NORTH AMERICAN MONITORING OF A HOTEL WITH ROOM SIZE GSHPS

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ABSTRACT

This paper presents the first 12 months of monitored performance data for a ground-source hotel in Geneva, NY, USA. The 149-room lake front hotel has several unique features including a ground loop that is partially incorporated into the building's structural pilings and a heat pump water heating system that is integrated into the ground loop of the space conditioning system. The monitored data indicate that the innovative ground loop performed well with loop temperatures ranging between 40°F [4°C] and 80°F [27°C] across the year. The pilings portion of the ground loop were found to have better heat transfer performance than the conventional bore field, especially in the winter when heat was extracted from the ground. Heat extraction performance was better for the pilings at least in part because the building tended to shelter the pilings from ambient conditions. Water heating loads at the hotel were substantial. The integration of the water heating heat pumps into the system reduced the summer heat rejection loads by more than 15%. Variable speed loop pumping dramatically reduced system energy use by 92% compared to a conventional constant speed pumping system. Overall, this system demonstrates the performance benefits of geothermal heat pump systems and shows how the integration of water heating into the system enhances system performance and reduces first costs.

INTRODUCTION

Geothermal or ground-source heat pumps (GHPs) are becoming increasing popular in many commercial buildings. GHP systems offer the advantage of lower operating and maintenance costs compared to conventional HVAC systems. Geothermal heat pump systems are especially appropriate in applications where the benefits of using small single room heat pumps can be realized. Hotels are a good example of this type of application.

Hotels and motels in North America have traditionally used dedicated heating and cooling systems, such as packaged terminal heat pumps and air conditioners (PTHPs and PTACs), to provide independent control to each room. Another option frequently considered in hotels is the distributed water loop heat pump system, where individual water source heat pumps on a common water loop serve each room and a boiler and cooling tower add or reject heat to or from the loop as required. The water loop concept offers the benefit of more efficient heat pump operation but with the addition of a central plant. A geothermal heat pump system simplifies the water loop heat pump system by eliminating the cooling tower and boiler, thereby reducing maintenance costs, minimizing the floor space requirements for the central plant room, and further improving system efficiency. All heat is rejected to or absorbed from the ground loop heat exchanger.

The building-wide, integrated water loop also offers the ability for system integration and heat recovery, which can improve overall system efficiency and reduce installation costs. The water loop can be used as a heat source for heat pumps that provide domestic or service water heating as well as pool and spa heating. These water and pool heating loads are substantial and occur year round in a hotel, facilitating the efficient recovery of heat rejected to the loop for cooling. The integration of space conditioning and water heating into a common water loop system also reduces the net heat rejection imposed on the ground loop, allowing the size of the loop to be reduced (since most ground loop heat exchangers are sized based on the heat rejection loads).

This paper presents measured performance results for a 149 room lake-front hotel in Geneva, New York, USA, with a geothermal heat pump system. The GHP system includes an integrated heat pump water heating system that recovers heat rejected to the loop for service water heating. The system also uses an innovative ground loop that integrates about half of the ground heat exchanger into the building's structural pilings. The monitored performance results for the first 12 months of operation are presented and discussed.

BUILDING DESCRIPTION

The Geneva lakefront hotel is a 100,000 ft^2 [9,290 m^2] facility located on the north end Seneca Lake in Geneva, NY, USA. Figure 1 shows a photograph of the facility that houses a restaurant, common areas, meeting rooms, and 149 guest rooms. The hotel has 203 heat pumps with a total installed nominal capacity of 334 tons [1,175 kW]. Space conditioning heat pumps account for 284 tons [998 kW] of the installed capacity while service water heating and pool heating account for the remaining capacity. Four 10-ton [35 kW] water-to-water heat pumps supply all of the service hot water needs.

Table 1. Summary of Geneva Lakefront Hotel

Building	
Building Description:	Six story hotel and conference center, 149 rooms.
Building Size:	100,000 ft^2 [9,290 m^2]
Installed Capacity:	334 tons [1,175 kW]
Ventilation	
No. of Total Heat Recovery "Enthalpy Wheel" Units:	2
Manufacturer:	SEMCO FV-5000
Fresh Air Flow Rate:	10,000 cfm (5000 cfm to common areas) 34 cfm/room (0.10 cfm/ft^2)
Space Conditioning	
Number of Space Heat Pumps:	198 units, 284 tons [998 kW]
Size Range:	¾ – 5 tons [2.8 to 18 kW]
Manufacturer:	WaterFurnace SX series
Water Heating	
Water Heating Heat Pumps:	4
Size Range:	10 tons [35 kW]
Pool Heating Heat Pumps:	1
Loop Pumps	
Number of Loop Pumps:	2-staged, 1-backup
Size:	50 hp
Normalized Pump Power:	0.31 hp/ton w/ variable speed drives
Ground Loop	
Building Pilings	198 Pilings, 85 ft [26 m] deep, 33,660 ft [10,260 m] of pipe
Parking Lot Bore Field	120 Bores, 138 ft [42 m] deep, 33,120 ft [10,090 m] of pipe

About half of the ground loop heat exchanger is installed in the building pilings. Polyethylene pipe was incorporated into 198 pilings to an average depth of 85 ft [26 m]. The concrete pilings are arranged into eight circuits with a total pipe length of 33,660 ft [10,260 m] as shown in Figure 2. Each circuit includes 24 to 29 pilings from an area of the building as shown in the figure. Spacing between pilings is irregular, ranging from 2 to 15 ft [0.6 to 4.6 m]. The other half of the ground loop is 120 conventional bore holes that are 138 ft [42 m] deep and located under the parking lot near the lakeshore. The bores are spaced 15 ft [4.6 m] apart in a rectangular pattern. The total pipe length in the bore field is 33,120 ft [10,090 m]. One of the ten parking lot circuits used thermally enhanced grout.

Figure 1. Photograph of Lake-Front Hotel in Geneva, New York.

