND OPERATING COST

The first full year of operation has just completed, and the building has proven itself to be even more efficient than anticipated. Average energy use index is 19,800 Btu/ft^2/yr or 5.8 kWh/ft^2/yr (62.4 kWh/m^2/yr), which is especially impressive because the building operates with no night setback due to the dynamics of the radiant slab.

Sub-metering of the building zones allows the HVAC energy costs to be broken out and tracked. From utility bills, the operating cost of the HVAC system for the first year was about $5,350 or $0.41/ft^2 ($4.41/m^2).

OPERATING EXPERIENCES

Chiloquin Visions in Progress (CVIP), a non-profit organization who raised funds to construct the building, report that they are very happy with the low energy use and operating cost of the building. Low operating costs are an especially attractive feature for non-profit organizations.

As anticipated, the building design does not provide for rapid adjustment to load changes with its radiant slab heating/cooling systems. This might be perceived as a drawback, but the building has no morning warm-up or cool-down time since it is operated without night setback of thermostatic controls. As designed, it seems to work reasonably well with the normal functional requirements of the building.

One rapid load change scenario that has been somewhat difficult to deal with is the occasional large public gathering in the meeting hall room. To best provide for the sudden cooling load, it has been necessary to anticipate the event by overcooling the room, and then keeping the supply water temperature lower than would normally be called for at the central thermal storage tank. In addition, decorative ceiling fans have been proposed in the meeting hall room to increase air circulation as well as to give occupants a visual perception of air movement.

ACKNOWLEDGEMENTS

The Geo-Heat Center wishes to thank Gene Johnson of Solarc Architecture and Engineering, Inc. for providing the data and information for this case study, and Chuck Wells and Jim Walthers of CVIP for providing the drilling and utility cost information.

OVERALL SUMMARY

Building Description:

Location: Chiloquin, Oregon
Occupancy: Community Center with continuous occupancy is some zones
Gross Floor Area: 13,000 ft^2 (1,210 m^2)
Number of Floors: 1
Type of Construction: New
Completion Date: 2003
July Avg. High Temp.: 85^{o}F (29.4^{o}C)
Jan Avg. Low Temp.: 22^{o}F (-5.6^{o}C)
Annual Heating Degree Days: 7000^{o}F-day (3890^{o}C-day)
Annual Cooling Degree Days: 200^{o}F-day (110^{o}C-day)

Interior System:

Total Installed Heat Pump Capacity: 15 tons (53 kW)
No. of Heat Pump Units: 1
Pumping System: Central pumping, variable speed control
Additional notes: Radiant floor heating and cooling

Ground-Source System:

Geologic Materials: Sediments
Mean Ann. Ground Temp.: 56^{o}F (13.3^{o}C)
Type: Vertical closed loop, single U-tube
Configuration: 16 boreholes (4x4 grid pattern)
300 ft (98 m) deep, 20 (6.1 m) ft spacing
Borehole per ton: 342 ft/ton (29.6 m/kW)
Heat Transfer Fluid: Methanol/water solution

Economic Analysis:

Installed Geothermal HVAC Capital Cost:
$237,400 ($18.26/ft^2) (196.55/m^2)
Estimated Conventional HVAC Capital Cost:
$130,000 ($10.00/ft^2) (107.64/m^2)
Annual HVAC Energy Use:
19,800 Btu/ft^2 (62.4 kWh/m^2)
Annual HVAC Energy Cost:
$5,350 ($0.41/ft^2) ($4.41/m^2)

SOUTH CARIBOO RECREATION CENTRE
100 MILE HOUSE, BRITISH COLUMBIA, CANADA

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South Caribou Recreation Centre, 100 Mile House, BC

Interior BC Community eliminates greenhouse gas emissions and reduces energy costs in new recreation centre

INTRODUCTION

The recreation centre is the centre of activities in communities across Canada, and the hockey arena is the heart of most facilities. Rising energy prices over the last decade, however, has forced communities to look for energy efficient alternatives to industrial refrigeration plants that have been the norm for the last century.

At the turn of the century the community of 100 Mile House in the centre of British Columbia made a decision to replace their aging hockey arena that had served them for the last 50 years. The community began researching other new facilities that had been built recently. Two new facilities they visited in Chase and Kamloops, BC caught their attention. Both facilities had installed an integrated geothermal refrigeration, heating, ventilating and air conditioning (R/HVAC) system. The simplicity of operating the systems, low energy costs and low operating and maintenance costs, attracted their attention. The elimination of fossil fuels for heating the facilities also appealed to the growing concern for reducing greenhouse gas emissions.

THE BUILDING

Since the community is built around the forestry industry, it's only natural that wood is used for much of the structure. The building is well insulated (R20 walls, R30 ceiling). The ice arena is approximately 28,600 square feet (2,660 square meters), with approximately 700 spectator seats. The ice rink area and the concrete bleacher seating area is heated with a radiant floor heating system. The ice area is maintained at a comfortable 50°F (10°C). The ceiling is covered with wood for aesthetics. The wood surface on the ceiling, however, creates a much greater radiant heat load on the ice surface than a ceiling covered with a "low-emissivity" material.

