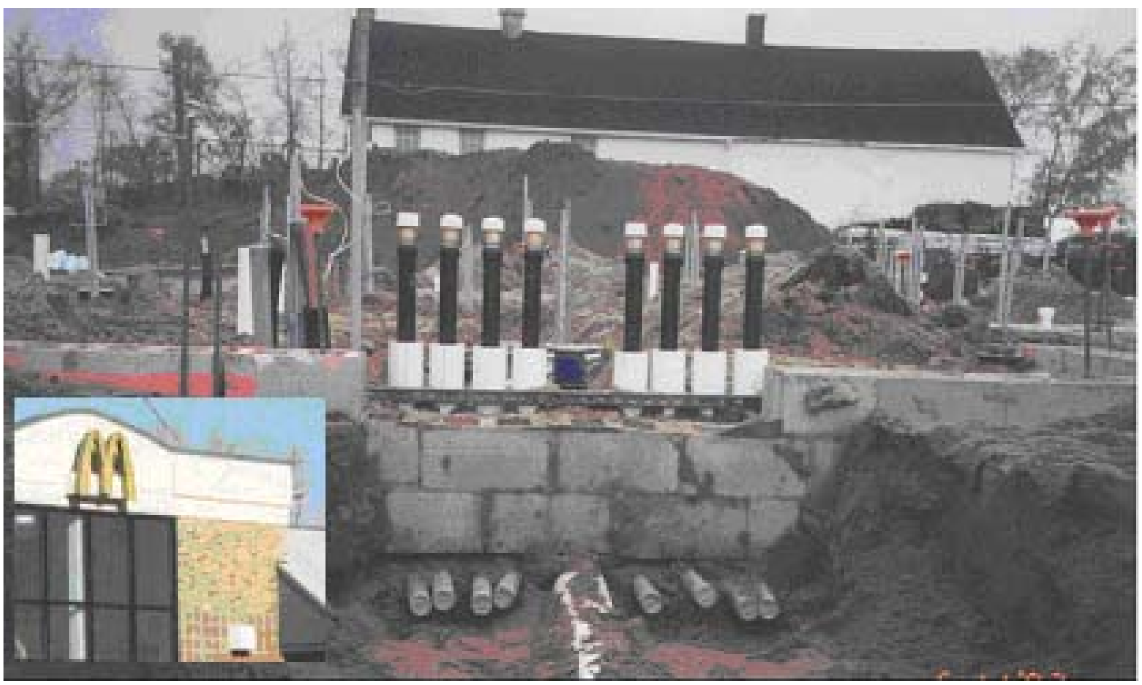
Long Term Geothermal Heat Pump System Ground Loop Heat Exchanger Performance

Field Data from a Quick Service Restaurant Application

1007398



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Technical Update, January 2003

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ABSTRACT

This report summarizes measured long-term performance of the ground loop heat exchanger in a geothermal heat pump system in a McDonald's Quick Service Restaurant located in Westland near Detroit, MI. Heat build up in the soil around the heat exchanger over a long period of time has always been a concern, but only limited data have been available in the past. The gradual increase in the return loop temperature over a period of five years is an evidence of the heat built up in the ground loop field, which eventually hurts the heat pump system cooling performance. The data also show that, like most commercial buildings even in the northern U.S., heat rejection into the ground from seasonal cooling loads greatly exceeded the heat extracted from the ground from seasonal heating loads in the quick service restaurant. This reinforces the importance of the proper ground loop field sizing, and the fact that under sizing in order to economize on the loop size can lead to poor system performance and unrealized energy savings in the long run. It also highlights the need for dissipation of the built up heat in order to maintain the system performance and operating efficiency, such as the use of hybrid systems.

EXECUTIVE SUMMARY

This report summarizes the monitored long-term performance of a ground loop heat exchanger in a geothermal heat pump system installed in a McDonald's Quick Service Restaurant in Westland, Michigan, about 23 miles west of Detroit. Detroit Edison worked with McDonald's to demonstrate and evaluate this innovative geothermal HVAC system among other energy efficient solutions. Detroit Edison teamed up with EPRI to monitor and evaluate the performance of this system. After two years of detailed measurements, the performance of the geothermal heat pump system and its comparison with a conventional HVAC system installed in another restaurant located only three miles away was published in an EPRI report, *Geothermal HVAC system Performance in a Quick Service Restaurant: Field Experience from McDonald's Demonstration.* (TR-114621, December 1999).

After the initial project was complete, the project team decided to leave the instrumentation in place with an additional objective of obtaining long-term geothermal heat exchanger performance data. This was, however, not one of the original objectives of the project; the additional data was obtained despite limited resources and budget. The project team extended the monitoring in hope of getting useful field data to understand heat built up in the ground heat exchanger loop field. There are some gaps in data availability over the last five years; however, the data still provide useful information.

Heat build up over a period of time in the soil around the heat exchanger has always been a concern, but only limited data have been available in the past. The gradual increase in the return loop fluid temperature is an evidence of the heat built up in the ground loop field, which eventually hurts the heat pump system cooling performance. The data show that the average return loop fluid temperature continued to increase from year to year; it increased from 51.2^{o}F in April of 1998 at the start of the project to 72.4^{o}F in April of 2002, just after four years of complete cycles of cooling and heating, or an increase of an average 5.3^{o}F per year. It is also important to note that the last year's increase was above average 5.8^{o}F. The ground temperature did not reach a plateau even after nearly five years of operation. A similar trend was observed at the end of the cooling season in August and September. Once again, the return loop temperature continued to rise from year to year; it increased from 80.3^{o}F in 1998 to 101.5^{o}F in 2002, an average of 5.3^{o}F per year. It is interesting to note that the amount of average annual temperature rise at the beginning of the cooling season in April happens to be the same as the amount of average annual temperature rise at the end of the cooling season in August/September. The data also show that the seasonal cooling loads are much larger than the seasonal heating loads even in this cold climate of the northern U.S. for this application. This is true for most commercial buildings.

The data emphasize the importance of proper system design and ground loop heat exchanger sizing. It reinforces the fact that under sizing in order to economize on the loop size can lead to poor system performance and unrealized energy savings in the long run. The higher loop temperatures in summer reduce heat pump's cooling capacity, about ½% per degree Fahrenheit, as well as its cooling efficiency, about ¾ to 1% per degree Fahrenheit. If the loop temperature becomes higher than the ambient temperature, which was observed, it would be more efficient to reject heat to the ambient instead to the ground loop.

Geothermal, however, is still a very attractive technology. In winter, when ambient temperatures are very low, the return fluid temperatures are still high, which allow heat pumps to operate very efficiently and provide higher heating capacity. It is only in summer that the system suffers from poor cooling performance due to high loop temperatures. This reinforces the need for some simple means for dissipation of the built up heat in order to maintain the system performance and high operating efficiency, such as a hybrid system to reject heat to the ambient air at night hours.

The authors propose the development of low-cost, simple-to-operate fluid coolers to reject the excess heat from the ground loop in order to maintain lower return loop temperature and increase system efficiency. If such fluid coolers could be developed, and if it could also withstand winter freezing weather without damage, it would revolutionize the geothermal heat pump industry. It would have a ready market for retrofitting all those applications where loop temperatures have risen very high over the last few years. It would also be useful in designing new hybrid geothermal systems where loops can be sized smaller, and more economically, to primarily meet the heating loads, and the fluid cooler would supplement the ground loop heat exchanger in summer.

CONTENTS

1 INTRODUCTION

Overview

Long-term performance of a ground loop heat exchanger in geothermal heat pump system in a Quick Service Restaurant is summarized here. Heat build up over a period of time in the soil around the heat exchanger has always been a concern, but only limited data has been available in the past. This report presents the measured performance of a ground loop heat exchanger applied in a McDonald's Quick Service Restaurant located in Westland near Detroit, MI, over a period of five years.

The gradual increase in the return loop temperature is an evidence of the heat built up in the ground loop field, which eventually hurts the heat pump system cooling performance. The data also show that the cooling season is more critical even in this cold climate of the northern U.S. The data also reinforce the fact that under sizing in order to economize on the ground loop heat exchanger size can lead to poor system performance and unrealized energy savings in the long run. It emphasizes the importance of the proper ground loop field sizing. It also reinforces the need for some simple means for dissipation of the built up heat in order to maintain the system performance and operating efficiency.