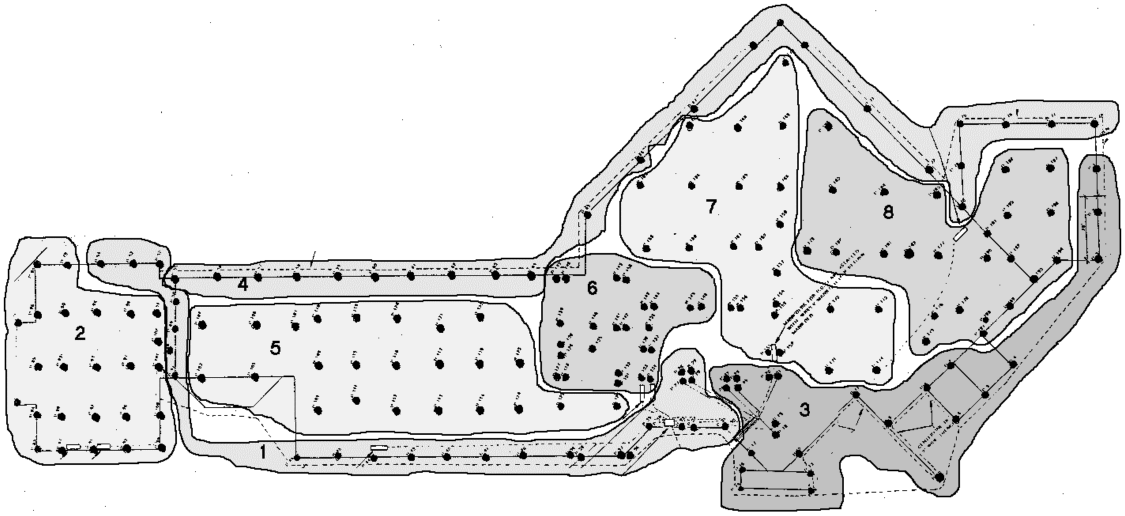

Figure 2. Piling Location and Circuit Layout under Hotel

Figure 3 shows the schematic of the integrated system with space conditioning heat pumps, variable speed loop pumps, the ground loop heat exchanger (including pilings and bore field), and water heating heat pumps. The water heating heat pumps are in parallel with the space conditioning heat pumps drawing water from the ground loop. During the summer the heat rejection load imposed on the ground loop by the space conditioning heat pumps is in part negated by the heat extracted by the water heating heat pumps.

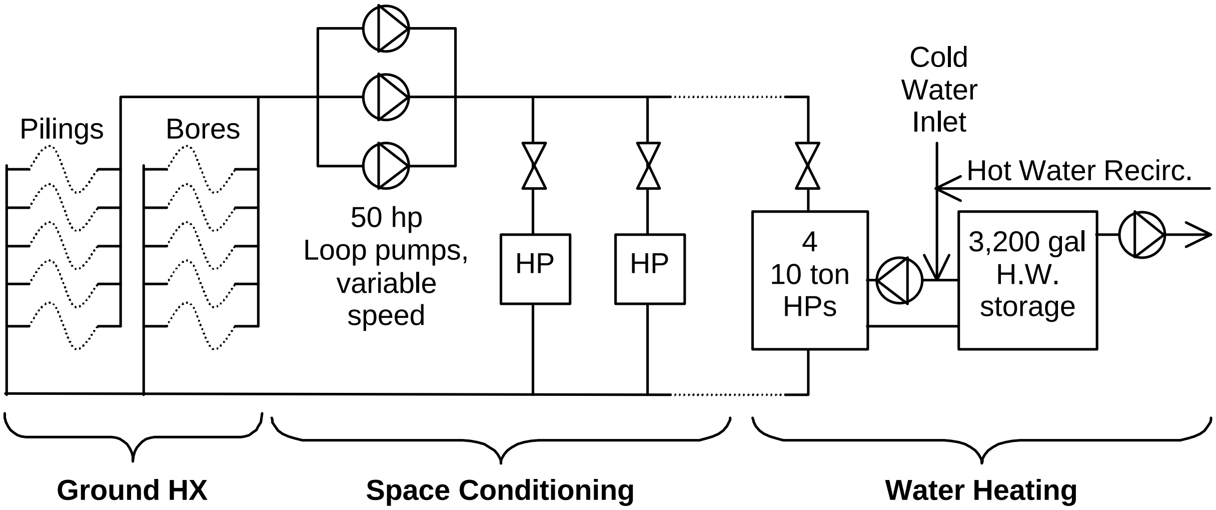

Figure 3. Schematic Representation of Integrated Geothermal Space Conditioning and Water Heating System

Each of the 149 guest rooms is conditioned by either ¾ or 1 ton [2.8 or 3.5 kW] heat pump. Most guest room heat pumps have a solenoid valve that only allows water flow through the heat pump when the unit operates. Figure 4 shows a typical heat pump with a solenoid valve. The 18 heat pumps on the sixth floor along with several units in the common areas do not have solenoid valves so that a minimum flow is maintained in the loop. Maintaining constant flow through the top floor units also eliminates stagnant water in the loop piping exposed to ambient in the attic. Common areas are conditioned with 1 to 4 ton [3.5 to 14 kW] heat pumps. The bypassed flow rate of the system with all solenoid valves closed is about 15% of the full design flow rate, or 120 gpm [7.6 l/s]. Each unit is controlled independently by a dedicated thermostat.

Figure 4. Typical Single Room Heat Pump Unit

Figure 5. Water Heating System Heat Pumps and Storage Tanks

The entire water heating load for the hotel is met by four 10-ton [35 kW] water-to-water heat pumps staged in series (no backup resistance elements are installed). Figure 5 shows the water heating heat pumps along with the accompanying storage tanks. Figure 6 schematically shows the configuration of the water heating system. The fourth heat pump was added in March 1998 to help alleviate the loss of hot water that occurs under peak load conditions. In conjunction with the heat pumps four 800-gallon [3,030 l] storage tanks provide 3200 gallons [12,120 l] of storage for the hotel. A pump pulls water from mid-tank through the heat pumps and re-injects at mid-level of the storage tanks. The building circulating pump cycles to maintain 110°F to 115°F [43°C to 46°C] return water from the building. The heat pump circulating pumps run continuously. The heat pumps stage on based on the water temperature entering the heat pumps. The set point was 120°F [49°C] from the storage tanks until December 1997 when it was changed to 135°F [57°C]. Water circulates through each heat pump regardless of its operation.