There are six change rooms alongside the ice area, under the bleachers. The change rooms are maintained at approximately 70°F (21°C) with a radiant floor heat system. One and a half inches (39 mm) of high-density foam insulation was placed under the floor to prevent heat loss to the ground. The change rooms are well ventilated with a heat recovery ventilation system that exhausts air from the change rooms. Fresh, preheated air from the heat recovery system is ducted to the ice arena and then brought back to the change rooms through transfer grills from the ice area. The change rooms and mechanical rooms cover an area of approximately 8,200 square feet (760 square meters)

The lobby and viewing area overlooking the ice rink is approximately 5,900 square feet (550 square meters). Adjacent to the lobby is an office area of approximately 2,100 square feet (195 square meters). These areas are heated and cooled with several ground source heat pumps connected to the horizontal ground loop in the field behind the building.

The refrigeration system of the existing curling rink adjacent to the new arena has been connected to the geothermal system. The heating system of the lobby and lounge of the curling rink, however, has not been connected because of cost. There are plans to convert the heating system in the near future.

THE REFRIGERATION SYSTEM

A hockey arena is typically the most expensive building to operate (energy cost and operating and maintenance costs) in most small communities. The electrical costs associated with operating the compressors and pumps of the refrigeration system are high. The majority of the hockey arenas throughout Canada and much of the United States use ammonia as the primary refrigerant. Ammonia is a very efficient refrigerant, but the large refrigerant charge (1,000 to 1,200 pounds or 450 to 500 kg) requires constant monitoring and stringent safety procedures, including airlock entries to the refrigeration room, high capacity ventilation systems, eyewash stations and oxygen masks. Because of the potential danger, most jurisdictions require highly trained operators and the system operating pressures must be monitored regularly.

Ammonia does not transport oil through the system. It collects in the evaporator, or chiller barrel, and must be drained regularly, and treated as a hazardous waste product. Fresh oil must be added to the refrigerant system to ensure lubrication of the compressors. An average rink will drain and replace close to a barrel of oil annually, depending on how heavily the rink is used. This adds approximately $500 to $1,000 to the operating cost every year.

In this arena, eight large water to water heat pumps were used in place of a traditional ice plant (Figure 1). The heat pumps are designed to operate at source temperatures as low as 0°F (-18°C). They are designed to produce water to temperatures as high as 125°F (51°C). Each of the heat pumps contains approximately 12 pounds (5.5 kg) of HFC refrigerant R404A. The entire refrigeration system of eight units contains approximately 10% of the refrigerant of a traditional refrigeration system, and it is contained in eight independent units. Since this is a non-toxic refrigerant, there is no need for the same level of safety considerations.

The eight separate heat pumps are piped as four pairs. Each pair of heat pumps is piped with two pumps connected to the chilled fluid side and two pumps to the hot fluid side. The chilled fluid can be circulated either to the ice surface piping, the thermal storage buffer or the earth loop to pick up heat. The heated fluid can be circulated either to the building heating system or the earth loop, based on the temperatures in the building. This arrangement provides a high degree of redundancy

Figure 1. ***Eight low temperature water-to-water heat pumps provide approximately 84 tons of refrigeration at ice rink temperatures. The heat pumps reject heat either directly to a radiant floor heat system or to a horizontal earth loop.***

HUMIDITY AND TEMPERATURE CONTROL IN THE ICE AREA

Humidity control is important in an ice arena, especially if the ice surface will be used in warm weather. Condensation will form on the ice surface if the humidity is too high, creating a significant load on the refrigeration equipment. Each pound of water that condenses on the ice surface absorbs over 1,100 Btu (0.33 kW) of energy. Steel at the ceiling above the ice area radiates heat to the cold ice below it. Warm air at the ceiling will condense on the cold steel, eventually causing rusting and structural damage. It can also collect and drip onto the ice, creating bumps on the ice.

Figure 2. ***Dehumidification, air conditioning and heating are provided by a 20-ton heat pump in the ice area. The unit can cool and reheat 40-50°F (5-10°C) air. It can also cool or heat the arena by either rejecting or drawing heat from the horizontal earth loop.***

A heat pump designed specifically to provide dehumidification is installed in the ice area (Figure 2). The heat pump is designed to cool the air enough to condense the moisture from the air. Heat from the cooling process plus compressor heat reheats the air to provide warmer, drier air. The heat pump is also connected to the earth loop through a fluid to refrigerant heat exchanger. If the air temperature in the ice area is satisfied, the heat can be rejected to the earth loop, and the unit is used to provide approximately 16 tons (56 kW) of air conditioning. It can also be used when the facility is used for other activities, such as inline hockey or lacrosse during the summer.

The heat pump can also be used to extract heat from the earth loop if additional heat is needed in the ice rink area. It will provide approximately 200,000 to 250,000 Btu/h (59 to 73 kW), depending on the earth loop temperature.

The spectator stands are heated with radiant floor heat piping embedded in the precast concrete bleachers (Figure 3). The warmed seats provide heat where it is most needed. If snow is tracked into the seats, or a drink is spilled in the stands, it is melted and evaporates quickly, reducing cleanup time and potential liability from someone slipping on wet concrete.

Figure 3. Much of the building, including the spectator seating, is heated with a radiant floor heat system. The warm floor dries snow that is tracked from outside into the building and reduces the opportunity for mildew growth in the change rooms.

