Haverhill Public Library

Figure 1. Original Library Prior to 1997 Renovation

The Haverhill Public Library is a 28,000 ft^2 two-story building located at 99 Main St. in Haverhill Massachusetts. The building was opened in 1969.

The original HVAC system used air-cooled chillers for cooling. Heating was provided by electric resistance elements in three air handlers as well as an electric boiler. A two-pipe system distributed hot or cold water from the chiller or boiler to the air handler.

The new system was placed in service in January of 1995. It replaced the chiller and electric boiler with water-to-water heat pumps. The heat pumps operate between the existing water distribution piping and two standing column wells.

Each of the open standing column wells is 1,500 ft. deep. Water is pulled from the bottom, run through the heat pumps and discharged at the top of the well.

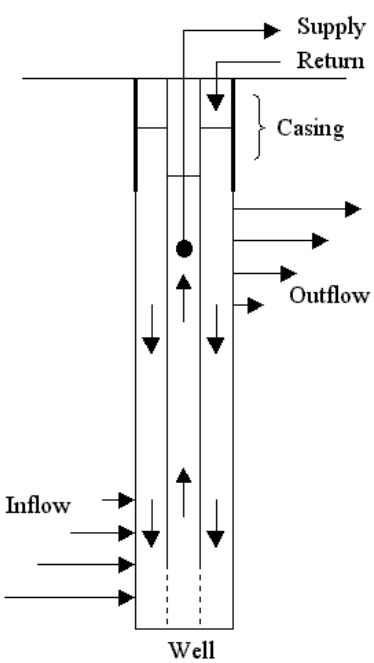

Figure 2. Standing-Column Well Concept

Each well has its own pump. The pumps cycle to maintain pressure (typically 25 psi to 40 psi) to the heat pumps. When the heat pump operates a motorized valve on the well water side opens. The well water loop is buffered by two expansion tanks to allow stable operation. Whenever the well water temperature drops below 40°F, a bleed cycle initiates. This automatic bleed diverts approximately 10% of the flow from returning to the wells. A bleed cycle typically lasts for 30 minutes. It acts to limit the lower well temperature by drawing in new warmer ground water. There is no bleed for high temperatures.

Six 10-ton water-to-water heat pumps are connected directly to the common well water manifold. Local regulations required nothing more than a general notification of the well drilling. The water was tested for pH and total dissolved solids to identify extreme conditions. High conductivity would lead to an investigation to confirm that the electric system ground was adequate. An inadequate ground could cause the well system to function as the electrical ground and give rise to potential heat exchanger corrosion. Water quality at the library was found to be normal.

The heat pumps are sequenced on to maintain the desired building-side water temperature (via a manually-set aquastat and series of time-delay relays for staging). The heat pumps are connected to three air handlers through a two-pipe arrangement using the existing chilled water piping and controls, (i.e., pneumatic controls with three-way valves). The original boiler supplied 160ºF to 180ºF water. The heat pumps can typically supply 120ºF in heating and 45ºF in cooling, however, the load has been satisfied by 90ºF water—the lowest setting on the aquastat. All heat pumps supply either chilled or heated water depending on the season. The heating/cooling changeover is manual. The existing three horsepower circulating pumps serve the air handling units. They were rebuilt as part of the project after flow rates were found to be inadequate.