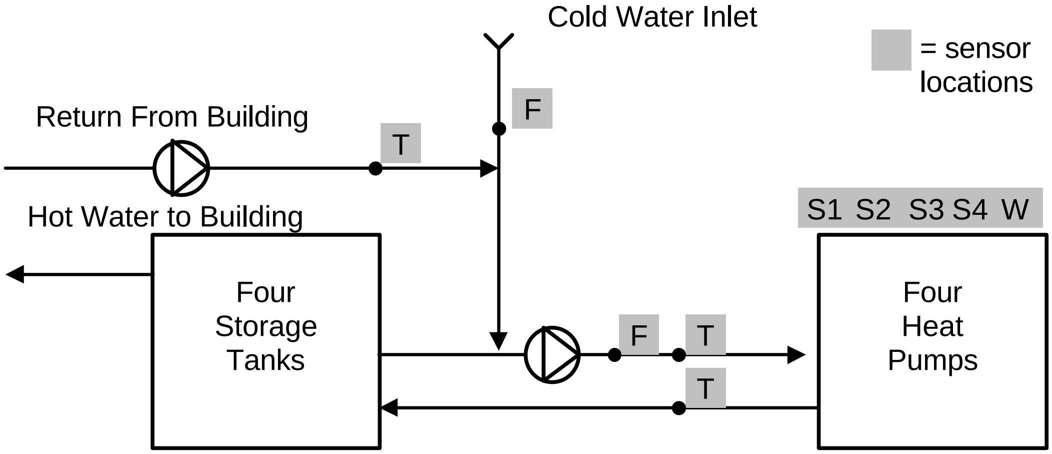

Figure 6. Schematic of the Domestic Hot Water System at Geneva Lakefront Hotel

MONITORING OBJECTIVES AND APPROACH

The goal of the field test was to quantify the performance of the geothermal heat pump system and demonstrate the benefits of the integrated space conditioning and water heating system. The specific goals of the monitoring effort were to:

1. Collect case study data to demonstrate the benefits of the geothermal system
    - measure building and HVAC energy use
    - quantify the water heating load
    - evaluate loop pumping system performance
    - quantify the performance of the integrated space conditioning and water heating system

2. Determine ground loop performance and quantify loop loads
    - compare piling and bore field heat transfer performance
    - compare thermally-enhanced and conventional grout in the bore field

Monitoring equipment was installed in the hotel to meet these project objectives. A dedicated datalogger[1] was installed in the mechanical room to collect the required data. Figure 7 schematically shows the locations on the monitored points in the main geothermal loop. These data points allowed the overall heat rejection and extraction loads to the ground loop to be quantified as well as the individual loads imposed on the pilings and bore field circuits. The temperature leaving each bore field circuit was also measured to compare the heat transfer performance of the enhanced and conventional grout (though, these results are not discussed in this paper). The energy use and operating state of the variable speed loop pumps were also monitored. Data were collected at 5-minute intervals throughout the monitoring period starting in May 1997.

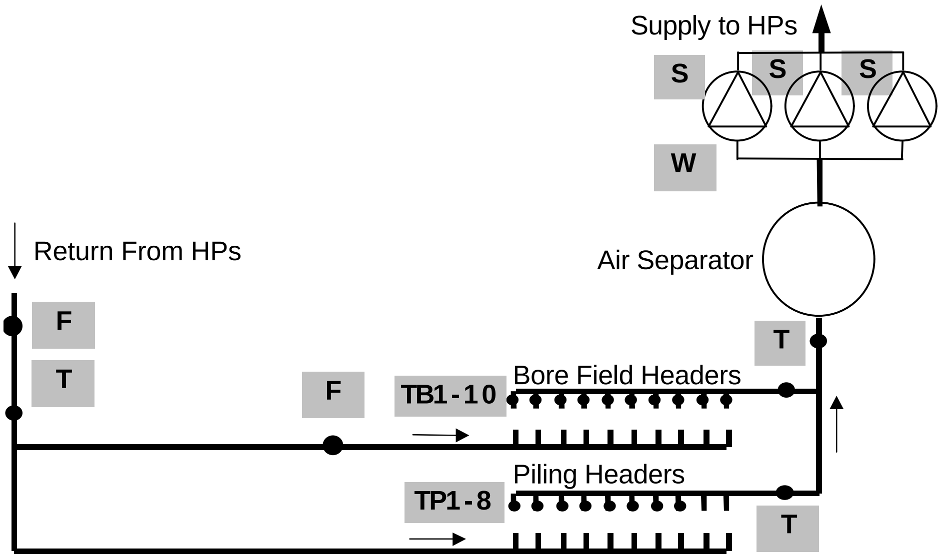

Figure 7. Schematic Location of Monitored Data Points

Data points were also monitored in the water heating system (see Figure 6) to measure total hot water use as well as system performance and efficiency. The heat rejection and extraction loads imposed on the loop by the water heating system were also quantified.

The electric energy use of the heat pumps could not be directly measured due to the layout of the electrical distribution system. Therefore, heat pump energy use was inferred from the total facility electricity data as well as the measured loop loads. The trend of total facility electricity use with ambient temperature was used to infer the portion of the facility loads attributable to the space conditioning heat pumps. This temperature-dependent portion of facility load was shown to agree well with the energy use derived from the measured heat rejection and extraction loads of the heat pumps and the expected COP of the heat pumps determined from the operating loop temperature. These inferred and derived estimates of heat pump energy use are shown in Figure 8. The comparable slopes on the plot show that the heat pump energy use estimated by these two independent methods are in close agreement. The measured loop loads and COP data are used to predict the heat pump energy use presented in the next sections.

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[1] The building's direct digital control (DDC) system was also evaluated as a possible means of data collection. However, a dedicated datalogger was selected because of its higher accuracy, larger data storage capabilities, and lower installation and data collection costs.