BUILDING HEATING AND COOLING

The ice surface and the Thermal Storage Buffer[1] are the primary heat source for the low temperature water to water heat pumps. Only when both the ice and the buffer temperatures are satisfied, and the building still needs heat, do the heat pumps extract heat from the earth loop. The building radiant floor heat system, the domestic hot water and snow melt are the primary heat sink for the heat pumps. Only when the building temperature is satisfied do the heat pumps reject heat to the earth loop. Conventional ground source heat pumps are connected to the earth loop to provide heating and air conditioning to the office areas (Figure 4).

A large site allowed the construction of a horizontal earth loop. The loop is a secondary heat source and secondary heat sink for the main heat pump system, storing excess heat that can't be used. It is the primary heat source/heat sink for the conventional forced air heat pumps, domestic hot water heat pump and the dehumidification unit.

Domestic hot water is preheated using a double wall heat exchanger. When hot water is used in the building in showers or flooding the ice, make-up water is preheated to about 75 to 85°F (25-30°C). A water to water heat pump operating directly from the earth loop heats the water to 120°F (50°C) (Figure 5).

Figure 5. A 10-ton water-to-water heat pump draws heat from the earth loop to produce service hot water (showers and ice flooding) at 120°F (50°C)

Heat removed from the ice is either used directly to provide space heating or domestic hot water, or is stored in the earth loop. This type of facility is very cooling dominant, and the earth loop becomes saturated with heat when the ice

[1] US Patent #6,170,278, Canadian Patent #2,273,760

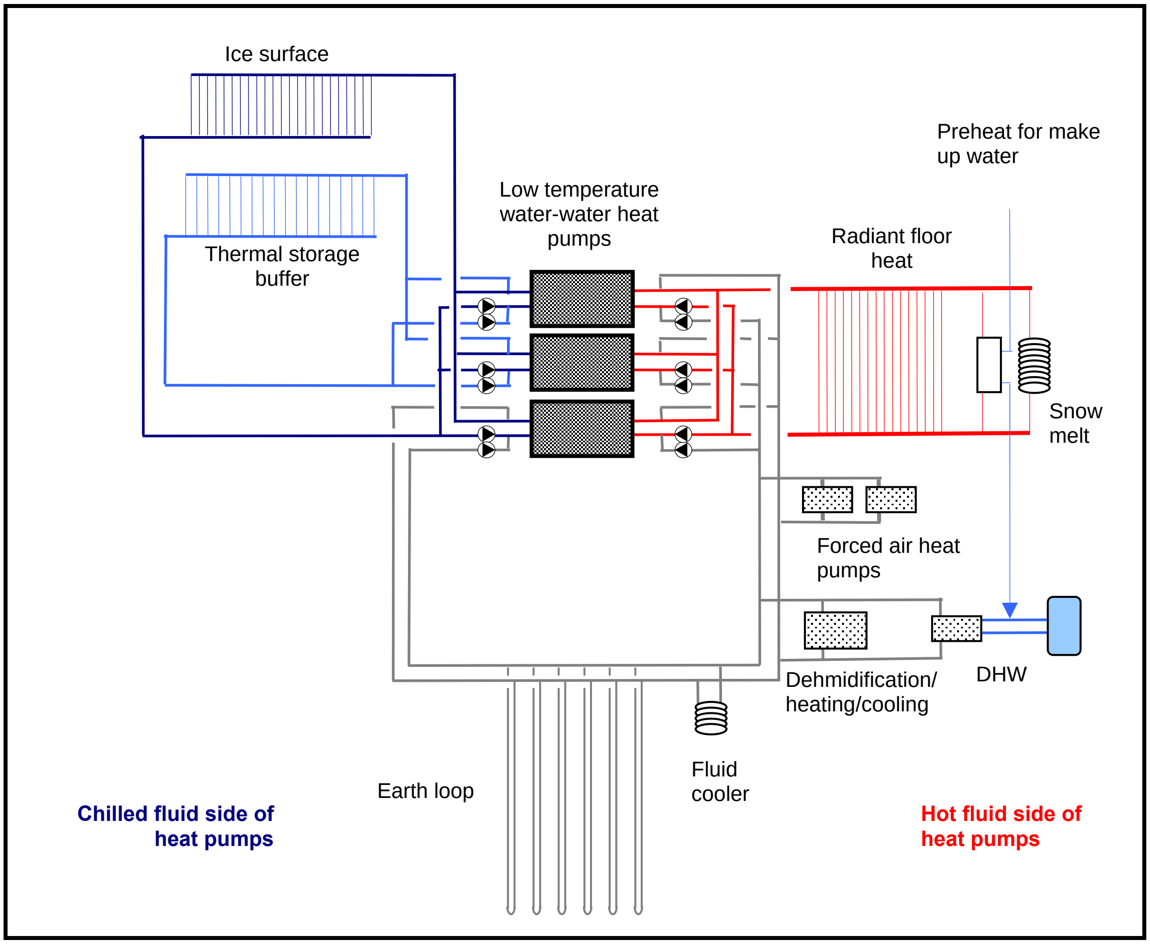

Figure 4.

is used in summer. A fluid cooler is used to prevent the earth loop from becoming overheated.

Air from the change rooms is continuously exhausted using a heat recovery ventilation (HRV) system. Fresh air from the HRV is introduced to the ice area. Air from the ice area is drawn into the change rooms through intake grills from the ice area.