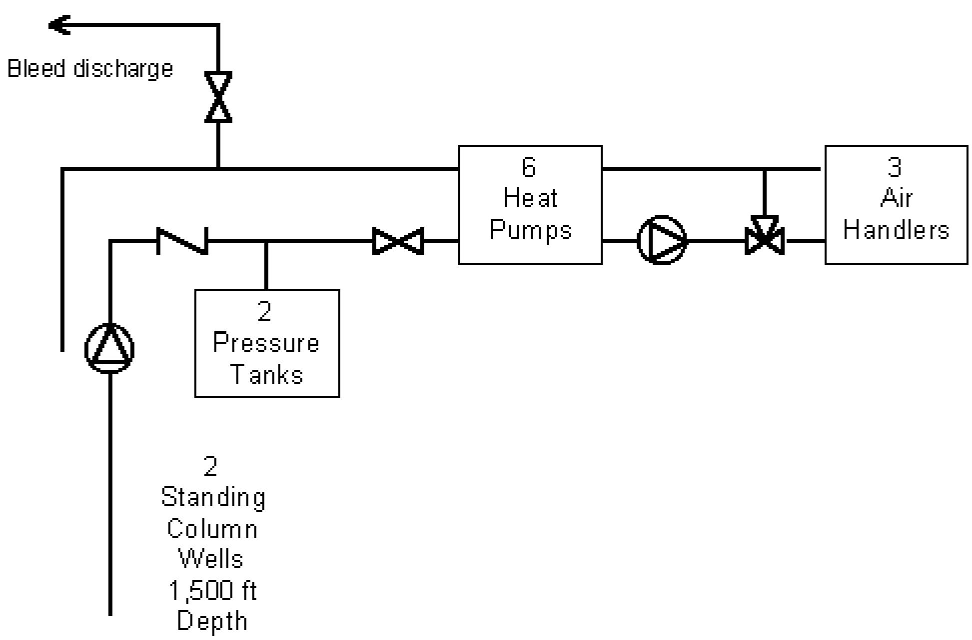

Figure 3. System Concept Schematic

The local electric utility, New England Electric/Massachusetts Electric, has been monitoring the system since May 1995. They collect 15-minute data and supplied us with hourly data on the following:

- Total power use of the six water-to-water heat pumps
- Total power use of the well pumps
- Outdoor air temperature
- Common water temperatures entering and leaving the wells

As Figure 4 shows, the well water temperature remained above 37ºF and generally operated in the lower 40s during heating. The peak loop temperature reached 70ºF in June. However, system operation changed after June 25 when the second well pump became active and the maximum well temperature remained below 66ºF thereafter. There was also less variation in the temperature after June 25 in both heating and cooling.