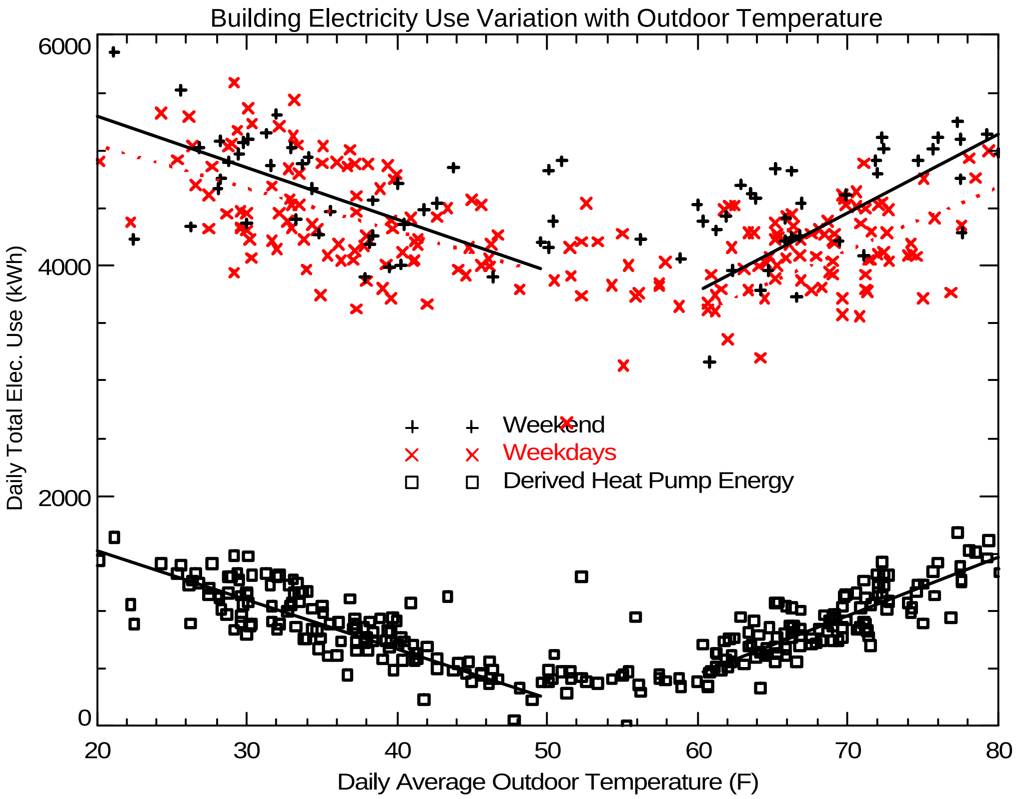

Figure 8. Comparing Heat Pump Electricity Use Inferred from Measured Facility Data and Derived Loop Heat Rejection Loads

RESULTS

Facility Energy Use

During the first 12 months of operation (June 1997 to May 1998) the facility used 1624,400 kWh or 16.2 kWh/ft^2-year [175 kWh/m^2-year]. Figure 9 shows the monthly energy use breakdown for the facility. The hotel is essentially an all-electric facility, with only a small amount of gas used for cooking in the kitchen. On an annual basis, HVAC (loop pumps and space conditioning heat pumps) accounted for only 3.5 kWh/ft^2-year [37.3 kWh/m^2-year] or 21% of the total facility energy use. Water heating energy use accounted for another 8% of facility energy use on an annual basis.

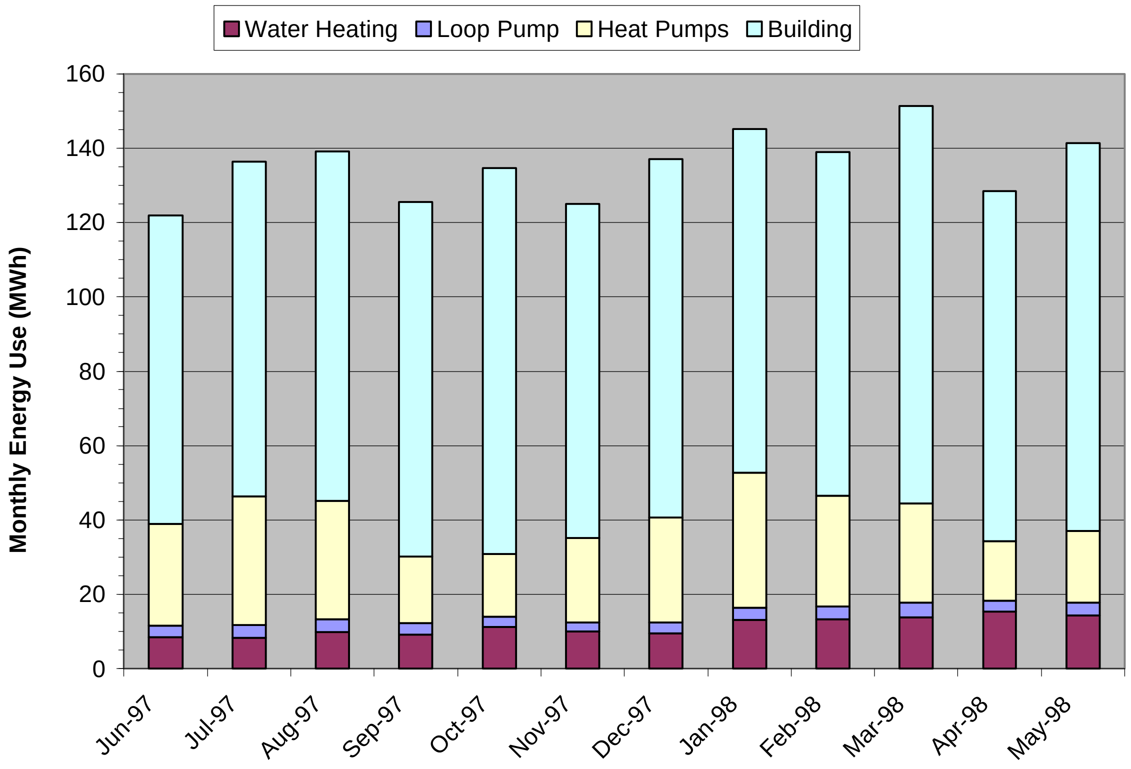

Figure 9. Monthly Breakdown of Facility Energy Use for the First Year

The loop pumps accounted for only 2% of total facility energy use and 11% of total HVAC energy use for the year, indicating that the variable speed pumping system worked well.

Loop Temperatures

The hotel was fully occupied starting in June 1997 and the loop temperatures remained modest throughout the first year of operation. Figure 10 shows the trend of loop temperatures to and from the ground loop for the 12 month period. The temperature from the ground loop (and supplied to the heat pumps) was always below 80°F [27°C] for the first summer and remained above 40°F [4°C] during the winter season. These modest temperatures imply that the ground loop was conservatively sized to meet the building loads.