THERMAL STORAGE

The patented rink floor design provides thermal cold storage directly beneath the ice surface. It provides several advantages over a conventional thin rink floor design:

- The large mass maintains a more consistent ice temperature than a floor with little storage. This is especially noticeable when the ice is being heavily used and resurfaced often.
- The large mass of the floor is "sub-cooled" several degrees lower than the ice surface when the ice is not being used. This is the heat source used for the heat pumps to heat the building, while simultaneously providing a significant amount of refrigeration for the ice when it is being heavily used.
- The sub-cooled buffer provides a significant portion of the refrigeration during peak use. Both the refrigeration capacity and the fluid circulation pumps required to maintain the ice surface during peak use can be reduced. A conventional system would require a 20 to 30-hp circulation pump for the ice surface and a 7.5 to 10-hp circulation pump for the curling rink. Four 3-hp circulation pumps provide the flow for both the ice surface and the curling rink. This reduces the refrigeration load created by friction losses in the rink
- surface pipe by 57 to 70% compared to a facility with a conventional thin floor.
- In the event of a power failure, the mass of the rink floor will maintain the ice for up to 3 days.

INTEGRATING SYSTEMS WITH AN EARTH LOOP

The integration of the entire system revolves around the earth loop. The facility is built on a large site that allows space for a horizontal earth loop (Figure 6). An area was excavated behind for the installation of the earth loop. All heat pumps in the system are connected to the earth loop. The large water-to-water refrigeration units use the earth loop as a secondary heat source when the ice temperature is satisfied, and a secondary heat sink when the building temperature is satisfied. The forced air heat pumps in the office spaces, the water-to-water heat pump that produces hot water for showers and flooding the ice, and the dehumidification/heating/air conditioning unit are all connected directly to the earth loop, and either pull heat from it, or reject heat into it as needed.

Figure 6. This photo shows the installation of the horizontal earth loop at 100 Mile House, BC. 50,000 feet (15,200 m) of 1 inch (25 mm) pipe was installed to a depth of 8 feet (2.4 m).

The primary benefit of integrating all the systems into a common earth loop takes advantage of the thermal storage capacity of the earth. In a building such as the South Caribou Recreation Centre, the water-to-water heat pumps used to make the ice either reject heat directly to the building radiant floor heat system, or to the earth loop. Since only a portion of the heat taken from the ice can be used in the building directly, even during a cold winter day, the earth loop is constantly being recharged by "waste heat" taken from the ice.

Heat pumps operate more efficiently and have higher heating capacity when the source temperature is higher. The heat pumps used for space heating and heating water typically operate with an earth loop of 55-70°F (13°C), and operate at a COP between 4.4 and 5.4.

In spring and fall when less heat is needed in the building, the earth loop temperature typically climbs to 80-90°F (27-32°C). To prevent the earth loop temperature from climbing even higher, an evaporative fluid cooler was installed. During peak use of the ice the fluid cooler works in parallel with the earth loop to reduce the load on the loop. More importantly, at night when the building is not being used, the fluid from the earth loop is circulated through the fluid cooler to take advantage of cooler night time temperatures to drop the loop temperature. This allows the loop to absorb heat more readily during peak use the following day.

SYSTEM ECONOMICS

The cost of installing a geothermal system is typically higher than the cost of installing a conventional system. This holds true with an integrated geothermal ice rink application as well. The building qualified for a Commercial Building Incentive Program (CBIP) from Natural Resources Canada (NRCan) of $60,000. The capital cost of the integrated system is compared to the estimated cost of installing a conventional refrigeration plant and heating system in Table 1. As is often the case, the difference in cost of the two systems is typically the approximate cost of the installation of the earth loop.

The additional cost of installing the integrated system is offset by lower energy costs as well as lower operating and maintenance costs. The energy costs of the facility are shown in Figure 6, along with a comparison of the energy costs of a typical conventional system. Annual energy cost savings are estimated at approximately $48,000 annually.

Operating and maintenance costs for a conventional refrigeration plant are typically much higher than the cost of maintaining other mechanical equipment. Ice rink owners and operators typically budget approximately $14,000 to $17,000 annually for maintenance costs.

Table 1.

	Integrated System	**Conventional System***
Refrigeration heat pumps, circulation pumps, rink floor	$575,000	$525,000
Horizontal loop	$105,000	---
Building heating, cooling, ventilation	$112,000	$96,000
Incentives (NRCan / CBIP)	($60,000)	---
Connecting Curling Arena Refrigeration	$30,000	---
Dehumidification	$72,000	$110,000
Domestic hot water	$34,000	$18,000
Total	**$868,000**	**$749,000**

** estimated cost of conventional system*

Some of the costs of operating a conventional ammonia ice plant include:

- Oil to lubricate the compressor (ammonia vapor does not transport oil from the evaporator (chiller barrel) back to the compressor – it must be drained regularly and replaced. Typical cost is approximately $500-1,200 annually. The waste oil must then be disposed of appropriately
- Compressor rebuilds. A conventional reciprocating ammonia compressor must be rebuilt after approximately 6,000 to 8,000 hours of runtime, at a typical cost of $6,000 to $12,000. With the schedule of this facility, one compressor would typically be rebuilt every year.
- In most jurisdictions it is required that an industrial refrigeration plant must be monitored regularly.