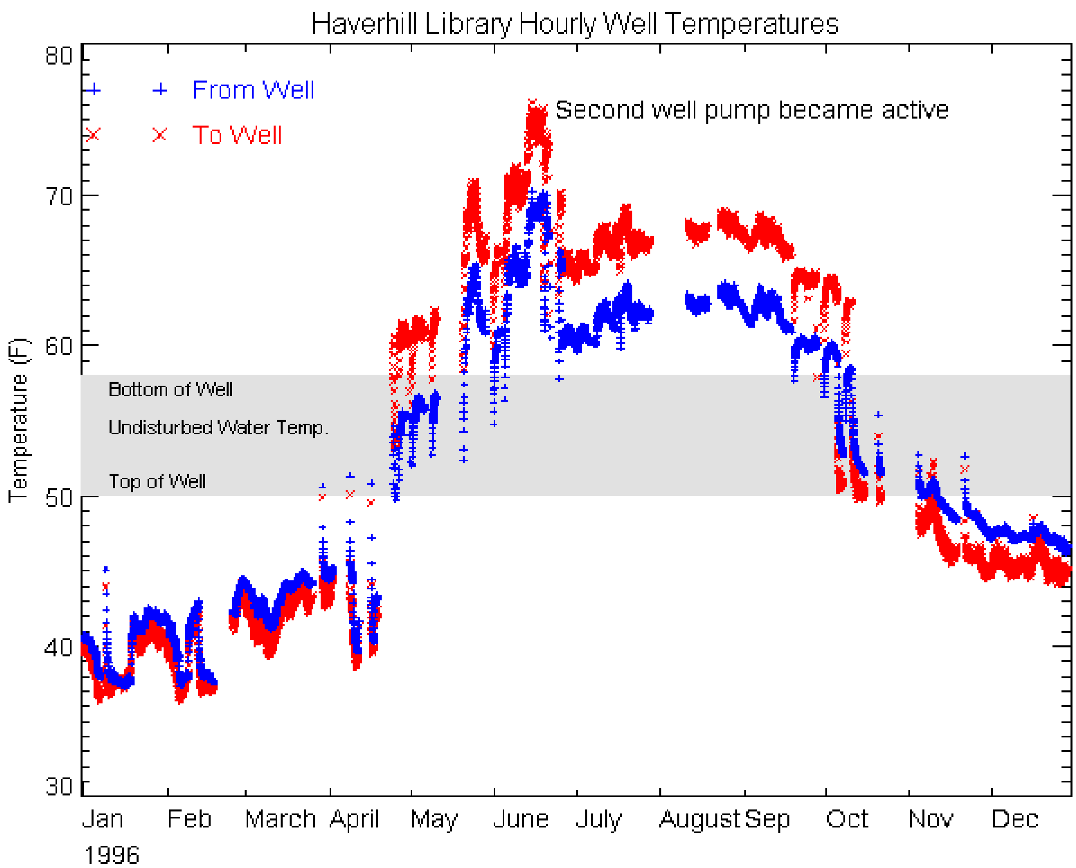

Figure 4. Well Water Temperature Trends

The static water level of the wells is 40 ft. below grade. 20 ft. to 50 ft. is typical. According to the designer the temperature of the water table is usually 50° F at the top and 58°F at the bottom of the well. A 3/4 °F temperature rise per 100ft below a 500 ft. depth is typical. A similar system in Manhattan had an undisturbed temperature profile starting at 52°F at the top that decreased to 47°F then increased to 56°F at 1,300 ft.

The average temperature difference across the well water side of the heat pumps was -1.5ºF in heating and +4.9ºF in cooling as shown in Figure 5. The small water temperature difference is due to the large water flow when only one or two heat pumps operated. The well pumps can pump 90 gpm. There was a one-minute time delay before the second heat pump came on and a three minute delay for the next units. The delay can be set up to 8 minutes. The design flow rate of 30 gpm only occurred when three heat pumps and one well pump or six heat pumps and two well pumps operated. At all other times the flow rate through each operating heat pump was above the design flow rate, leading to the small temperature differences.

While there were no status data on the bleed cycle occurrences, there might be indications of bleed cycles in January and February as the loop temperature remained below 39ºF for 444 hours and below 38ºF for 286 hours. These periods of coldest loop temperature lasted from days to weeks and had higher heat pump power, indicating more units operated.