Background

Detroit Edison teamed up with its customer, McDonald's, to demonstrate a geothermal heat pump system in a quick service restaurant, and teamed up with EPRI to monitor and evaluate its performance. A geothermal heat pump system was installed in a newly constructed restaurant in Westland, MI, about 23 miles west of Detroit in 1998. For comparison purposes, a similar restaurant in nearby Northville with a conventional HVAC system was also monitored. The performance of the Geothermal HVAC System and its comparison with the conventional HVAC system was detailed in an earlier EPRI report, *Geothermal HVAC system Performance in a Quick Service Restaurant: Field Experience from McDonald's Demonstration* (TR-114621, December, 1999).

Objectives

This report focuses only on the long-term performance of the geothermal ground loop heat exchanger. Specifically, it documents the return fluid temperature from the ground loop that shows how the ground is unable to dissipate all of the heat rejected into the ground loop over long term.

2
GEOTHERMAL GROUND LOOP AND HEAT PUMP SYSTEM DESCRIPTION

The McDonald's restaurant is located in Westland, Michigan, a suburb 23 miles west of Detroit. The geothermal heat pump system includes three 11-ton water source heat pump rooftop units. Each rooftop unit includes an economizer with two compressors. The ground heat exchanger consists of 32 vertical bores that are 196 feet deep (190 feet of bore per installed ton). The bores are spaced 14 feet apart. The ground heat exchanger is located behind the restaurant at the rear of the property. A variable speed loop pump provides flow to the WSHPs, and five of the six compressors have a two-way valve that only allows flow when the heat pump stage is activated. The Westland restaurant also includes other energy saving measures, including day-lighting controls, efficient lighting fixtures, efficient exhaust fan motors, and low-e glass.

Photograph 2-1
Geothermal McDonald's Restaurant in Westland, Michigan

Building

Table 2-1 summarizes the main characteristics of the Westland GHP restaurant.

Table 2-1
Westland McDonald's Building Characteristics

Building	
Building Description:	Quick service restaurant w/ children's "Playplace"
Orientation:	Facing South
Gross Area:	2,711 ft^2 (1,511 ft^2 restaurant, 1,200 ft^2 Playplace)
Installed Capacity:	33 tons
Sizing (gross area per ton)	82 ft^2/ton
Cooking Appliances	Gas-fired
Lighting	
Interior Playplace Lighting:	Nine 320 Watts metal halide lights with time clock and photocell
Dining Area Lights	Fluorescent with more efficient ballast
Exterior Lighting	Twenty two 350 Watts time clock controlled parking lot lights with photocell

HVAC System

Table 2-2 summarizes the characteristics of the HVAC. It uses three equally sized rooftop units to condition the kitchen, dining, and Playplace areas. The rooftop water source heat pumps are shown in Photograph 2-2. The geothermal rooftops have an economizer that provides "free-cooling" when ambient temperatures are modest (e.g., below 55°F). The geothermal system also has standard 7.5 kW of backup resistance heat installed on each unit, although the back up resistance heat was not used after the initial commissioning period. The energy efficiency of the water source heat pumps used in this application, seemingly higher than the conventional air source equipment, is actually lower than the equipment available in this class. However, high efficiency equipment could not be selected due to configuration limitation. While high efficiency equipment, as much as 25% or even more efficient than the ones selected, are available, but these are suitable only for indoor application. Since the McDonald's design team decided to use only roof top equipment due to space limitation, it was unfortunately restricted to the use of lower efficiency equipment.

Table 2-2
HVAC System Specifications

	Westland GHP System
HVAC Units	
Number of Units	3 WSHPs
Nominal Size	11 tons
Heating Section	150.3 MBtu/h (at 70°F EWT) with 7.5 kW duct heater (backup)
Cooling EER	11.7 Btu/Wh (at 85°F EWT)
Heating Efficiency	3.9 COP (at 70° EWT, ARI 320 conditions)
Manufacturer	WaterFurnace/Addison (model# DWH122E)
Total Ventilation Rate:	2,800 cfm (measured)
Kitchen Exhaust Fan Control	Off midnight to 5 am
Loop Pumps	
Number of Loop Pumps:	2 (1 standby)
Pump Size:	5 hp on VSD
Normalized Pump Power:	0.15 hp/ton
Ground Heat Exchanger	
Borefield:	32 bores, 196 feet deep, 14 foot spacing, 2 bores in series per circuit
	190 ft/ton
Piping:	12,500 feet, 1.25 inch polyethylene, 1.5 inch headers in the building

Photograph 2-2
Three Geothermal Heat Pump Rooftop Units at McDonald's in Westland, Michigan

Ground Loop

The ground heat exchanger was installed at the rear of the property as schematically shown in Figure 2-1. The loop field consists of 32 vertical bores that are 196 feet deep with 14 foot spacing. The loop uses 12,500 feet of 1¼ inch polyethylene piping. Every two bore holes are connected in series with a total of four circuits on each of the four main supply and return headers terminating in the mechanical room (see Photograph 2-3). As Figure 2-1 shows, the loop field in located behind the parking lot of the building. The first row of bores closest to the parking lot is located under an 8-foot sound-attenuation berm.

Photograph 2-3
Ground Loop Heat Exchanger Headers in Westland, Michigan

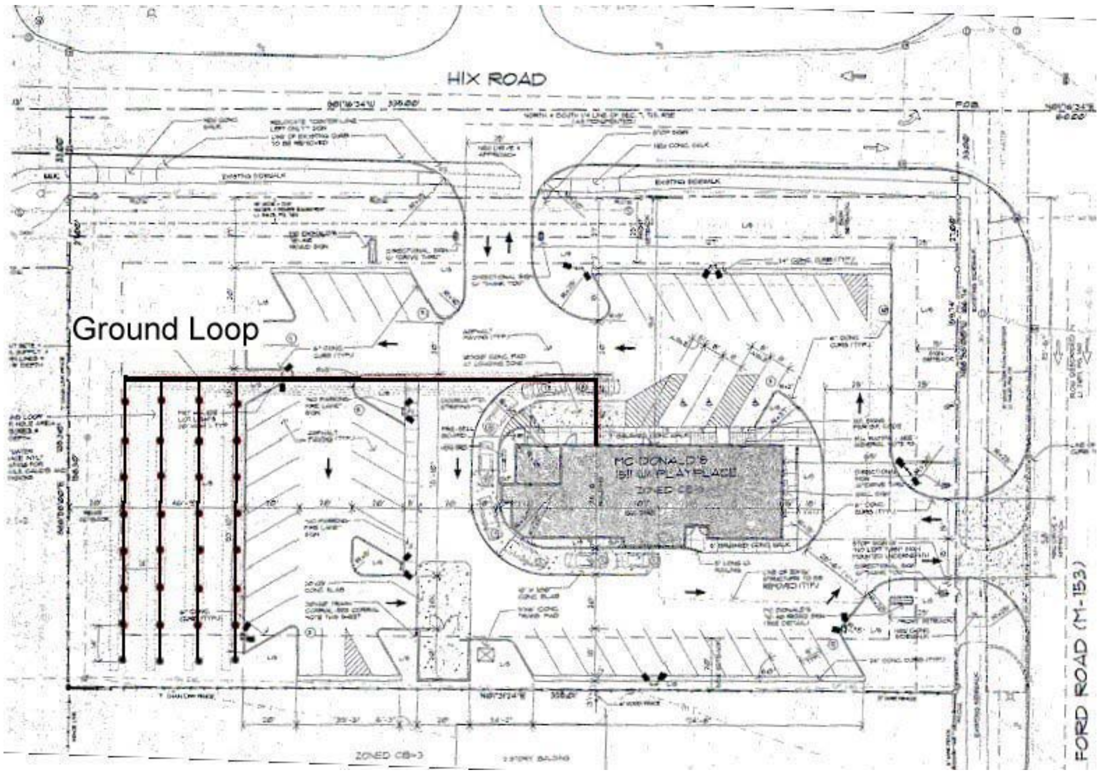


Figure 2-1
Site Plan and Ground Loop Location at Westland, Michigan

To help reduce the uncertainties associated with sizing the loop, an in situ soil conductivity test was completed at the site. After the first bore was drilled, a company specializing in in-situ ground conductivity measurements came on site with an appartus to measure the average conductivity of the soil. The ten hour test predicted a soil conductivity of 1.12 Btu/h-°F-ft. This value was used in the loop sizing calculations.

Pumping System

Two loop pumps are used by the geothermal heat pump system. The pumps operate one at time with the other available for standby. The two 5 HP pumps are connected to a variable speed drive (VSD) and pump controller. One pump is designated as a lead pump and one as a backup (and this status can alternated). The VSD is controlled to maintain a constant differential pressure across the heat pumps to ensure proper flow rates and valve operation. Figure 2-2 schematically shows the ground loop system and Table 2-3 lists the specifications of the pumping equipment.