Typically a rink operator must check the operating pressures and flows of the system 4-6 times per day (1.5-3 hours per day) This time is taken away from other needs in the facility.

- Special circumstances. The integrated geothermal system is designed with a high level of system redundancy. The design includes eight independent water-to-water heat pumps designed to operate with four sets of circulation pumps. If a heat pump or circulation pump fails, the other heat pumps and circulation pumps simply carry on to maintain the ice. If the single circulation pump, or one of two or three large compressors fails, the system must be repaired immediately, often at emergency service rates.

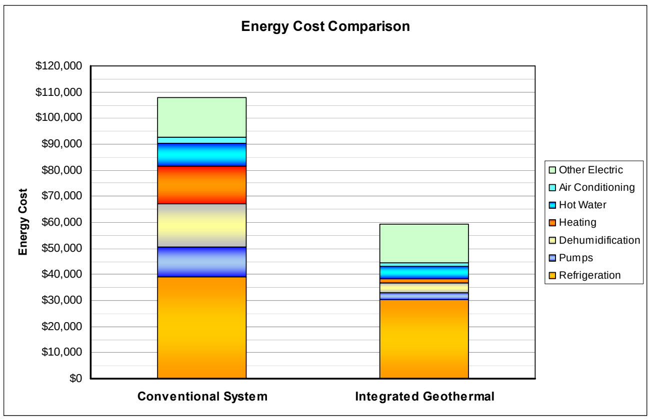

Figure 6. ***The actual energy cost of the facility in 2004 was slightly over $60,000. Energy consumption was 1,195,000 kWh, with a peak electrical demand of 257 kW. The total energy consumption of a comparable rink with a conventional refrigeration plant and gas fired heating system is estimated at approximately $107,000 annually. Heating, service hot water and dehumidification would typically be done with gas equipment. Gas costs for a conventional system in this building are estimated at approximately $40,000 annually.***

The water-to-water heat pumps do not require compressor rebuilds. Oil does not have to be drained from the system regularly. The size of the compressors of the water-to-water heat pumps and built in redundancy of the system eliminates the much of the daily operating cost of the system and reduces the cost of service. Similar ice rink facilities report operating and maintenance costs of $4,000 to $5,000 annually after several years of operation.

The simple payback of the system installed in 100 Mile House is estimated at approximately two years if the NRCan / CBIP incentive is included, and approximately three years if no incentive is considered.

OVERALL SUMMARY

Building Description:

- Occupancy: Hockey arena, curling arena, office space
- Location: 100 Mile House, BC
- Gross Floor Area: 56,400 square feet (5,241 square meters)
    - Arena: 28,600 square feet (2,498 square meters)
    - Offices, change rooms, lobby: 15,400 square feet (1,430 square meters)
    - Curling Arena: 9,000 square feet (836 square meters)
    - Curling Lobby & Lounge: 3,600 square feet (335 square meters)
- Construction
    - Hockey Arena: new construction, well insulated
    - Curling Arena: retrofit
- Completion Date: 2002
- Heating Degree Days (below 64.4°F / 18°C): 9,076 / 5,042

System Description:

- Refrigeration heat pumps (hockey and curling combined): 88 tons (310 kW)
- Hockey Arena climate control
    - Humidity control: 15 tons (52.8 kW)
    - Cooling: 15 tons (52.8 kW)
    - Heating: 230,000 Btu/h (68.6 kW)
- Heating / cooling (offices, change rooms, lobby etc.): 24 tons (84 kW)
- Fluid: Methanol 30%, & water
- Circulation pumps
    - Refrigeration heat pumps (Hockey and Curling Arenas)
        - 4 3-hp circulation pumps building heating system / earth loop
        - 4 3-hp circulation pumps for ice floor circulation / earth loop
    - Heating / cooling heat pumps
        - 1 3-hp circulation pump
- Earth Loop: Horizontal earth loop, buried to 8 feet (2.4 meters), 50 circuits of 1” (25 mm) HDPE SDR11 pipe, 1,000 feet (300 m) length

Special Features:

- Thermal storage buffer floor (patented) design to minimize peak refrigeration demand and maintain constant ice temperature
- Optimized rink pipe layout to reduce pumping power requirements
- Earth loop to store excess heat and provide additional heat as needed

SUNDOWN M RANCH
YAKIMA, WASHINGTON

Dr. R. Gordon Bloomquist, Ph.D.,
Washington State University Energy Program

Photo credit: http://www.sundown.org/

BUILDING CHARACTERISTICS

The Sundown M Ranch, located just northwest of Yakima, Washington, is a drug and alcohol rehabilitation center for both youths and adults. The 134,880 ft^2 (12,531 m^2) complex was built in several phases beginning in 1985 with the adult facility totaling 77,300 ft^2 (7,181 m^2), followed by a family annex of 20,650 ft^2 (1,918 m^2) in 1990, a 39,730 ft^2 (3,961 m^2) youth facility in 1992, and the 7,200 ft^2 (669 m^2) administration building in 1995. The facility also provides laundry and food services for the patients. The buildings are stick-built wood frame, low-rise residential style. The buildings are well insulated and use primarily fluorescent lighting.

The residences are occupied 24 hours per day, while other facilities are normally occupied during normal office hours except for the gym that has an intermittent occupation pattern.

