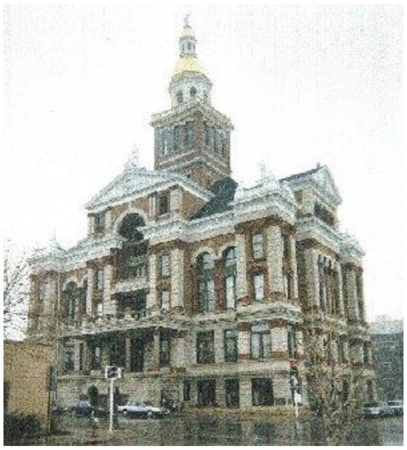
GeoExchange at the Dubuque County Courthouse



The Dubuque County Courthouse is a 38,000 sq. ft. five story building that replaced a boiler/tower water loop heat pump system with new heat pumps and an open well. A plate frame heat exchanger replaced the tower and boiler, freeing additional storage space in the mechanical room. A 93 ft. well supplies water to the building loop through the plate frame heat exchanger.

Due to the historic nature of this building, the new system used the existing loop piping from the original system. The original piping system created some challenges to the implementation of the new system. Most notable was the questionable state of the monoflow valves that diverted a portion of the water to each heat pump. These valves were buried in the walls and could not be serviced. To overcome low flow conditions, each heat pump used a small booster pump to achieve proper flow. Despite these restrictions, the new system reduced energy use and cost by 20%. Another 21% of energy savings would have been possible had new building loop piping been feasible.

The main objective in monitoring this site was to demonstrate the performance of this unique system in a historic building. Data were collected from January 1998 through March 1999. This project relied on limited monitoring of the loop thermal loads, pump operation and total building electricity use to assess the performance of the system. The monitoring was implemented through a dedicated data logger and associated sensors, including well and building flow, temperatures in and out of the heat exchanger, total building electricity use, well and building loop pump currents and outdoor temperature and humidity.

Ground Heat Exchanger

A single extractor well pumps water through a plate-frame heat exchanger and discharges to the municipal storm sewer. The well is 93 ft. deep and is capable of providing 350 gallons per minute (gpm).

Figure 1. Plate Frame Heat Exchanger

The plate-frame heat exchanger (Figure 1) separates the well water from the building circulation loop. The building loop circulates water through the heat pumps continuously. The well pump speed is controlled to maintain the building loop temperature between 50° F and 75° F. It shuts off when the temperature is between these set points.

Performance

Loop Temperatures

The well provided water at a constant temperature of 56°F year round. The system maintained the building loop supply temperature by controlling the well flow rate. Initially the temperature was controlled between 50°F and 80°F. In June the upper set point was reduced from 80°F to 75°F resulting in a net annual savings of 6,100 kWh or 4.8%.