Loop temperatures at the end of the first year (May 1998) were 10°F [6 °C] higher than during the same period in 1997, when the building was just opened and occupancy was modest. The peak loop temperature observed as July 1998 was about 86°F [30°C], or about 6°F [3°C] higher than was observed in 1997.

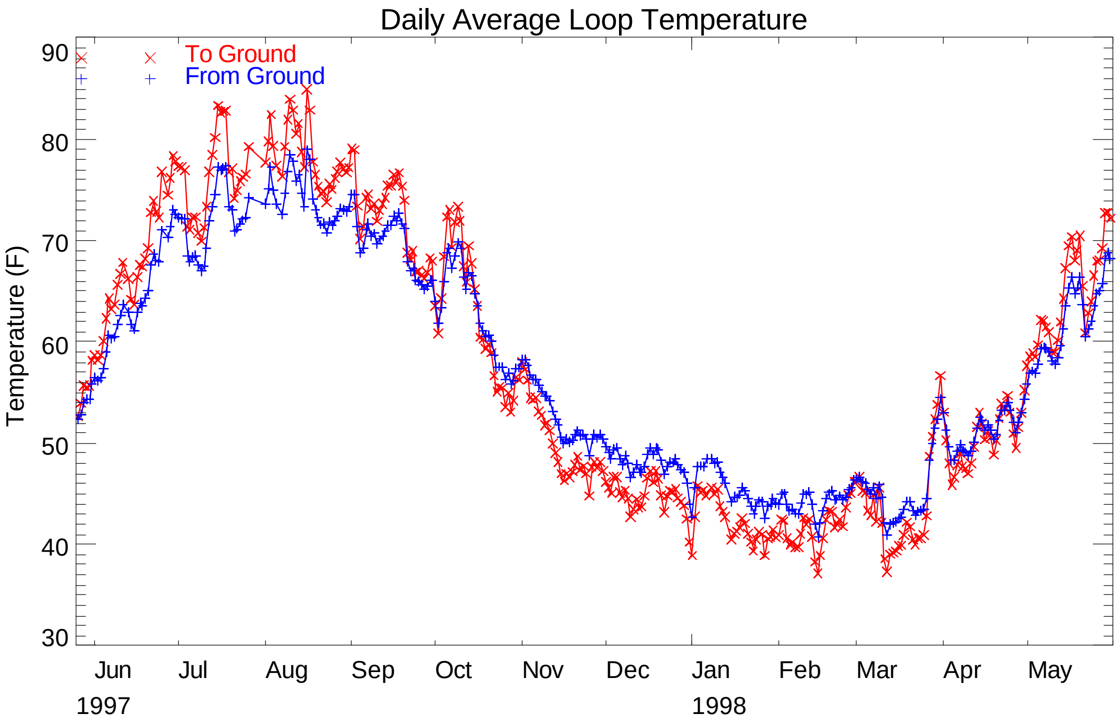

Figure 10. Annual Ground Loop Temperatures from Hotel

At these loop temperatures the space conditioning heat pumps operated very efficiently. The load-weighted average loop temperatures were 66°F [19°C] for cooling and 47°F [8°C] for heating. The seasonal efficiencies were estimated using these average loop temperatures and the manufacturer's performance data. The estimated seasonal COPs (listed in Table 2) are 4.4 for cooling and 4.0 for heating.

Table 2. Estimated Seasonal Efficiency of Space Conditioning Heat Pumps

	Average Entering Temperature (load weighted)	**Seasonal COP**
Cooling Season	66°F [19°C]	4.4
Heating Season	47°F [8°C]	4.0

Comparing Piling and Bore Field Heat Transfer Performance

The heat rejection and extraction loads on the pilings and bore field were separately measured to compare the heat transfer performance of the structural pilings to the conventional bore field. Figure 13 compares the heat transfer rates of the two different ground fields normalized per length of bore and for temperature difference. The structural pilings were generally found to handle significantly more of the heat extraction load and slightly more on the heat rejection load. On a seasonal basis the pilings -- which accounted for about half of the total loop length -- rejected 56% of the total summer load and extracted 70% of the total winter load. The significantly better winter performance of the pilings is at least in part attributed to the shielding effect of the building. While the surface of the bore field is exposed to ambient conditions, the "surface" of the structural pilings is exposed to indoor conditions. Other factors such as the higher conductivity of concrete in the pilings and the “narrower” aspect ratio of the piling field may have also affected piling performance.