GEOTHERMAL HEAT PUMP SYSTEM CHARACTERISTICS

A process schematic is shown in Figure 1.

Geothermal Source Description

The complex is served by two production wells at ca 57ºF (13.9ºC) and one injection well. The main well is approximately 200 ft (61 m) deep, and provides 360 gpm (22.7 L/s) via a 15-hp (11 kW) submersible pump. The second well is 187 ft (57 m) deep and supplies 260 gpm (16.4 L/s). It has a 15-hp (11 kW) submersible pump. After passing through the heat pump, the water is injected or used for irrigation during the summer months. The well pumps are run 24-hours per day at constant speed. Flow is controlled through the use of throttling valves. There are also two domestic water wells on the property. In addition to use for heating and cooling and domestic purposes, the wells together can supply a maximum of 1,100 gpm (69.4 L/s) for fire protection.

Heating, Ventilation, and Air Conditioning (HVAC) System Description

The various facilities are served by a combination of heat pumps and heat pump unit ventilators (Figure 2). Water is circulated in an open loop to each building. Circulating pumps serves to boost the flow through the various buildings. A total of 297 heat pumps supply the complex comprised of 257 1-ton (3.5 kW) heat pump unit ventilators, 12 3-ton (10.5 kW) units, and 28 5-ton (17.6 kW) units for a total of 433 tons (1,523 kW). In addition, there are four 5-ton (17.6 kW) water-to-water heat pumps in the adult building for hot water and two 5-ton (17.6 kW) units with back-up electric water heaters serving the youth facility (Figure 3). There is a 1,000 gallon (3785 L) hot water storage tank in the adult facility.

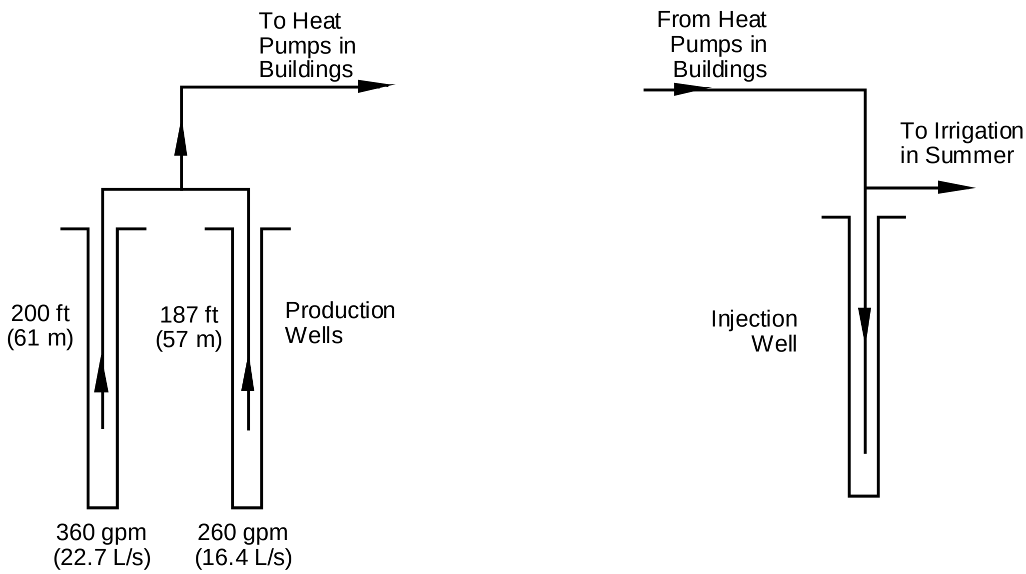

Figure 1. Process schematic of Sundown M Ranch.

SELECTION OF THE GEOTHERMAL HEAT PUMP SYSTEM

The geothermal heat pump system was selected upon the recommendation of the serving utility, Pacific Power and Light; the availability of adequate supplies of reliable warm water; a desire for energy efficiency; and a guaranteed reduction in electrical rates by the serving utility if the heat pump system was installed. They were also very interested in having the ability to provide individual room control.

OPERATING HISTORY

The system has been built-out over 14 years, with additional buildings added every few years. The system has performed as expected, and has experienced few operating problems. The fact that for each subsequent phase of the build-out, the decision has been to continue with geothermal heat pumps is a good indication of the system's excellent operational performance.

OPERATION AND MAINTENANCE ISSUES

The system is operated and maintained by in-house staff. Since the well pumps are not equipped with variable speed drives, the pumps must be operated 24 hours per day. Flow is controlled by use of a throttling valve. In summer use, the water coming out of the loop is used for irrigation purposes and in certain cases this can reduce the water available to the loop to the extent that the system does experience some high head problems on the heat pumps.

Each heat pump has a valve that opens or closes depending on whether the heat pump is on. The heat pumps and unit ventilation have outdoor air access and are controlled by thermostats.

Figure 2. Console heat pump.

Figure 3. Water to water heat pump.

The one on-going operational problem has been associated with the injection well. The well tends to plug up and will not accept the return flow. This in turn causes a pressure build up in the injection system and often results in broken PVC pipes. Because of this, the well is now cleaned every six months by reversing the flow. Chlorine is also added to kill organic material that is the source of the plugging.

Since going into operation in 1985, compressors have been replaced on 11 unit ventilators and 3 heat pumps. Three fan motors have also been replaced. Once a month they change filters and back flush the coils on each heat pump, and check the screens going into each unit ventilator.