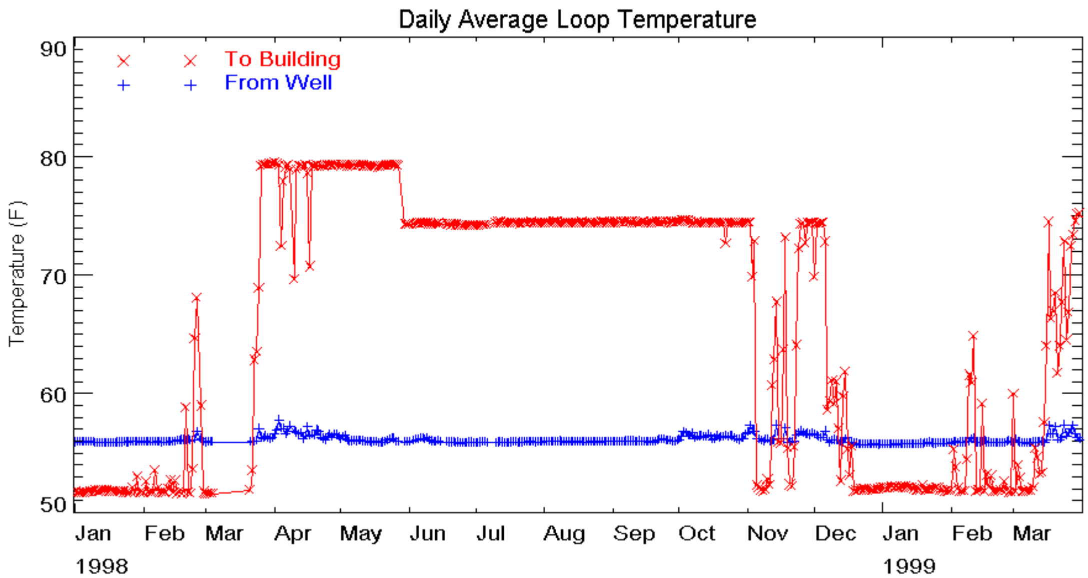


Figure 2. Daily Average Well and Loop Temperature

Additional savings are possible with a lower set point. The limiting factor is the uninsulated piping. The loop temperature must be kept above the interior dew point to avoid condensation on the piping within the walls.

Pumping

The adjustable speed drive on the well pump kept the flow rate well below the 350 gpm design flow rate. As Figure 3 shows, the flow rate varied from 10 to 60 gpm in cooling and reached as high as 140 gpm in heating. The flow rate was turned down at or below 20% of the design flow during 86% of the time the pump operated.