The compressors on most heat pumps have a two-way valve that shuts off flow to the water coil when that stage is deactivated. The exception was the first stage compressor on the Playplace unit, which does not have a shutoff valve. This ensures that some flow is always maintained in the loop system. The Playplace unit was selected since it is farthest from the pump and because it was expected to have the most consistent runtime due to its envelope-dominated heating and cooling loads. Each compressor circuit also has a flow-limiting valve to prevent excessive flow through the unit. The valves were installed in an effort to prevent excessive pressures in the water-to-refrigerant heat exchangers.

Table 2-3
Loop Pumping Equipment

Component	Manufacturer / Model	Notes
Loop Pump(s) Variable Speed Drive	US Motors 80-2X9 .5B-9BF Bell and Gossett	2 pumps, 5 hp, 85.5% efficient

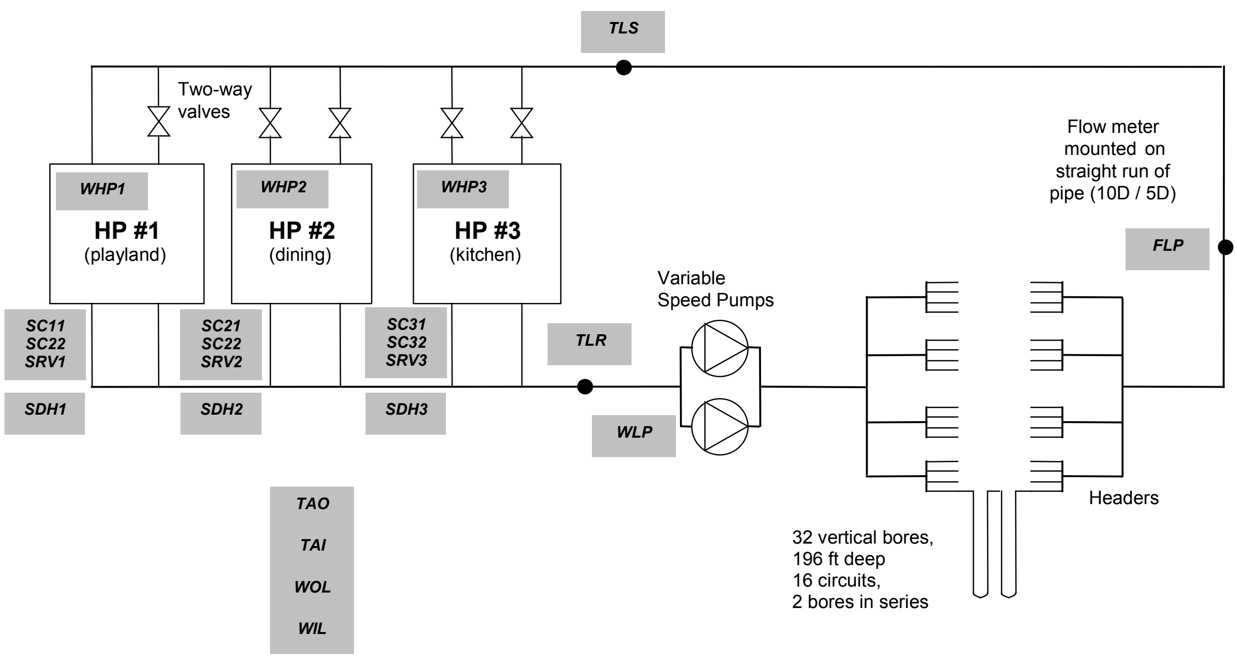


Figure 2-2
Schematic of Geothermal Heat Pump System (with Monitored Points Shown)

System Design Issues

One of the biggest design and installation challenges was to integrate a geothermal system into the streamlined construction process used by McDonalds. The original design of the 1511 Series restaurant used conventional rooftop units. Since virtually no free space was available inside the restaurant to install the more typical indoor-mounted heat pump units, a novel configuration with rooftop-mounted water source heat pumps was used in this application. This rooftop configuration also allowed the economizer option–which is typically not used in most geothermal systems–to be integrated into the design.

Another issue was the need to integrate the loop installation into the fast-tracked construction schedule at the site. The loop installer had to coordinate closely with the general building contractor. Photograph 2-4 shows the headers for the ground loop piping at the beginning of construction. The types of details shown in the photograph required careful coordination the loop installation with the foundation work and masonry curb construction on the small building lot. The geothermal heat pump system was successfully integrated into the design of the restaurant without negatively impacting the construction schedule. The restaurant opened on time in the beginning of 1998.

Photograph 2-4
Ground Loop Heat Exchanger Piping Stubouts Installed During Restaurant Construction

3
DATA ANALYSIS AND RESULTS

The system performance was monitored in detail for the first two years in order to compare the geothermal system performance to the conventional system, and these results were reported in the earlier EPRI report (TR-114621). After the project was complete, the project team decided to leave the instrumentation in place with the objective of obtaining long-term ground heat exchanger loop field performance. This was, however, not one of the original objectives of the project; the additional data were obtained despite limited resources and budget. The project team extended the monitoring in hope of getting useful field data to understand heat built in the ground loop heat exchanger. There were several instances of gaps in reported data, some for short and some for long periods, when data were not available due a variety of reasons. For example, data were missing for nearly half of the time during the years of 2000 and 2002, but had good data fro 1998, 1999 and 2001. The quality of data collected, however, is good and it still provides valuable information for the intended purpose of gauging heat build up and measuring temperature rise in ground loop field. Nevertheless, we need to be cognizant of missing data in deriving inferences and conclusions. Table 3-1 below summarizes the time periods when data were missing.

Table 3-1
Data Collection and Missing Data Periods

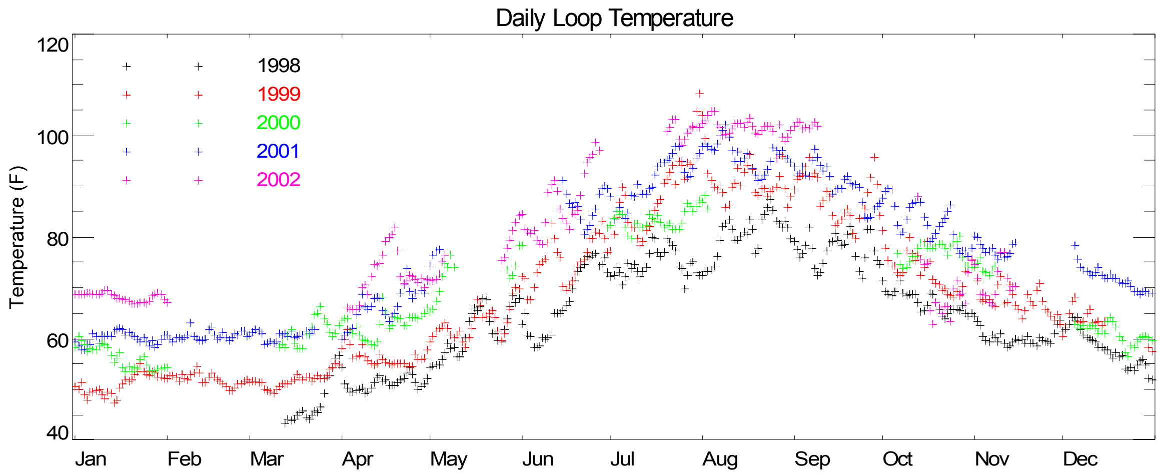
Year	Missing Data Periods	Total Number of Missing Hours	% of Missing Hours	Comments
1998	01/01/1998-03/28/1988	2062	24%	Missing winter data early in the year before data collection began.
1999	12/15/1999 - 12/30/1999	383	4%	Missing winter data for a very short period.
2000	02/01/2000 - 03/11/2000 05/09/2000 - 05/27/2000 06/01/2000 - 06/30/2000 08/03/2000 - 10/06/2000 11/08/2000 - 12/05/2000	4288	49%	Missing data for nearly a half of the year in winter, spring, summer and fall.
2001	03/23/2001 - 04/01/2001 05/04/2001 - 06/15/2001 11/15/2001 - 12/05/2001	1702	19%	Missing data mostly in spring and fall.
2002	02/01/2002 - 04/03/2002 05/06/2002 - 05/25/2002 06/27/2002 - 07/20/2002 09/09/2002 - 10/13/2002 11/26/2002-12/31/2002	4381	50%	Missing data for nearly a half of the year mostly in spring, summer and fall.