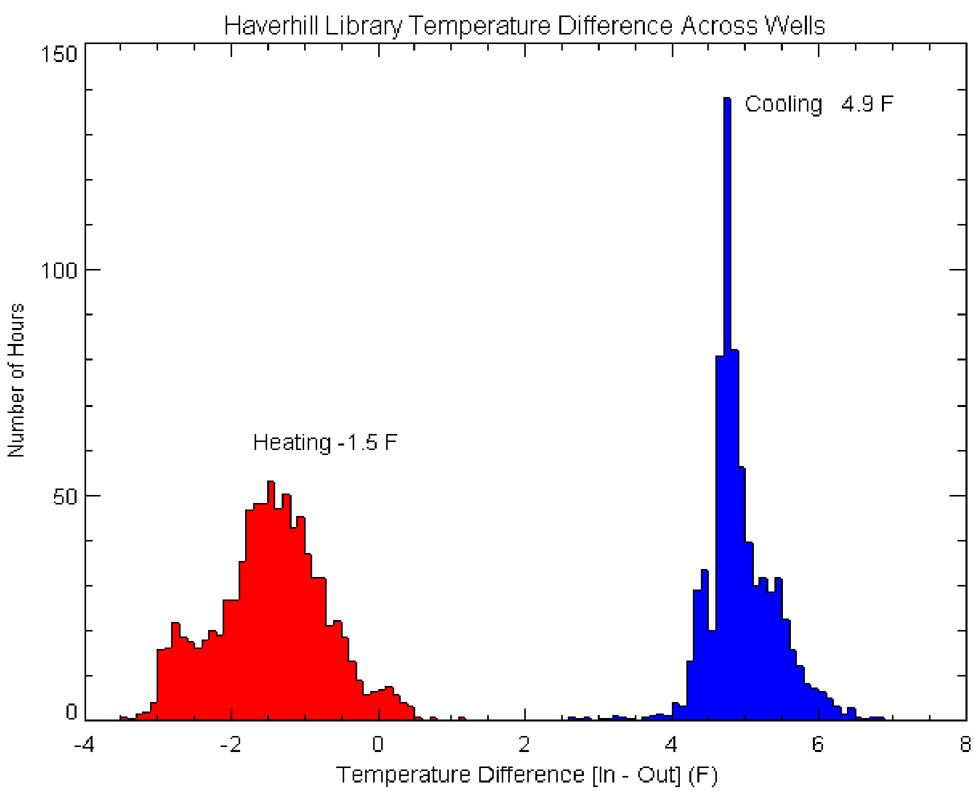

Figure 5. Temperature Difference Across Well Water Side of Heat Pumps

The change in system performance before and after June 25, 1996 is most apparent in Figure 6. Prior to June 25 the maximum heat pump power would be reached at a lower pump power. Furthermore, the temperature extremes were larger before this date. A malfunctioning contactor on one of the well pumps caused this behavior. The 5 hp well pump on the second well was not operational until June 25.

These two distinct operating conditions are useful in showing the impact of the well sizing on the system behavior. Prior to June 25 the system operated with only half of the original ground heat exchanger design capacity. Water temperatures from the well were more extreme by nearly 10˚F in both heating and cooling. The lower winter temperature presumably led to more water bleeding. By adding the second well the pumping power was increased, but the water temperatures were moderated.

This plot also shows the heat pump power remaining below 23 kW, suggesting that only four or five units ever ran simultaneously. The lowest power draw for the ClimateMaster WE120 is 5.7 kW. This occurs when the water temperature on the heat extraction side (evaporator) is 30˚F at 20 gpm and the water temperature on the heat rejection side (condenser) is 80ºF at 11.5 gpm. Conditions were generally not this extreme suggesting more power draw than 5.7 kW per unit and that there were probably very few times that more than four units operated together.

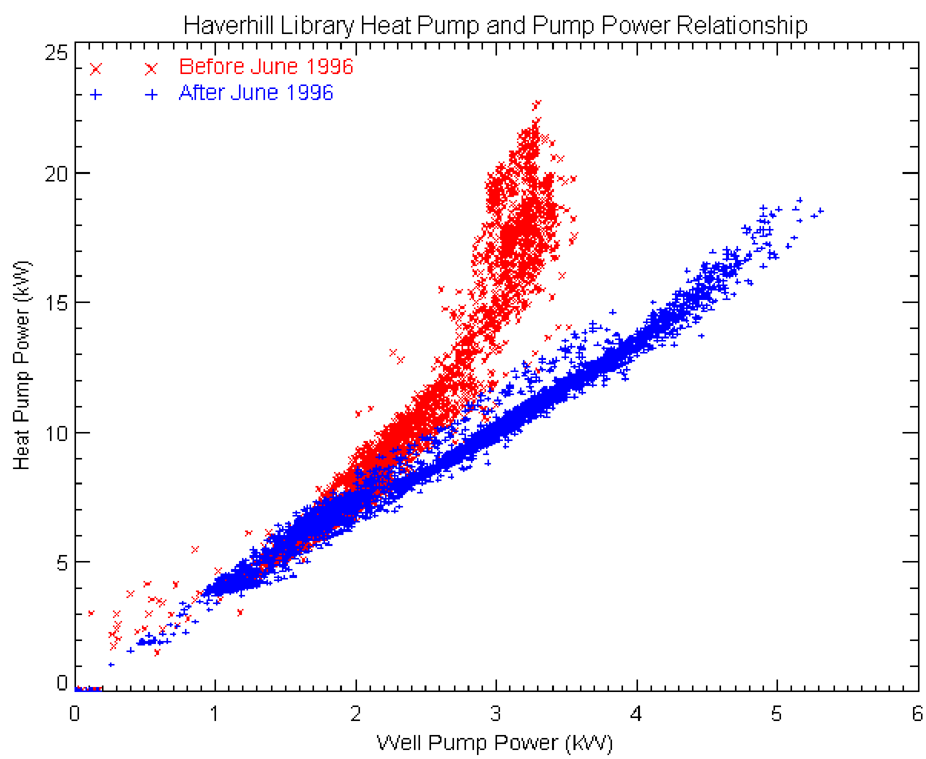

Figure 6. Heat Pump and Well Pump Power Relationship

The relationship in Figure 7 shows an increase in heat pump power with extremes in the well water temperature. As more units turn on to meet the increasing load, they drive the water temperature higher or lower.