Every six months, they do a thorough inspection of all heat pumps and unit ventilators including coils, fans and motors, water flow, and operation. Once a year, they do a thorough cleaning of the heat pumps and coils.

Annual maintenance costs are running \$0.12 to \$0.15 ft^2 (\$1.29-\$1.61/m^2).

SYSTEM ECONOMICS

Because of the phased build-out of the system over the past 14 years, there are no records available in relation to overall system costs. The owners, however, feel that the system has been very economic to operate, and the annual maintenance costs of \$0.12 to \$0.15/ft^2 (\$1.29 to \$1.61/m^2) is very acceptable.

SATISFACTION WITH THE SYSTEM

The owners and operators of the complex seem to be very satisfied with the system. It has been economic to operate, requires only normal maintenance and a very few units have required repair or replacement. Operational staff indicated that there was less than 100 percent satisfaction on the part of some patients due to the fact that the units do not provide instantaneous heat. They get on the average of one complaint per month.

OVERALL SUMMARY

Building Description:
Location: Yakima, WA
Occupancy: Drug rehabilitation
Gross Floor Area: 134,880 ft^2 (12,531 m^2), multiple buildings
Type of Construction: New
Completion Date: 1985-1995
July Avg. High Temp.: 87°F (30.6°C)
Jan Avg. Low Temp.: 21°F (-6.1°C)
Annual Heating Degree Days: 6012°F-day (3340°C-day)
Annual Cooling Degree Days: 465°F-day (258°C-day)

Interior System:
Total Installed Heat Pump Capacity: 433 tons (1523 kW)
No. of Heat Pump Units: 297 water-to-air, 5 water-to-water
Heat Pump Capacities: 1, 3 and 8.5 ton (3.5, 10.5 and 17.5 kW) water-to-air; 5 tons (17.5 kW) water-to-water

Ground-Source System:
Type: Open loop
Mean Groundwater Temp.: 57°F (13.9°C)
Configuration: 2 production wells, 1 injection well
Well Depths: 187-200 ft (57-61 m)
Pumping Rates: 620 gpm total (39 L/s)

Economic Analysis:
Installed Geothermal HVAC Capital Cost:
unavailable
Total Annual Building Energy Use:
20.07 kWh/ft^2 (216 kWh/m^2)
Annual Maintenance Costs:
\$0.12-\$0.15/ft^2 (\$1.29-\$1.61/m^2)

INN OF THE SEVENTH MOUNTAIN
BEND, OREGON

Dr. R. Gordon Bloomquist, Ph.D.,
Washington State University Energy Program

BUILDING CHARACTERISTICS

The Inn of the Seventh Mountain is a hotel/condominium complex located approximately seven miles (11 km) from Bend, Oregon, on the road to the Mt. Batchelor ski area, about 175 miles (280 km) south of Portland. The Inn was first built in 1972, and consists of 22 individual condo buildings containing 350 units for a total of 248,800 ft^2 (23,115 m^2). The complex contains restaurants, a conference center, ice rink, spa, and other amenities common to a first-class destination resort. The complex is of wood construction. Heat was originally provided with resistance electric ceiling heat. Most of the lodging units are three stories. The buildings were built to meet the energy codes of the early 1970s, and according to operation staff under insulated. Windows are all double-paned.

GEOTHERMAL HEAT PUMP SYSTEM CHARACTERISTICS

A process schematic is shown in Figure 1.

Geothermal Source Description

The geothermal source is provided by one well located close to the central heat pump plant. Water flow is 1,150 gpm (72.5 L/s) at 50ºF (10^{o}C). The production well is 400 ft (122 m) deep. Pumping is provided by a 225-hp (168 kW) variable speed pump. After passing through heat exchangers (Figure 2), the water is disposed of through an injection well located near the edge of the property.

Heating, Ventilation, and Air Condition (HVAC) System Description

The central heat pump system consists of two 250-ton (879-kW) screw compressor heat pump/chillers (Figure 3). Originally, when the retrofit to heat pumps took place in 1992, one 300-ton (1053 kW) centrifugal unit was installed but, because it was oversized, it continued to surge and would not stay on-line. The two 250-ton (879-kW) screw compressors have proven to be much more satisfactory. The heat pump/chillers are separated from the geothermal source through the use of two plate and frame heat exchangers. Distribution of hot [ca 115ºF (46^{o}C)] or chilled [50ºF (10^{o}C)] water is via a four-pipe distribution system. The distribution system is centrally controlled for optimum temperature balance and energy use. The four-pipe system supplies fan coil units distributed throughout the condo units and other buildings. Hot water from the distribution system also preheats the domestic hot water supply to buildings. The swimming pool, spa tubs, and the bath house are also heated by the heating loop. The chilled water loop serves as the condenser water for the ice ring.

SELECTION OF THE GEOTHERMAL HEAT PUMP SYSTEM

By the late 1980s, the 1972 complex was beginning to experience problems with the ceiling electric resistance heating units, and there was an increasing need to be able to provide air conditioning during the summer months. The owners first looked at replacing the system with gas heating and gas absorption cooling. The servicing electric utility, however, recommended the geothermal heat pump option as a means to meet both heating and air conditioning requirements and provided incentives to the owners. The conversion was made at an investment of ca $3 million. The conversion project resulted in a 49 percent savings in metered energy, but only a 3 percent savings in energy costs. However, it must be remembered that the system now also provides air conditioning that was not provided by the system replacement.