Return Loop Temperature

The key data for measuring the overall performance of the geothermal heat pump system as well as the performance of the ground heat exchanger loop field is the fluid temperature returning from the ground loop heat exchanger. This is the temperature at which the fluid is delivered to the heat pumps in the building. The heat pump operating efficiency and capacity, whether in summer cooling mode or winter heating mode, are directly dependent on this loop temperature.

When warm fluid enters the ground loop heat exchanger in summer, the return loop temperature indicates how much of the heat is rejected to the loop field. Similarly, when the cold fluid enters the loop field in winter, it indicates how much heat is extracted from the surrounding.

The average daily loop return temperature over the last five years is plotted in Figure 3-1. The plot also shows the average daily ambient temperature for ready reference.



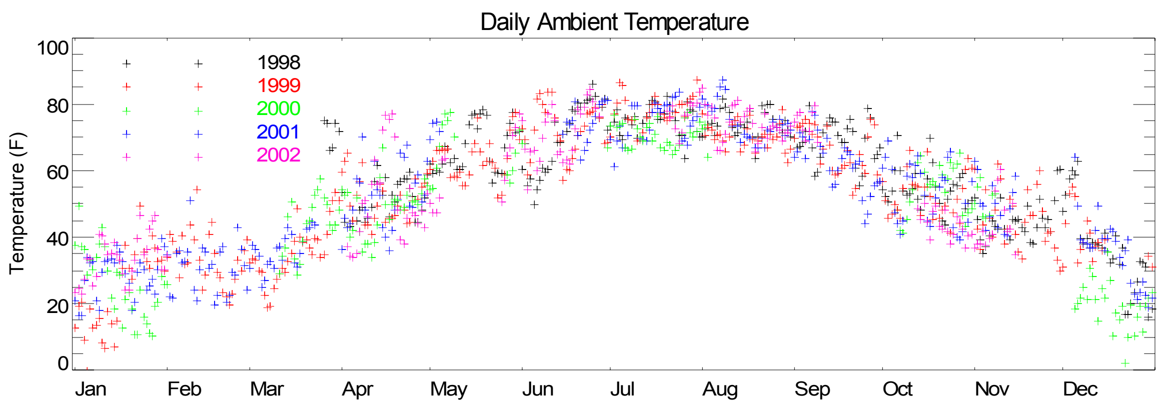


Figure 3-1
Return Loop and Ambient Air Temperatures

Figure 3-2 plots the daily fluid temperature entering and returning from the ground heat exchanger loop field over five years. The ambient air temperature is also plotted for reference. The plot also shows the daily average loop field flow rate at the bottom of the figure.

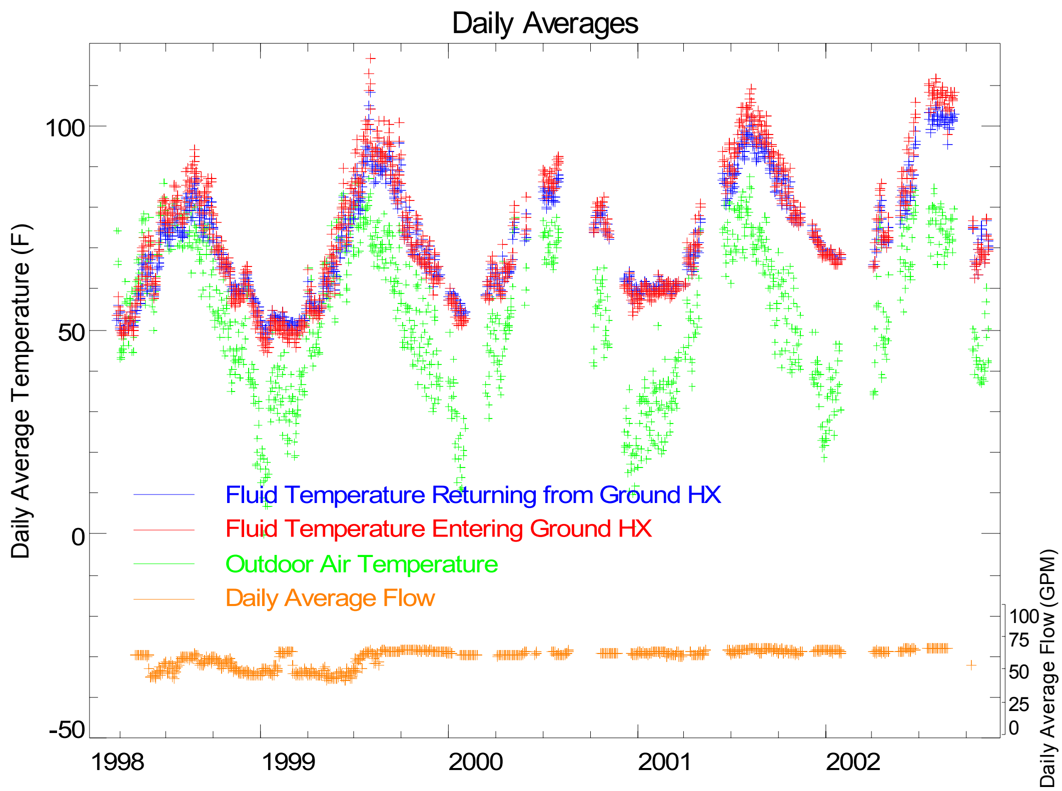


Figure 3-2
Daily Average Fluid Temperature Entering and Returning from the Ground Loop Heat Exchanger

As observed from Figure 3-1 and 3-2, the average fluid temperature returning from the ground loop heat exchanger increases from year to year. The average loop-return temperature in 1999 is higher than in 1998, 2000 is higher than 1999, and so on, with the highest temperature in the most recent year for which data are available. The daily ambient temperature does show some variation from day-to-day over the years, but the seasonal total cooling and heating loads did not change much from year to year. However, the daily loop return temperature changed appreciable from year-to-year as shown in Figures 3-1 and 3-2. This shows that the ground is unable to dissipate all the heat transferred into the loop by the heat pumps, and the residual heat begins to warm up in the ground field. This build up of the heat continues throughout the five years of operation and did not show any sign of reaching a plateau.

The average daily fluid temperatures entering and returning from the ground heat exchanger loop field as well as ambient temperatures for individual years of 1998-2002 are shown in Figures 3-3 to 3-7. In winter, cold fluid enters the heat exchanger and warm fluid returns; in summer, warm fluid enters and colder fluid returns. The loop temperature swings over a wide range, from 50's to 90's from winter to summer in a year.

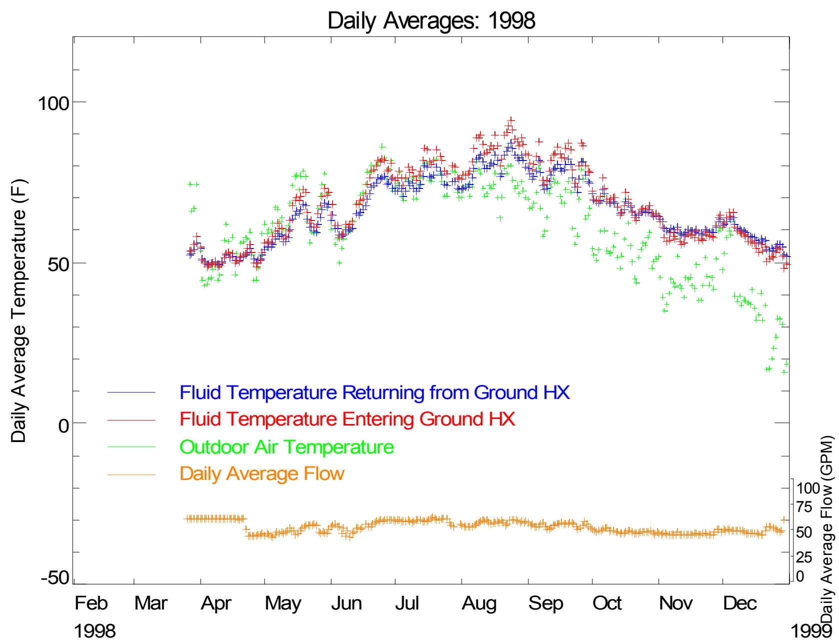


Figure 3-3
Daily Average Fluid Temperature Entering and Returning from the Ground Loop Heat Exchanger for 1998