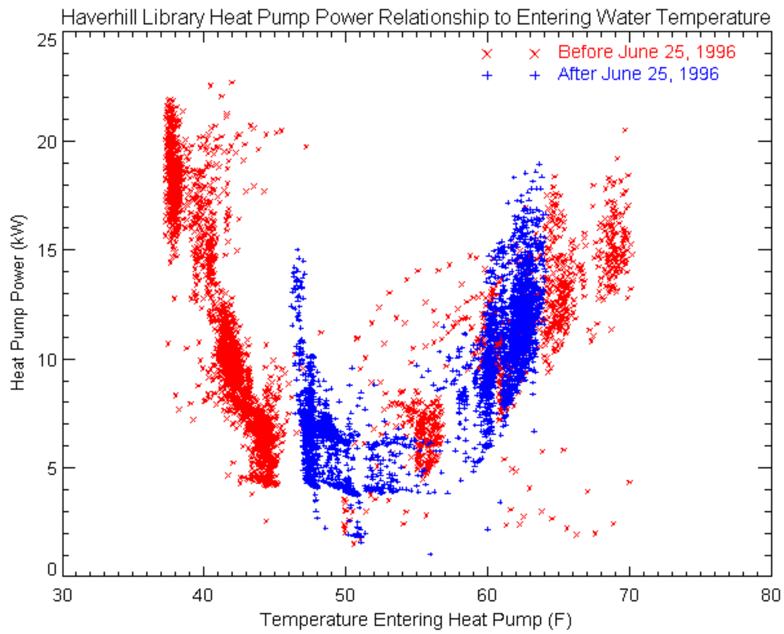

Figure 7. Heat Pump Power and Well Water Temperature Relationship

A comparison of the electricity bills between the geothermal system and the previous system in Figure 8 shows a drop in total building electricity use of 135 to 140 MWh. The elimination of the electric resistance boiler and elements in the air handler are apparent in the second plot showing the monthly billing demand. The monthly demand leveled out after the system became operational in early 1995.