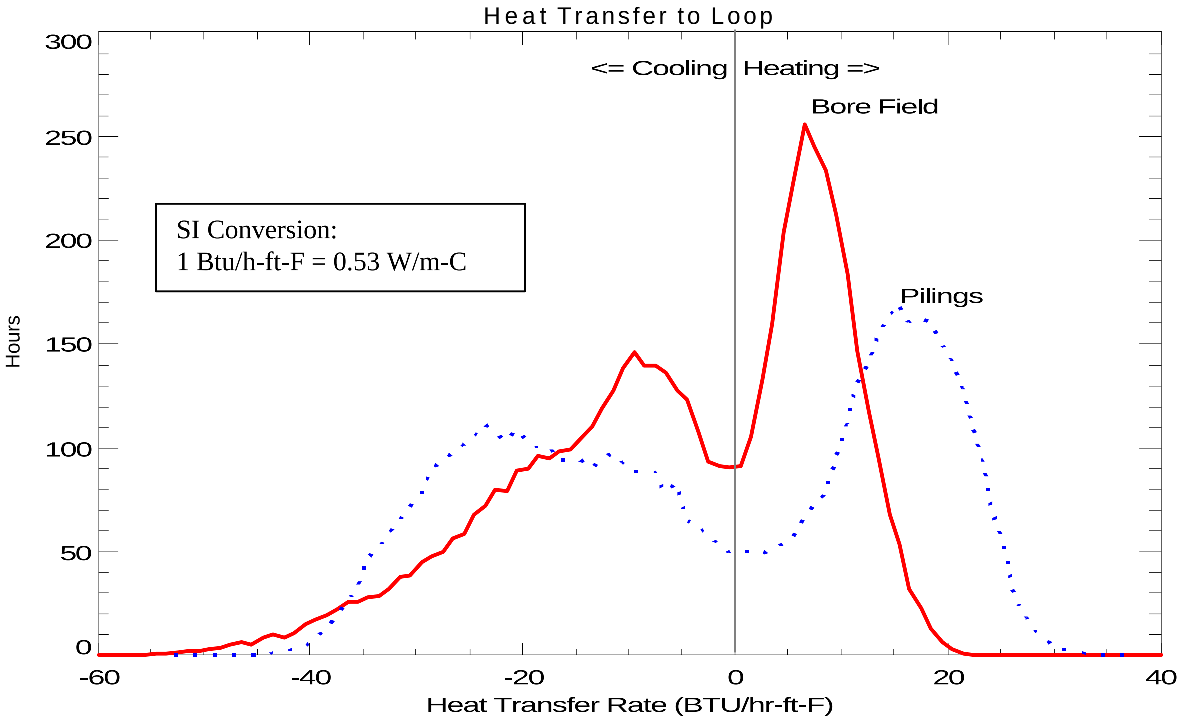

Figure 11. Distribution of Loop Heat Transfer Rates

Water Heating Loads

The water heating loads at the hotel have been substantial. Figure 12 shows the distribution of daily hot water loads at the facility. The measured average usage for the first year was 5,800 gallons/day [22,000 l/day], or nearly twice the water storage capacity of the system. The typical usage at the facility ranged from 3,000 to 9,000 gallons/day [11,000 to 34,000 l/day] with the higher usage on weekends. The highest usage for the first year occurred on New Years Day when the hotel was fully booked. Hot water use for that day was 11,100 gallons [42,000 l], or 3 to 4 times the storage capacity of the facility. The demand for hot water was not fully satisfied for that day and the return water temperature dropped below the 110-115°F [43-46°C] level that was normally maintained. As a result, the fourth water heating heat pump was added in March 1998.

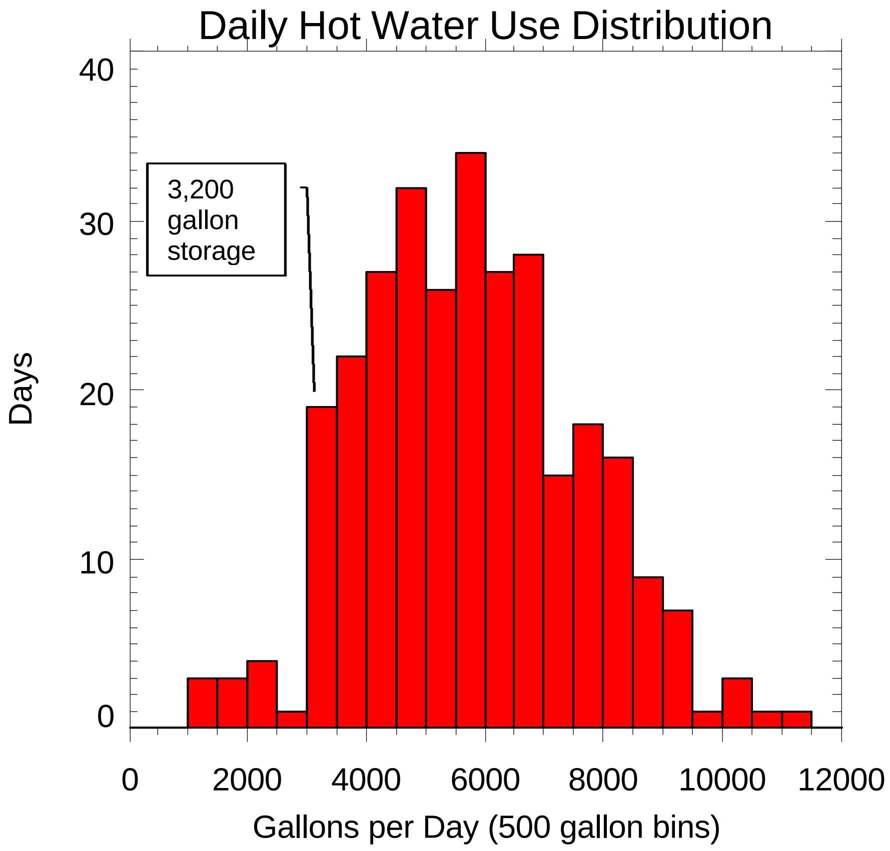

Figure 12. Distribution of Daily Hot Water Use at Hotel

The Benefits of System Integration

The water heating heat pump system imposed a significant heat extraction load on the ground loop. Figure 13 shows the monthly heat rejection and extraction loads imposed on the ground loop and indicates the impact that the water heating system had on these loads. As the building operated, with the water heating system extracting heat from the ground loop, the loop rejected a total of 2,000 million BTU [2,108 GJ] to the ground for the year and extracted 1,430 million BTU [1,507 GJ]. The peak monthly rejection and extraction rates of the system were 504 million BTU [531 GJ] and 326 [344 GJ] million BTU, respectively.

If the water heating system had not been integrated into the ground loop, then the annual heat rejection would have increased by 25% to 2,520 million BTU [2,656 GJ] and the annual heat extraction load would have decreased by 38% to 890 million BTU [938 GJ]. The peak monthly rejection and extraction rates would have become 591 million BTU [623 GJ] and 243 million BTU [256 GJ], respectively. Without the integrated water heating system, the peak monthly heat rejection would have been 17% higher. Since the ground loop was sized to meet the heat rejection loads, the integration of water heating into the system actually reduced the loop length requirements by 15%. The integration of the water heating system into the loop also increased the monthly and annual heat extraction rates, but did not impact the loop design since the ground heat exchanger was sized to meet the cooling requirements.