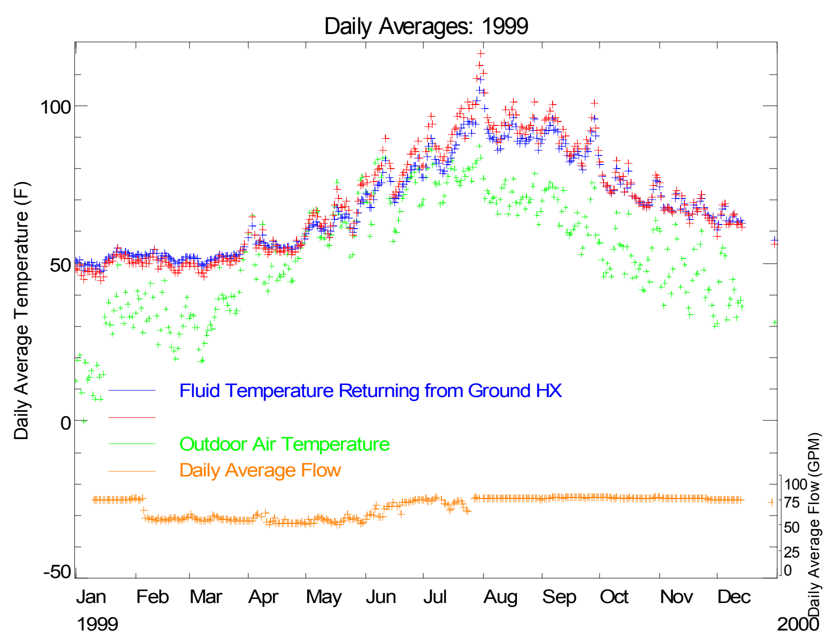


Figure 3-4
Daily Average Fluid Temperature Entering and Returning from the Ground Loop Heat Exchanger for 1999

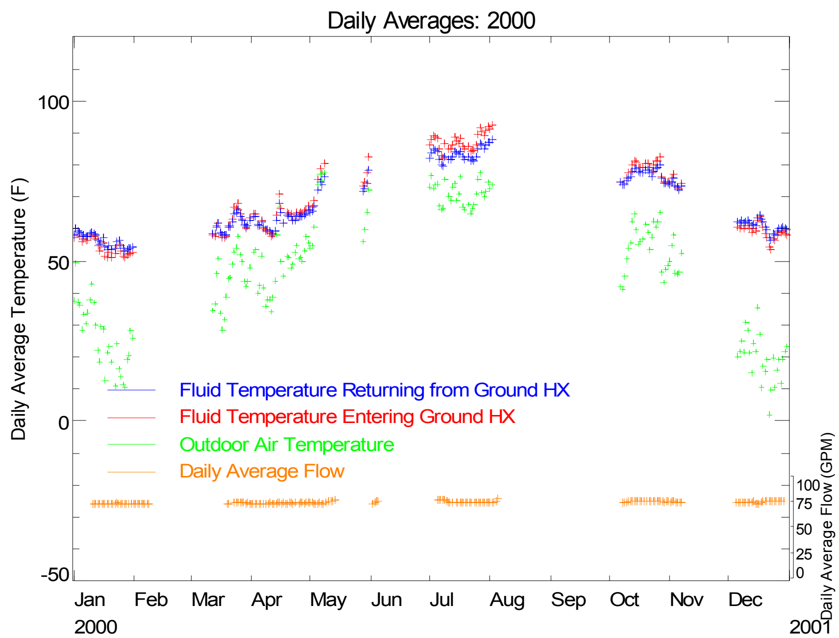


Figure 3-5
Daily Average Fluid Temperature Entering and Returning from the Ground Loop Heat Exchanger for 2000

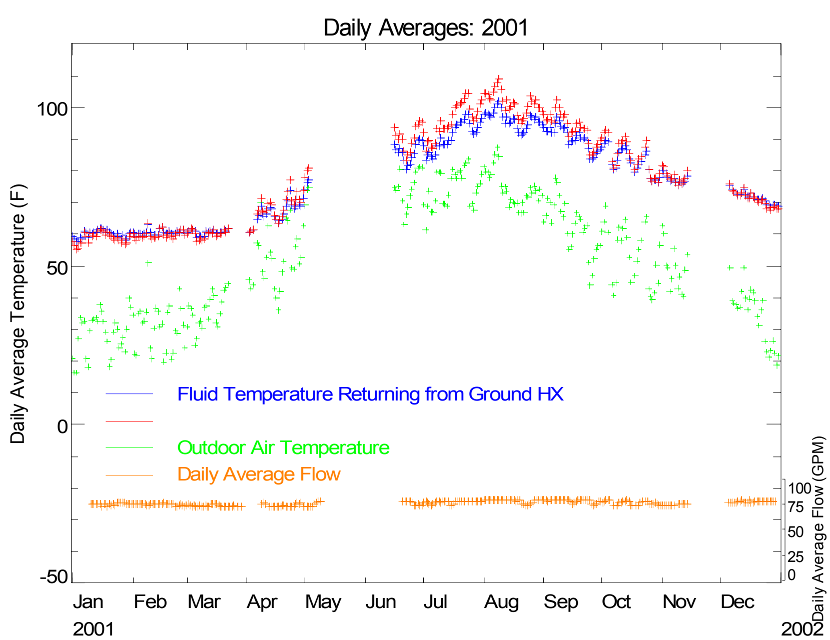


Figure 3-6
Daily Average Fluid Temperature Entering and Returning from the Ground Loop Heat Exchanger for 2001

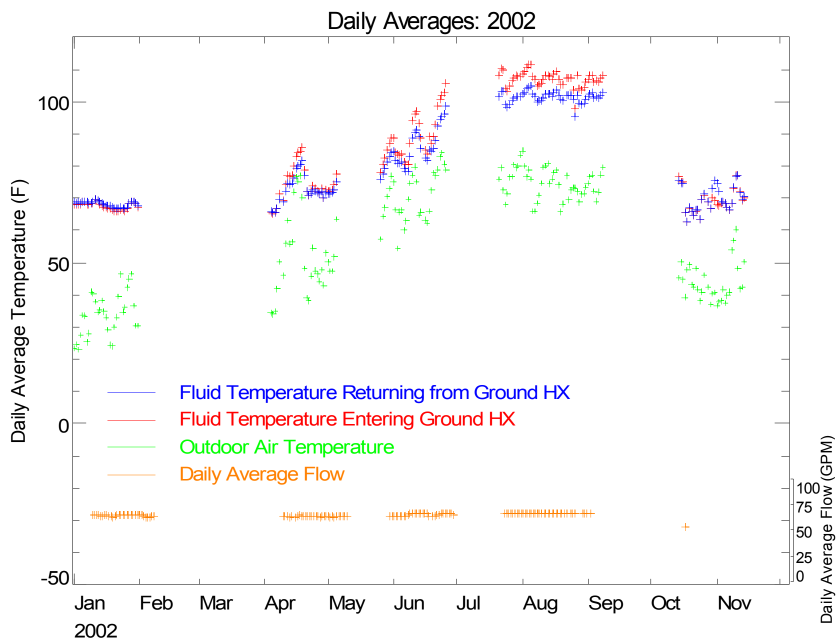


Figure 3-7
Daily Average Fluid Temperature Entering and Returning from the Ground Loop Heat Exchanger 2002

Variable Loop Flow Rate

The heat exchanger performance also depends upon the fluid flow rate. While fluid flow rate generally remains invariable with the use of constant speed pumps in typical geothermal heat pump systems, a variable speed drive pump was used in this application to reduce the overall pumping power. The earlier EPRI report (TR-114261) documented the energy savings from the variable speed pump and its cost effectiveness. Briefly, the variable speed pump saved 54% of the pumping energy, and could have saved as much as 79% if the operating set points were optimized. Since the pump operates almost continuously, or whenever even a single heat pump on the loop is ‘on’, it turns out that the variable speed drive is an attractive and cost effective option. The system operation was switched between constant speed and variable speed mode from time to time. When the fluid flow rate is reduced, the fluid temperature tends to reach closer to the surrounding ground temperature; therefore, it would be slightly warmer in winter and slightly cooler in summer as compared to the constant flow rate operation, although there are concerns that the slow moving fluid would form a laminar flow within the heat exchanger tubes which would reduce overall heat transfer coefficient. From review of the field data, the investigators estimate that the temperature difference with or without variable flow rate would indeed be very small, less than about one half of one degree Fahrenheit.

Return Loop Temperature vs. Outdoor Air Temperature

The monthly average return loop temperature versus ambient air temperature is plotted in Figure 3-8.