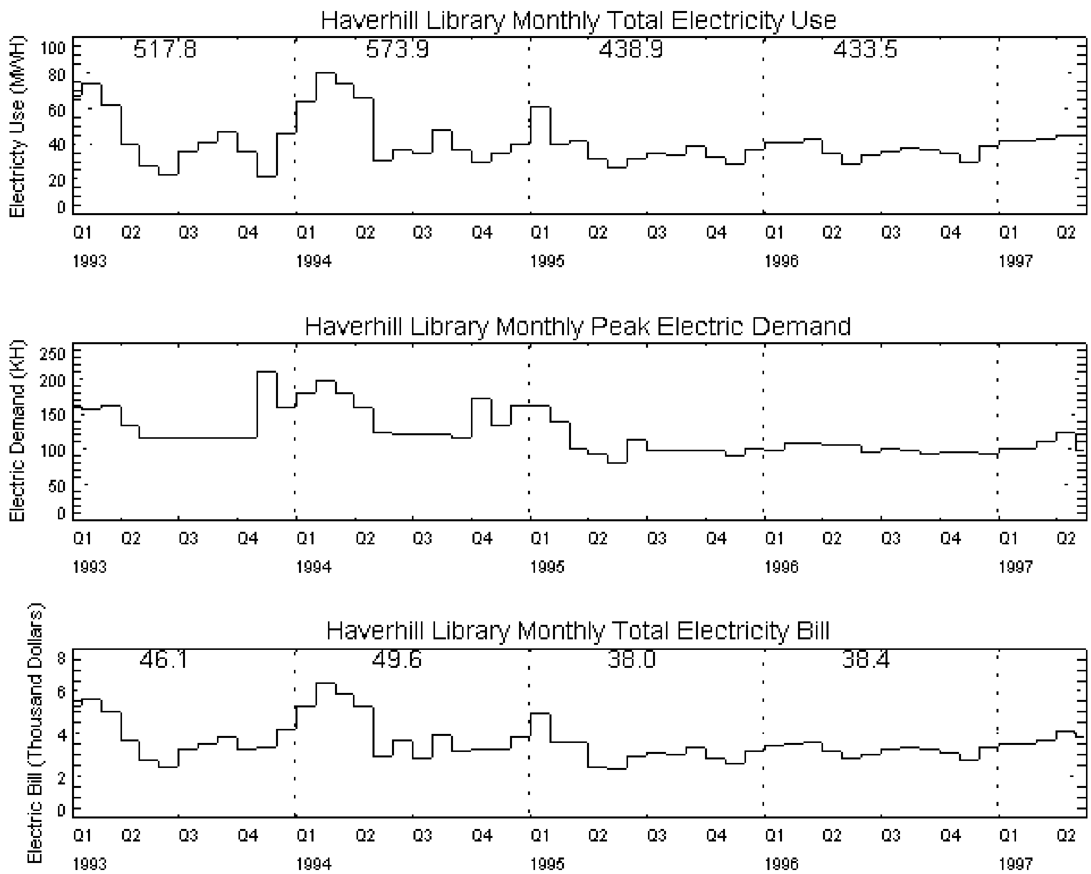

Figure 8. Electricity Bill Comparisons

The bills were fairly consistent before and after the system change. Normalizing the bills for weather resulted in annual savings of 129 to 131 MWh compared to the raw savings of 135 to 140 MWh. The relationship of the 1994 billing data to outdoor temperature, Figure 8, defined the weather dependence that was used to estimate the previous system's energy use in 1995 and 1996. Using the average annual cost of electricity and the normalized electricity savings, the annual billing savings were $11,300 and $11,400 per year in 1995 and 1996 respectively.

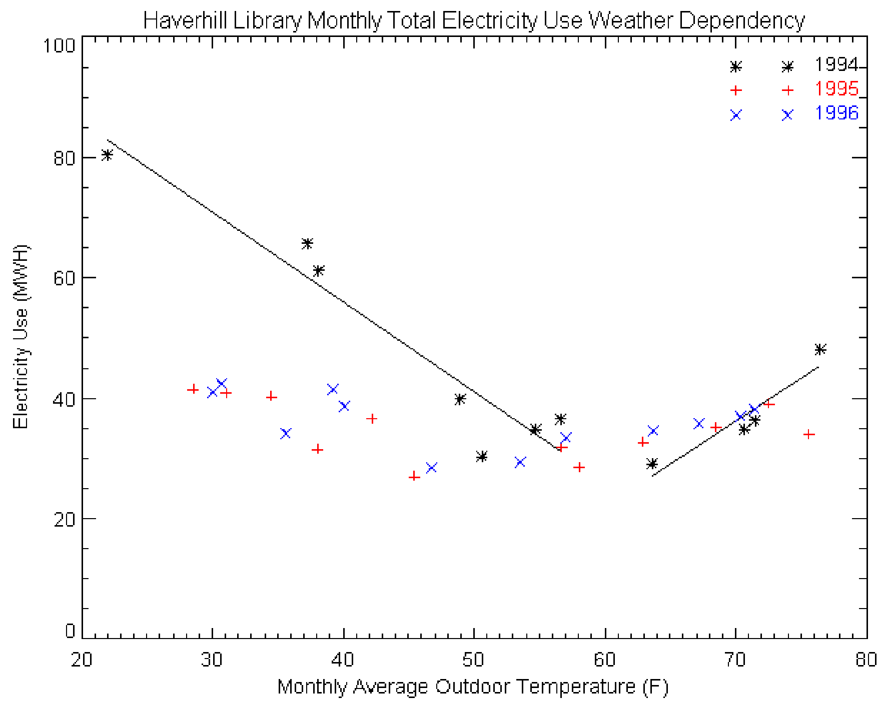

Figure 9. Monthly Total Electric Bill Weather Normalization

The total cost of the system was $209,000 or $3,480 per ton. Typical costs for wells are $900 to $1,200 per ton, making the incremental cost at least $54,000 to $72,000 based solely on the ground heat exchanger cost.