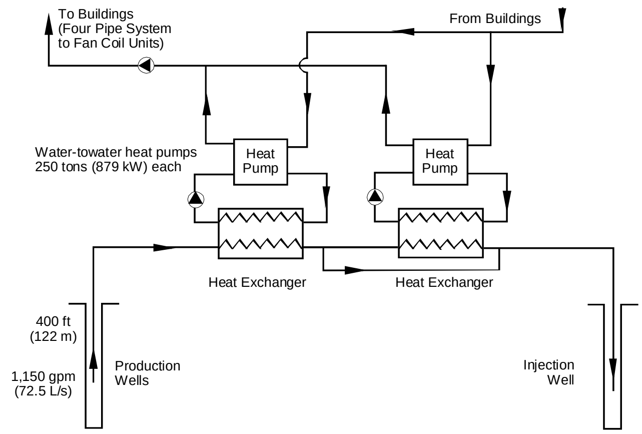

Figure 1. The process schematic for the Inn of the Seventh Mountain.

Figure 2. Photograph of one plate and frame heat exchanger at the Inn of the Seventh Mountain.

OPERATING HISTORY

When the conversion from electric ceiling resistance units to a central geothermal heat pump system was made, the decision was made to go with one 300-ton (1053 kW) centrifugal heat pump/chiller. This, however, proved to be a poor choice, and during light loads, the unit was considerably oversized and continued to surge and would not stay on-line. After only a short period of time, it was decided to replace the 300-ton (1053 kW) centrifugal unit with two 250-ton (879 kW) screw compressor units. These units also suffered some initial problems due to faulty thrust bearings, and both motor assemblies had to be replaced within the first year. However, after these initial design and equipment problems, the system has operated as expected and with minimal operational or maintenance problems.

Figure 3. Photograph of one of the water-to-water heat pumps at the Inn of the Seventh Mountain.

The only short coming of the system is that there is no central control over thermostats in individual condo units, thus when units are not occupied, there is no way to monitor or control temperature levels. This has resulted in many unoccupied units being heated or cooled needlessly and, of course, with a substantial waste of energy and with a significant cost penalty.

OPERATION AND MAINTENANCE

The system has operated extremely well since initial problems associated with the centrifugal heat pump/chiller and motor thrust bearings were solved. In neither case was the problem a result of or caused by the geothermal source. Maintenance and operation are both taken care of by an experienced and very competent in-house staff.

SYSTEM ECONOMICS

The $3 million retrofit to geothermal heat pumps resulted in a 49 percent reduction in metered electrical energy consumption, and a 3 percent reduction in overall energy cost, while at the same time providing air conditioning. The total energy consumption for the facility is 24.47 kWh/ft^2/yr (263.4 kWh/m^2/yr), while the heat pump plant uses 10.14 kWh/ft^2/yr (109.1 kWh/m^2/yr). Annual maintenance cost for the past several years have averaged approximately $0.18/ft^2 ($1.94/m^2). The annual energy usage as well as the maintenance cost is somewhat of an over estimate, as the system also provides heating to two swimming pools and the spa pools, and the chilled water. loop serves as the condenser water for the ice ring.

SATISFACTION WITH THE GEOTHERMAL HEAT PUMP SYSTEM

Operation and maintenance staff are both extremely happy with how the system has operated and the lack of maintenance problems that have occurred. The system seems to provide a high level of comfort to guests. It would appear that even greater energy and cost savings would be possible if the system were set up so that individual units could be monitored and thermostats adjusted when the units were unoccupied for any extended length of time.

ACKNOWLEDGEMENT

The author wishes to thank Jon Menzic, the director of facilities for the Inn of the Seventh Mountain and Clark Satrae of Pacific Power and Light for their assistance in obtaining data.

OVERALL SUMMARY

Building Description:

Location: Bend, OR

Occupancy: Hotel/condominium resort

Gross Floor Area: 248,800 ft^2 (23,115 m^2), 22 buildings

Type of Construction: Retrofit

Completion Date: Buildings in 1972, heat pump retrofit in 1992

July Avg. High Temp.: 81.7°F (27.2°C)

Jan Avg. Low Temp.: 23°F (-5.0°C)

Annual Heating Degree Days: 4490°F-day (2494°C-day)

Annual Cooling Degree Days: 12°F-day (7°C-day)

Interior System:

Total Installed Heat Pump Capacity: 500 tons (1758 kW)

No. of Heat Pump Units: 2 water-to-water

Heat Pump Capacities: 250 tons (879 kW)

Ground-Source System:

Type: Open loop

Mean Groundwater Temp.: 50°F (10°C)

Configuration: 1 production well, 1 injection well

Well Depths: 400 ft (122 m)

Pumping Rates: 1,150 gpm (72.5 L/s)

Economic Analysis:

Installed Geothermal HVAC Capital Cost:
$3 million

Total Annual HVAC Energy Use:
10.14 kWh/ft^2 (109.1 kWh/m^2)

Total Annual HVAC Energy Savings:
49% plus the additional benefit of cooling

Annual Maintenance Costs:
$0.18/ft^2 ($1.94/m^2)

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