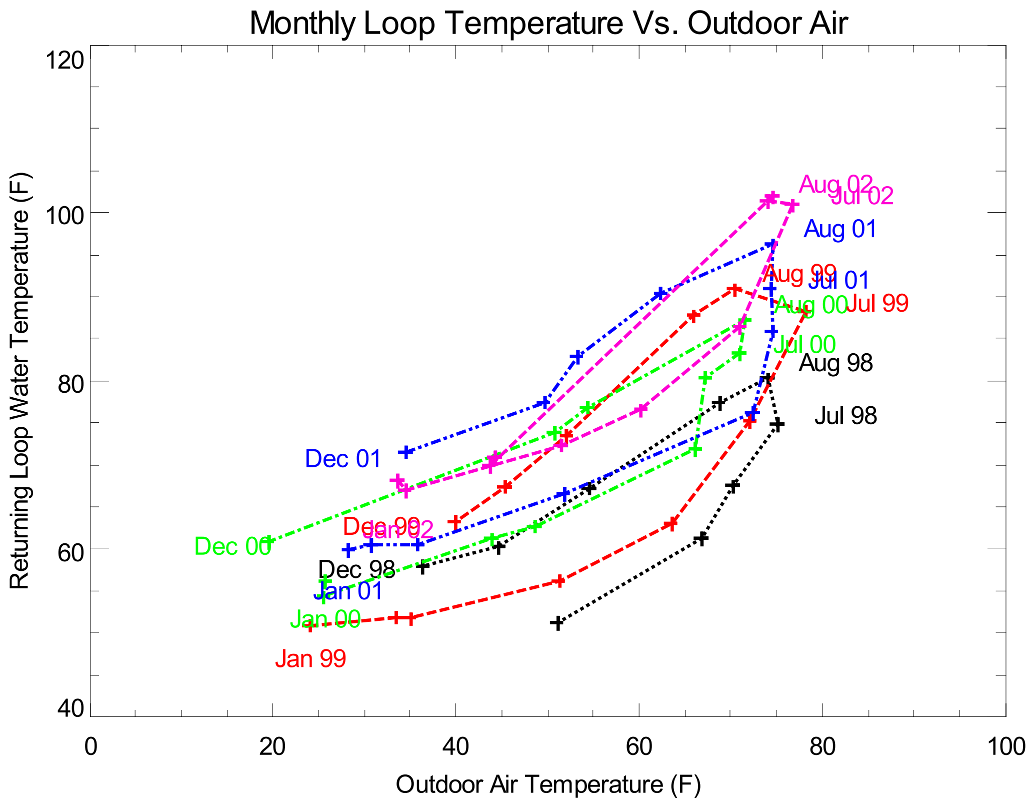


Figure 3-8
Monthly Return Loop Temperature vs. Ambient Air Temperature

The data of Figure 3-8 is also presented in Table 3-2, which shows monthly average return loop and ambient air temperatures. There are several months for which there are gaps in monitored data, and such data are shown in italics. Incidentally, the data for the month of April for all years is complete. The month of April is also the end of the heating and onset of the cooling season. This gives a good picture of the ground loop return temperature at the end of a complete cycle of summer cooling and winter heating. The return loop temperature continued to increase from year to year; it increased from 51.2^{o}F in 1998 to 72.4^{o}F in 2002, just after four years of complete cycles of cooling and heating, or an increase of an average 5.3^{o}F per year. It is also important to note that the last year's increase was above average 5.8°F. It appears that the ground temperature did not reach a plateau even after nearly five years of operation.

The months of August and September also portray the end of summer, and the loop temperature will probably be the highest at the end of summer. Full month average return loop temperature data were available for the month of August for all years except 2000. Once again, the return loop temperature continued to rise from year to year; it increased from 80.3°F in 1998 to 101.5°F in 2002, an average of 5.3°F per year. It is interesting to note that the amount of average annual temperature rise at the beginning of the cooling season in April happens to be same as the amount of average annual temperature rise at the end of the cooling season in August/September.

Table 3-2
Monthly Average Return Loop Temperatures

Month	Average Loop Temperature Returning from Ground Loop Heat Exchanger, Deg. F					Average Ambient Air Temperature, Deg. F				
	1998	1999	2000	2001	2002	1998	1999	2000	2001	2002
Jan	-	50.9	56.2	59.9	68.2	-	24.1	25.8	28.3	33.6
Feb	-	51.9	*54.3*	60.5	*67*	-	33.4	*25.6*	30.8	*34.5*
Mar	-	51.8	*61.2*	*60.5*	-	-	35	*44*	*35.9*	-
Apr	51.2	56.3	62.7	66.6	72.4	51.1	51.3	48.6	51.8	51.5
May	61.2	63.1	*71.9*	*76.2*	*76.6*	66.9	63.6	*66.2*	*72.5*	*60.2*
Jun	67.5	75.3	*80.5*	*85.9*	*86.4*	70.3	72.2	*67.3*	*74.5*	*71.1*
Jul	74.8	88.3	83.2	91	*101*	75.1	78.1	71	74.4	*76.8*
Aug	80.3	90.9	*87.2*	96.2	101.5	74.1	70.5	*71.6*	74.5	74
Sep	77.5	87.8	-	90.5	*102*	68.8	66	-	62.4	*74.6*
Oct	67.3	73.5	*76.9*	83	*69.9*	54.6	52.1	*54.4*	53.3	*43.7*
Nov	60.2	67.4	*73.9*	*77.5*	*71*	44.7	45.4	*50.8*	*49.7*	*44.3*
Dec	57.9	*63.2*	*60.9*	*71.6*	-	36.4	*39.9*	*19.5*	*34.5*	-
The data for months in italics show incomplete data for that month.										

Table 3-3 presents the numbers of hours in a year the return loop temperature remains above a certain temperature. For example, in 1998, the first year of operation, the loop temperature was rarely above 90°F; it just exceeded it for only 16 hours, but in the following year in 1999, it exceeded that temperature for more than 874 hours, and in the year 2001, it exceeded by 2524 hours. The increase in loop temperature directly affects the cooling efficiency; typically, one degree Fahrenheit loop temperature rise reduces cooling energy efficiency by ¾ to 1%. When the return loop temperature exceeds 90°F for a large number of hours in cooling season, it may be more energy efficient to reject heat to the ambient air, which is at cooler temperature, rather than to the hot ground loop fluid. For example, for a large number of cooling hours when the ambient air temperature is between 80-85°F, the loop return temperature exceeded 92°F in 2001 and 96°F in 2002 (see Table 3-4). At these high loop fluid temperatures, it is more efficient to reject heat to the colder ambient air than to the hot loop fluid.

Table 3-3
Numbers of Hours in a Year Above Certain Return Loop Temperature

Year	**Hours Above Temperature, Deg. F.**							**Comments**
	>80°F	>85°F	>90°F	>95°F	>100°F	>105°F	>110°F	Summer Missing Data
1998	694.5	182.5	15.5	0	0	0	0	No summer missing data
1999	2176	1573	873.5	397.5	140	56.5	5.5	No summer missing data
2000	777.5	251.5	10	0	0	0	0	Missing Data Days: 30 in Jun; 29 in Aug; 30 in Sep; 6 in Oct.
2001	3077.5	2523.5	1657	736.5	97	0	0	Missing Data Days: 30 in June
2002	1863	1524.5	1375.5	1271	989.5	35	0	Missing Data Days: 4 in Jun; 20 in Jul; 21 in Sep; 13 in Oct

Table 3-4 presents the average coincident return loop temperature versus outdoor ambient temperature bins. The numbers of hours of occurrence at each outdoor ambient temperature bins of 5°F are also included in Table 3-3. Since there are gaps in monitored data and the data set is 'incomplete', the numbers of hours in each temperature bin from year to year do not clearly reflect the weather in a particular year. Similarly, the average coincident return loop temperature may not reflect the true value if certain data for a particular temperature bin is missing; however, it does provide an average temperature for those hours for which data was available in a temperature bin, which is valuable in determining the trend of return loop temperature rise from year to year.