There is a general daily trend of heat pump use increasing with extremes in weather. However, Figure 10 shows a high degree of scatter in the trend. This characteristic is indicative of loads being more dependent on factors other than the outdoor dry-bulb temperature (e.g., solar gains, occupancy, etc.).

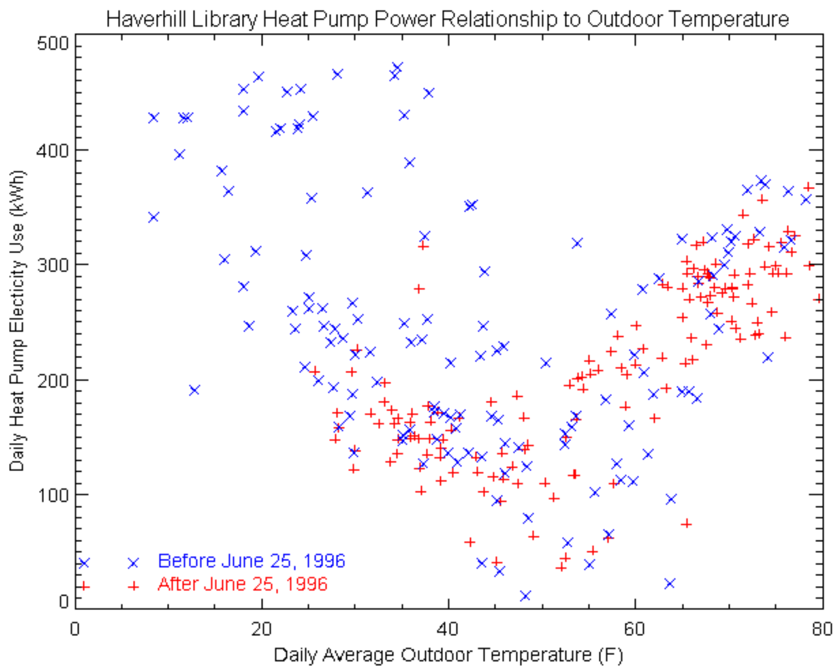

Figure 10. Outdoor Temperature Influence on Heat Pump Energy Use

There do not appear to be strong daily patterns in heat pump energy use. Each vertical stripe remains the same shade of gray from top to bottom. Rather there is a broad period of summer use and several days of higher use in the winter. The shade plot in Figure 11 depicts higher power levels by darker shades of gray. Each day is shown as a vertical strip. The days progress throughout the year along the horizontal axis.