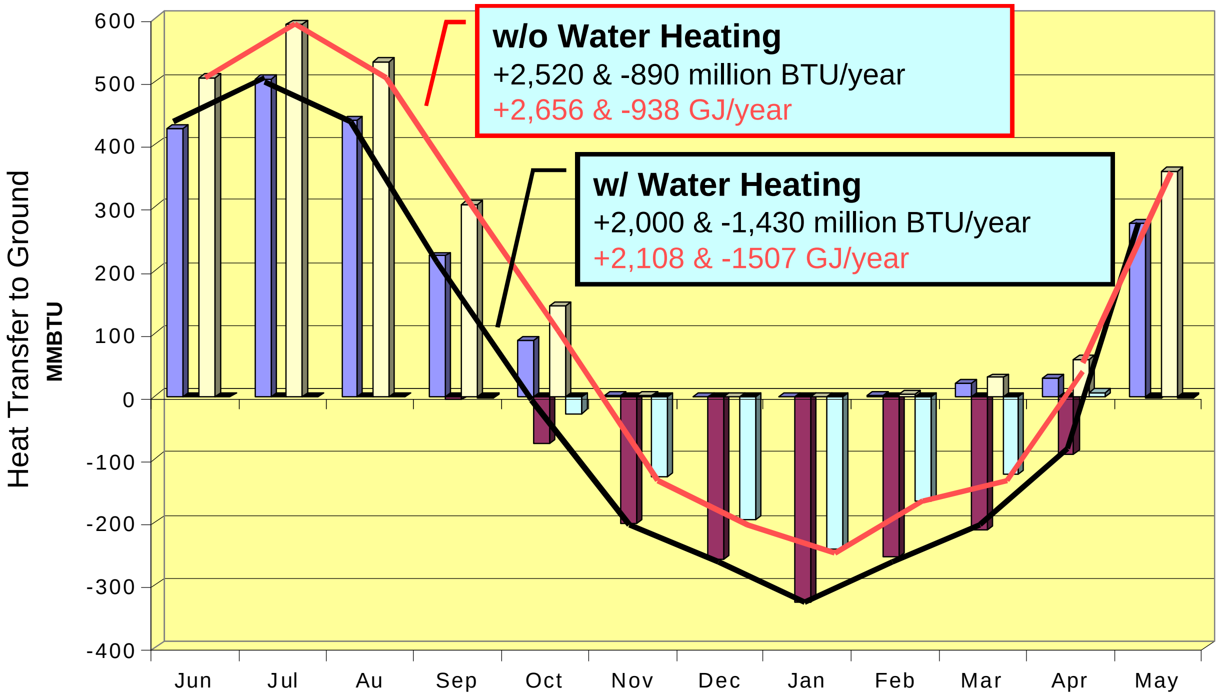

Figure 13. Comparing the Ground Loop Loads With and Without the Impact of Water Heating

Overall, the water heating heat pumps had a significant impact on the loop, recovering 20% of the heat rejection load from the space conditioning heat pumps and accounting for 30% of the heat extracted from the ground loop.

Variable Speed Loop Pumping

Variable speed loop pumping significantly reduces the system energy use in applications with load diversity. Figure 14 shows the trend of reduced pump power at lower flow rates. The design flow rate for this system is 810 gpm [51.1 l/s], or 2.5 gpm per installed ton. The data in Figure 14 show that the flow never exceeded 50% of the design flow rate and the power consumption never exceeded 11 kW for the 50 HP pump motor[2]. The flow rate dropped as low as 120 gpm [7.6 l/s] and pump power decreased to 2 kW.

Figure 15 shows the distribution of the flow rates observed during the first year of operation in both the cooling and heating mode. Again, the flow rate rarely exceeded 350 gpm [22.1 l/s] and only reached 400 gpm [25.2 l/s] at peak conditions during the summer. The average flow rate is only a fraction of the nominal flow rate.

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[2] At 90% efficiency, the full load power use for one 50 HP motor is about 41 kW.