Table 3-4
Average Return Loop Temperature at Different Ambient Temperature Bins

Typical Season	Outside Ambient Temperature Bins, Deg. F	Number of Hours of Occurrence					Average Coincident Ground Heat Exchanger Return Loop Temperature, Deg. F				
		1998	1999	2000	2001	2002	1998	1999	2000	2001	2002
	-10 to -5	0	2	0	0	0		46.9			
	-5 to 0	0	7.5	10.5	0	0		47.4	57.4		
Winter	0 to 5	0	43	52	0	0		48	57		
	5 to 10	0	74.5	94.5	22.5	0		48.4	56.5	57.7	
	10 to 15	38.5	115	149	39.5	0	52.9	49.3	57.1	60	
	15 to 20	65	174.5	228	161.5	44	53	49.9	58.6	61.4	68.3
	20 to 25	46.5	207.5	308.5	323	60	54.4	50.7	58.4	62.8	68.3
	25 to 30	71	362.5	275.5	498	142.5	55.7	53	58.5	62.1	67.5
	30 to 35	230.5	680	262	704	383.5	57	55.6	59.3	62.5	68.3
	35 to 40	348	737	351	668	425	57.8	58.2	62.8	65.5	68.9
Spring/Fall	40 to 45	506.5	628	344	550	410	58	60.8	64.2	70.9	69.6
	45 to 50	537	628.5	360.5	491.5	355.5	59.5	63.3	66.4	74.3	70.7
	50 to 55	557.5	654.5	392	423	249	60.9	66.1	68.3	76.2	73.5
	55 to 60	688.5	682.5	372.5	455	288	62.2	69.5	72.1	81.7	80.9
	60 to 65	753.5	625	343.5	549.5	297	65.4	74	75.1	84.8	87
	65 to 70	735	852.5	332.5	607.5	357	68.8	78.5	79.3	87.7	91.8
	70 to 75	749.5	676	310	567.5	434	72.6	81.9	81.6	90.8	94.8
	75 to 80	567	517	173.5	408.5	421.5	75.6	85.2	83.1	92.4	96.4
Summer	80 to 85	458	354	106	304.5	275.5	77.1	89.5	83.8	92.6	97
	85 to 90	265	252	30.5	198	164	79.6	88.5	83.5	94.5	96.4
	90 to 95	74.5	89.5	0	77	70	81	90		97.5	99.1
	95 to 100	6.5	14	0	9.5	2.5	83.2	96.5		102.1	103.4
	Total number of hours for all bins	6698	8377	4496	7058	4379					
	Data Missing, %	24%	4%	49%	19%	50%					

Heat Flow In and Out of the Ground Heat Exchanger Loop Field

In a geothermal heat pump system, heat is extracted from the ground heat exchanger loop field in winter and it is rejected in it in summer. The ground heat exchanger loop field acts as a source of heat in winter and a sink for heat in summer. In most commercial buildings, seasonal cooling loads are far greater than the seasonal heating loads, and heat discharged into the ground is much larger than the heat extracted from the ground. This results in the annual imbalance of heat rejected into and heat removed from the ground loop field. This imbalance leads to gradual temperature rise in the return loop temperature over the long term as observed earlier. In a well-designed and sized loop field, the excess heat will be slowly dissipated to the surroundings without heat build up in the ground loop field, or if the heat is built up in the field, it will reach a plateau soon and its rise in temperature will stop after a couple of years.

Figure 3-9 below shows daily amount of heat rejected into the ground or extracted from the ground for the five years. If heat is extracted during early morning for heating and rejected into the ground in the afternoon for cooling, as is likely in the spring and fall, the net heat transfer difference will be very small as observed from the Figure. The daily heat transfer is also indicative of the daily net cooling and heating loads met by the geothermal heat pump system. The Figure clearly shows that even in this northern U.S. climate, the seasonal cooling loads are much higher than the seasonal heating loads for this application. Figures 3-10 to 3-14 show daily ground heat exchanger loop field heat transfer for individual years.

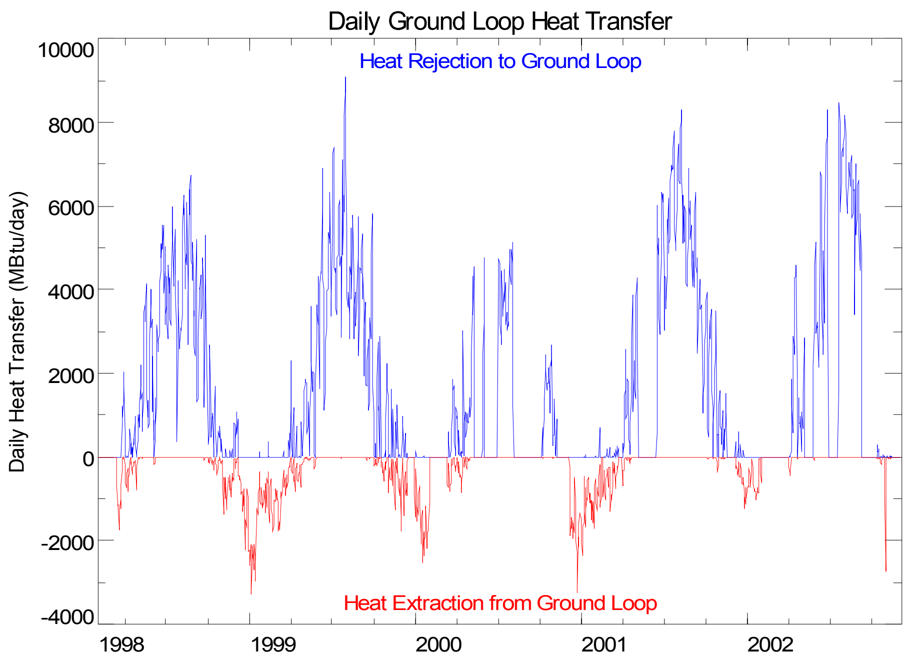


Figure 3-9
Heat Rejection Into and Heat Extraction From the Ground Loop Heat Exchanger from 1998 to 2002

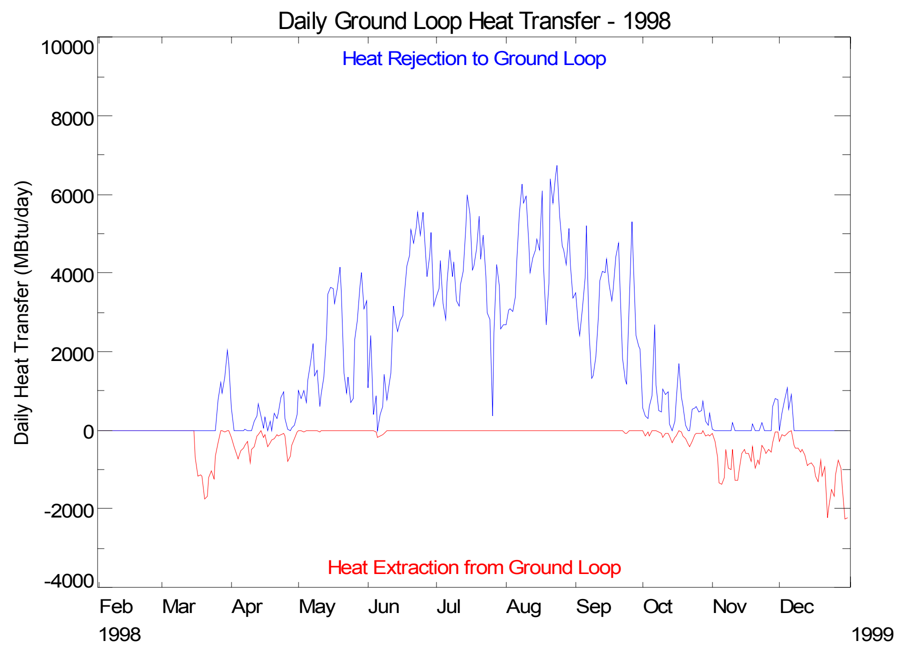


Figure 3-10
Heat Rejection Into and Heat Extraction From the Ground Loop Heat Exchanger-1998

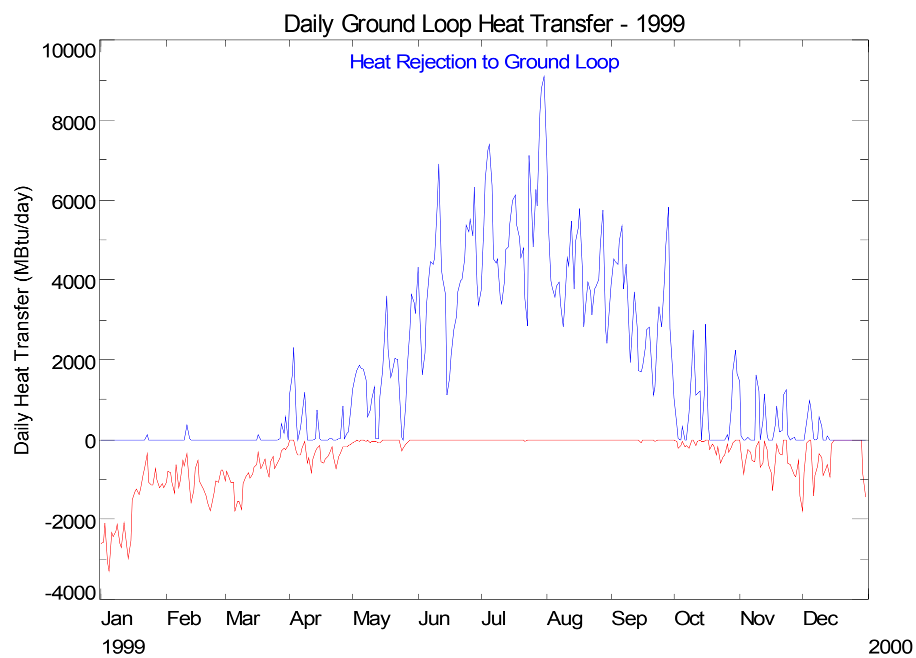


Figure 3-11
Heat Rejection Into and Heat Extraction From the Ground Loop Heat Exchanger-1999