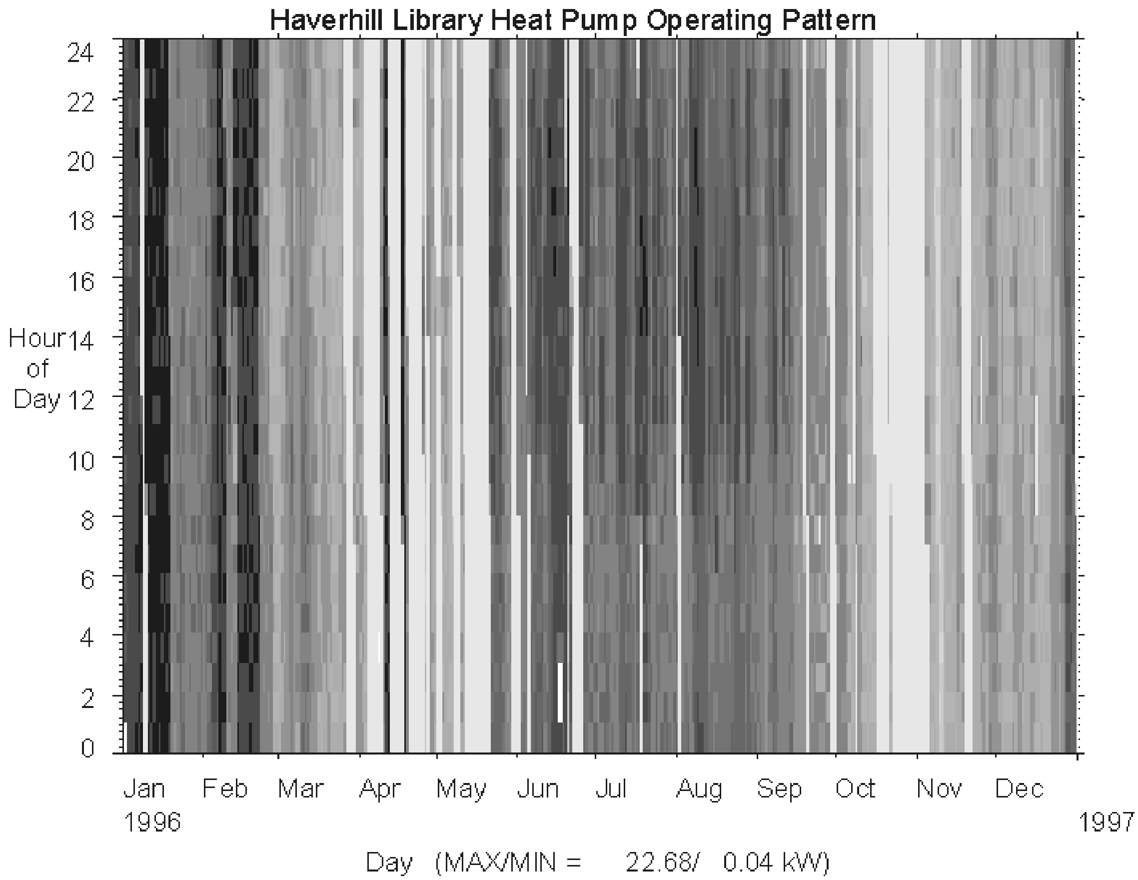

Figure 11. Heat Pump Operating Pattern

A monthly summary of the data in Table 1 shows the seasonal trend in energy use and the average well water temperatures each month. The heat pump energy use was equally divided between heating and cooling. The well pump used 18,375 kWh or 20% of the combined heat pump and well pump energy. The heat pumps used 72,967 kWh for the year.

Table 1. Monthly Data Summary

1996		Heating					Cooling				
Month	Average Outdoor Temp (F)	Hours of Heating Data	Temp from Well (F)	Temp to Well (F)	Heat Pump Elec. Use (kWh)	Well Pump Elec. Use (kWh)	Hours of Cooling Data	Temp from Well (F)	Temp to Well (F)	Heat Pump Elec. Use (kWh)	Well Pump Elec. Use (kWh)
1	27.7	730	40.3	39.5	9,982	1,927	13	41.3	44.5	1	0
2	27.4	696	40.4	39.6	8,934	1,830	-	-	-	-	-
3	35.4	732	44.5	43.2	4,909	1,286	12	48.9	52.0	1	0
4	47.8	544	51.0	50.3	2,109	408	175	52.3	56.9	678	183
5	57.9	361	58.1	57.7	26	6	383	59.2	64.4	3,524	855
6	68.1	101	63.2	63.3	18	4	617	64.3	69.4	7,768	1,772
7	72.2	-	-	-	-	-	744	61.7	66.5	8,718	2,577
8	70.1	-	-	-	-	-	744	63.0	67.8	9,156	2,705
9	62.7	88	59.6	59.8	19	5	632	61.4	66.1	6,203	1,846
10	51.5	554	55.6	55.1	925	253	190	58.3	62.3	1,360	412
11	39.3	720	50.1	48.4	3,387	915	-	-	-	-	-
12	38.2	729	47.3	45.4	5,250	1,392	-	-	-	-	-
Totals		5,255			35,559	8,024	3,510			37,407	10,351

The library is very pleased with the system. They are expanding the system to accommodate a building addition. Two new wells and expansion tanks have been added to the existing header along with thirteen water-to-air heat pumps ranging in size from 11/2 to 5 tons.