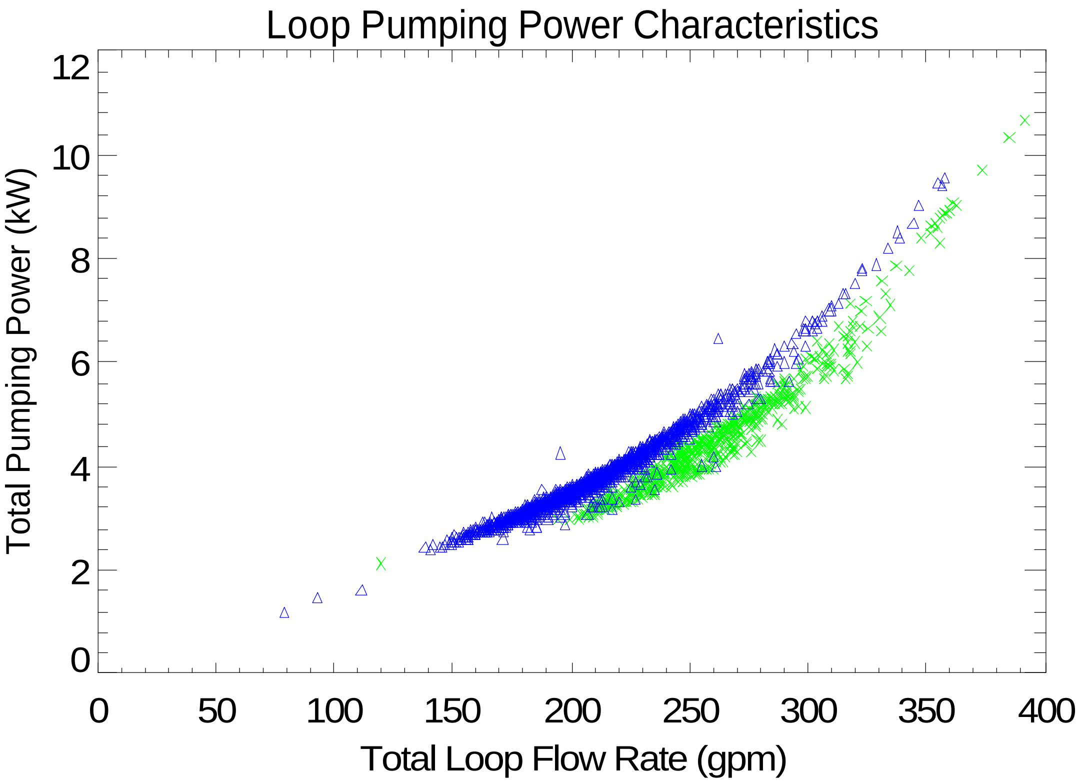

Figure 14. Loop Pumping Power Verses Loop Flow Rates

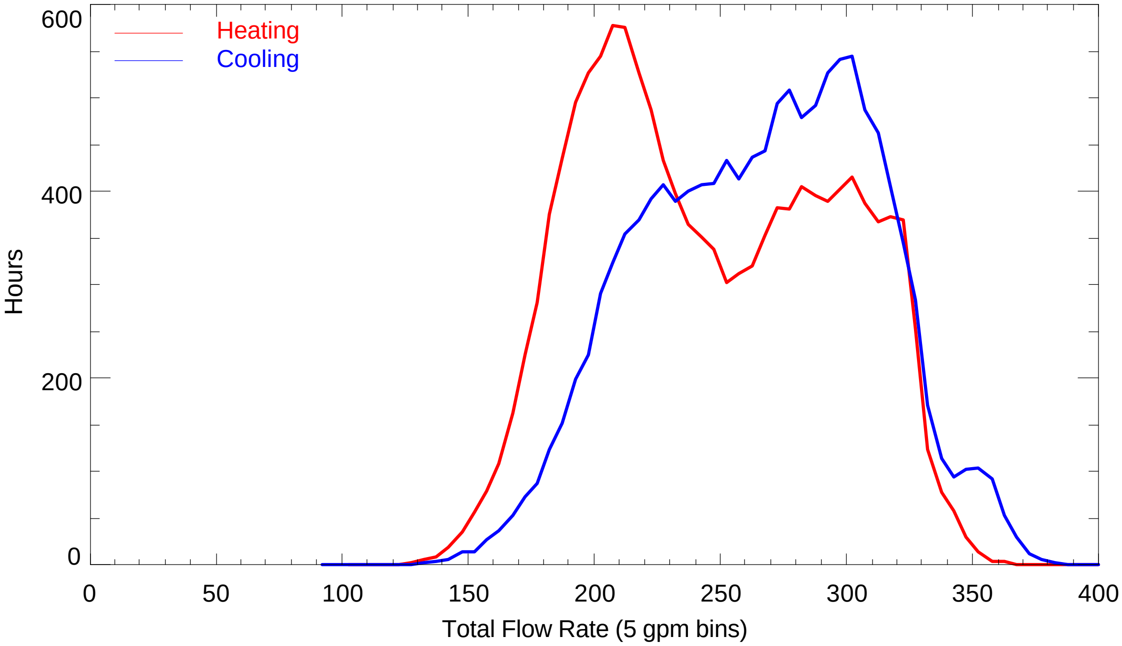

Figure 15. Distribution of Loop Flow Rates at Hotel

If constant speed loop pumps had been used at the hotel (without solenoid valves installed on each heat pump), the energy use of the loop pumps would have been dramatically higher. Table 3 gives the predicted loop pump energy use assuming the originally intended pair of 30 HP pumps were installed (i.e., a continuous pump demand of 53 kW)[3]. Assuming 24 hour operation, the constant speed pumps would have used 461.3 MWh per year. On an annual basis, the variable speed loop pumps used 92% less energy than the constant speed base case. These energy savings translate into cost savings of $25,368 per year, even using the discounted "economic development" rate of $0.06/kWh available to the facility.

Table 3. Estimated Savings Due to Variable Speed Pumping

	Hotel
Nominal Pump Sizing (HP/ton)	0.31
Annual Pumping Energy (MWh)	38.5
Annual - Constant Speed (MWh)	461.3
Variable Flow Energy Savings	92%
Variable Flow Cost Savings[1]	US $25,368
Norm. Pump Energy (kWh/ton-hr)	0.1

Notes: 1 – Annual energy costs assumed to be $0.06/kWh

The nominal loop pump sizing at the hotel had been very large – or more than 3-4 times the pump power recommended as "good design" in the ASHRAE Ground Source heat Pump Design Manual [1]. However, the variable speed system worked well and kept pumping power to a minimum. On an annual basis, the pumping energy per unit of cooling provided was 0.1 kWh/ton-hr [0.35 dimensionless]. This relatively low average value indicates that pump power closely followed the cooling load. As the system operated, the loop pump accounted for 11% of total HVAC energy use. If the loop pumps had operated continuously at full load (i.e., 53 kW), pump power would have accounted for 60% of HVAC energy use and 23% of total facility energy use.

SUMMARY

During the first 12 months of operation, the monitored data indicate that the innovative ground loop that is partially incorporated into the building's structural pilings performed well. Loop temperatures remained above 40°F [4°C] in the winter and under 80°F [27°C] in the summer, indicating that the loop was conservatively designed to meet the loads. The estimated seasonal average COPs for the space conditioning heat pumps were 4.4 and 4.0 for cooling and heating, respectively.

The pilings had better normalized heat transfer performance than the conventional bore field. While the piling and bore field lengths were equivalent, the pilings rejected 56% of the summer load and extracted 70% of the winter heating load. The significantly better heat extraction performance in the winter implies that the "shielding" effect of the building may have played a role by reducing the impact that ambient conditions had on that portion of the ground heat exchanger.

Water heating loads at the hotel were substantial, with heat pump energy use, accounting for 8% of total facility use. The integration of the water heating heat pumps into the ground loop reduced the summer heat rejection loads by more than 15%. This reduction in the load on the ground heat exchanger would have allowed the loop size to be reduced proportionally, indicating that geothermal designs that

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[3] The original design specification called for two 30 HP motors, not the 50 HP motors that were actually installed.

integrate water heating and space conditioning functions into a common loop can realize reduced installation costs.

Variable speed loop pumping reduced system energy use dramatically compared to a conventional constant speed pumping system. Because of the significant load diversity in the facility, the loop flow rate never exceeded 50% of the nominal loop flow rate. As a result the variable speed system reduced annual pump energy use by 92%. The annual cost savings at the hotel from variable speed pumping saved more than $25,000 US, even with the low cost "economic development" electricity rate available to the site.

Overall, the design and operation of the system has been a success. The system demonstrates the performance benefits of geothermal heat pump systems and shows how the integration of water heating into the ground loop can further enhance system performance and reduce first costs.

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1. Kavanaugh, S. P. and K. Rafferty. 1997. Ground-Source Heat Pumps: Design of Geothermal Systems for Commercial and Institutional Buildings. American Society of Heating, Refrigerating and Air-Conditioning Engineers. Atlanta, GA.