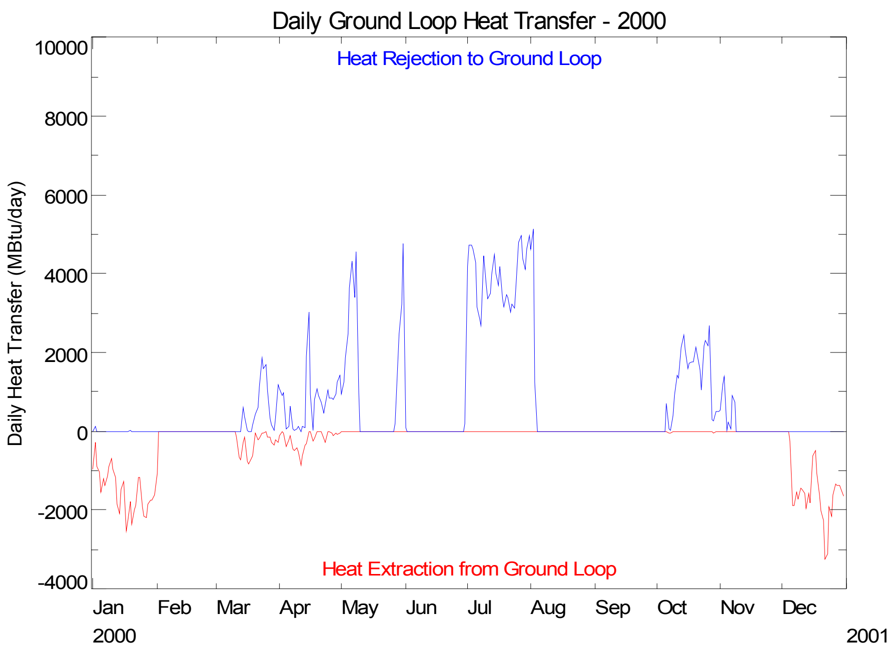


Figure 3-12
Heat Rejection Into and Heat Extraction From the Ground Loop Heat Exchanger-2000

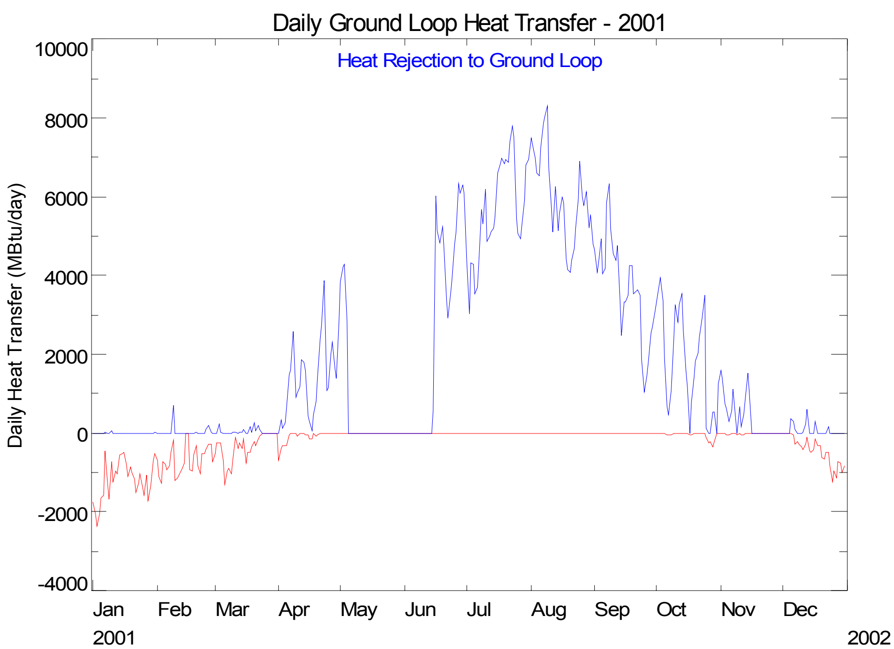


Figure 3-13
Heat Rejection Into and Heat Extraction From the Ground Loop Heat Exchanger-2001

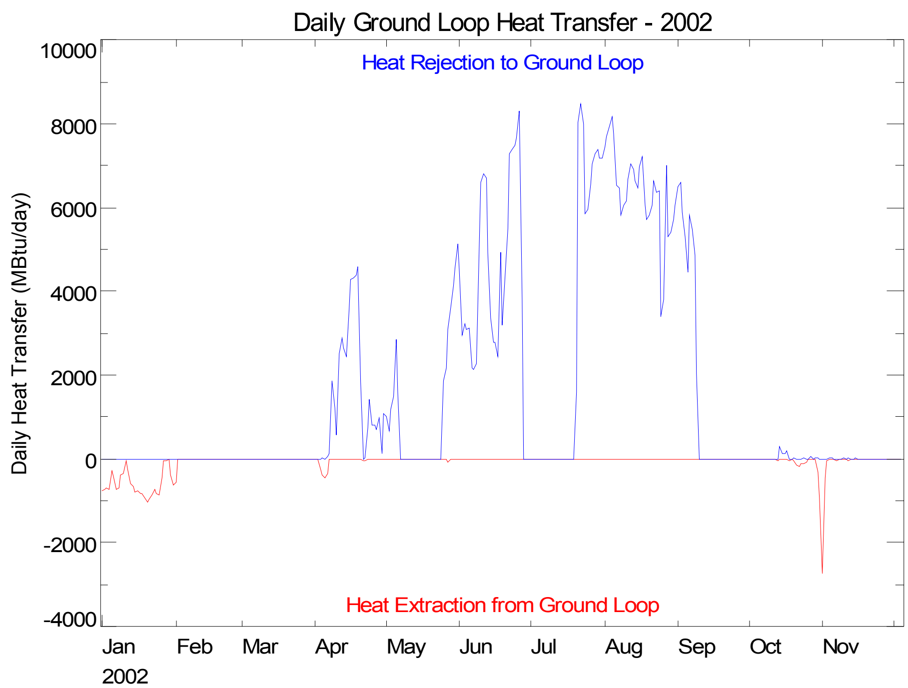


Figure 3-14
Heat Rejection Into and Heat Extraction From the Ground Loop Heat Exchanger-2002

The heat build up in the ground loop is not conducive to energy efficient operation. Even after five years of operation, the heat build up continues, which not only jeopardizes the heat pump energy efficiency, but may also compromise its compressor reliability under very high head pressure due to high loop temperature. In the least, it would create operational nuisance by tripping compressors 'off' on high head pressure, which would have to be reset manually in most heat pumps.

In the past loop field were often under sized in order to economize on the total system cost. The loop field in many commercial installations could constitute more than half of the total system cost. With the loop field cost of $800-1500 per ton, it is tempting to economize on it. Although it may not show up in the first couple of years of operation, it is clear that any under sizing would seriously hurt system performance as well as reliability in the long run.

It is also important that the consulting engineers have good design and sizing tools, so that they would not inadvertently undersize the loop field.

The data also underscores the need for a low cost means to remove the heat from the overheated ground heat exchanger loop field. For example, if a fluid cooler could remove heat from the ground loop during low ambient temperatures, such as at night, it could alleviate the problem of high loop temperatures. Such a heat exchanger can be used in retrofit applications where loop temperatures have risen over the last several years. This could also be used in new applications where the loop field could be sized smaller, primarily for the heating load considerations, and the fluid cooler would supplement the ground loop during summer. Such fluid coolers would also provide a cushion or margin of safety against unknown factors that may affect estimation of seasonal loads in design phase, or changes in actual operation affecting seasonal loads due to unforeseen use patterns in operating phase.

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