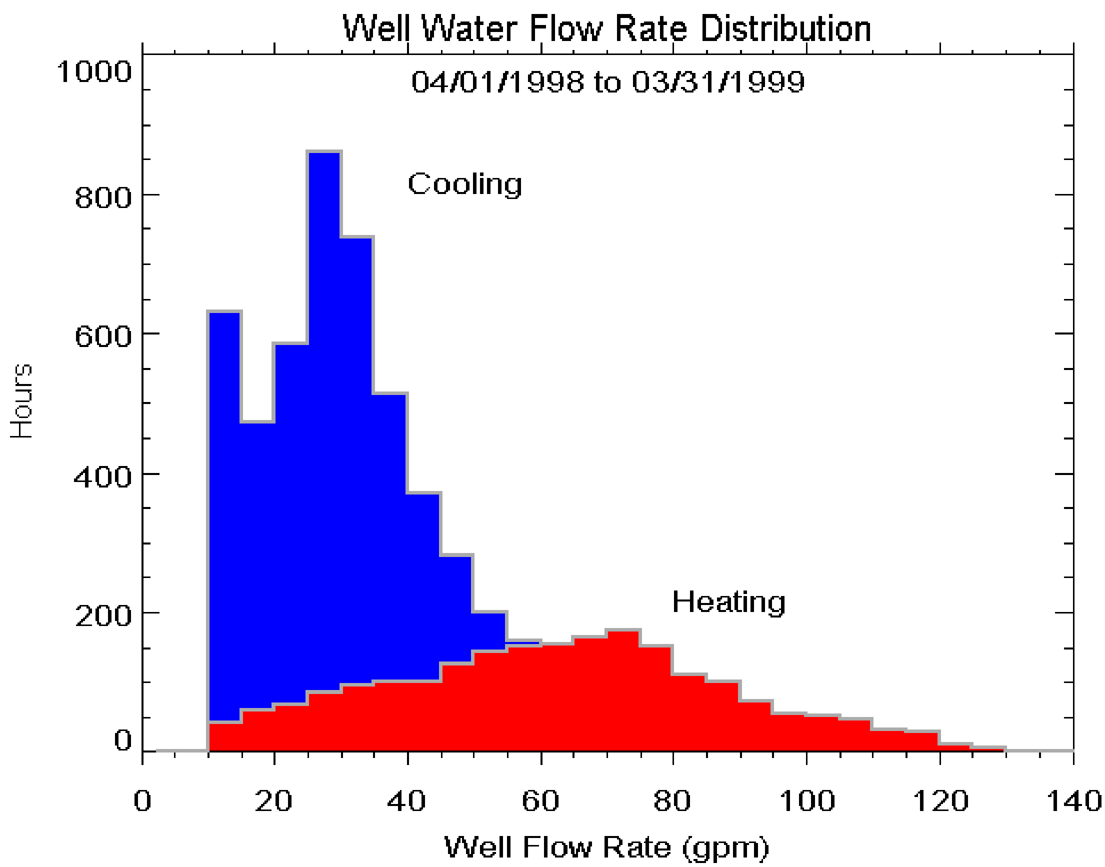


Figure 3. Well Water Flow Rate Distribution

Extrapolating the measured well pump power to the design rate of 350 gpm suggests that the well pump would have drawn 14.5 kW if operated continuously at the design flow rate. As Figure 4 shows, most of the well pump operation occurred in the 1.2 kW to 2.5 kW range. On an annual basis, continuous operation at the design flow for 5,979 hours would have consumed 86,700 kWh. With the adjustable speed drive the actual energy use was only 11,500 kWh, a reduction of 87%.

For 100 tons of installed capacity, a more typical well flow rate would have been closer to 150 gpm (1.5 gpm/ton) instead of the 350 gpm (3.5 gpm/ton) that was actually installed. At this lower flow rate, the well pump power would have been 3.6 kW and used 21,500 kWh, if run continuously. In this case the variable speed drive (VSD) would have reduced well pump energy use by 47%.

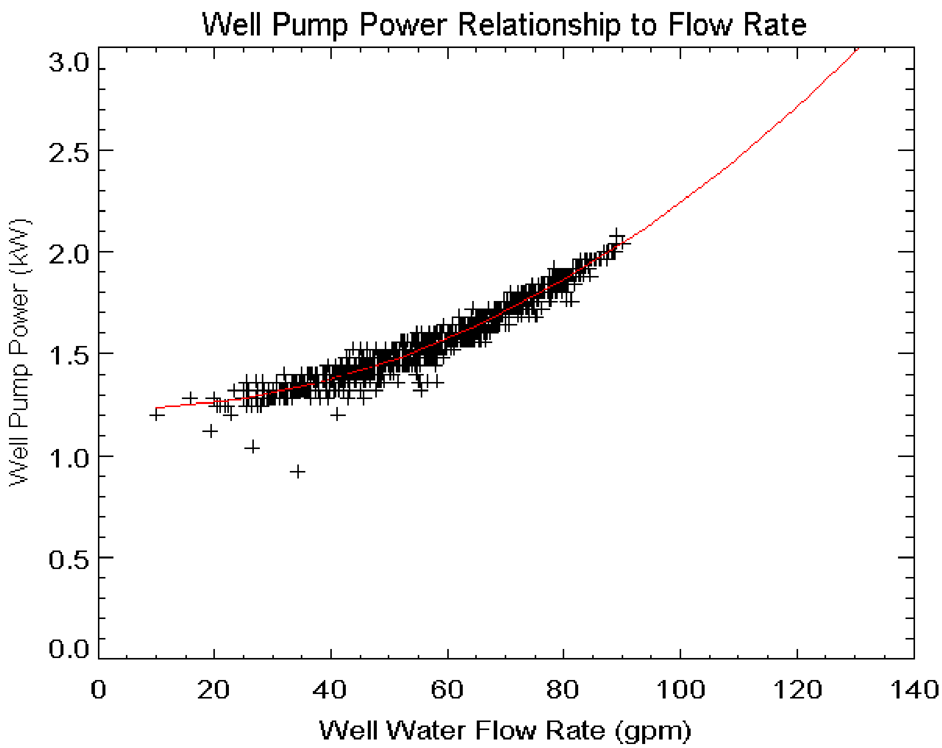


Figure 4. Well Pump Power Relationship to Flow Rate

Well water use was related to the building load. Winter water use reached 11,000 gallons per day. Summer water use reached 4,500 gallons per day, as shown in Figure 5. The asterisks in the summer period correspond to the operation at the higher 80°F water set point. These data show the lower water use with the higher set point. Over the entire 1998 year the well delivered 8 million gallons of water.

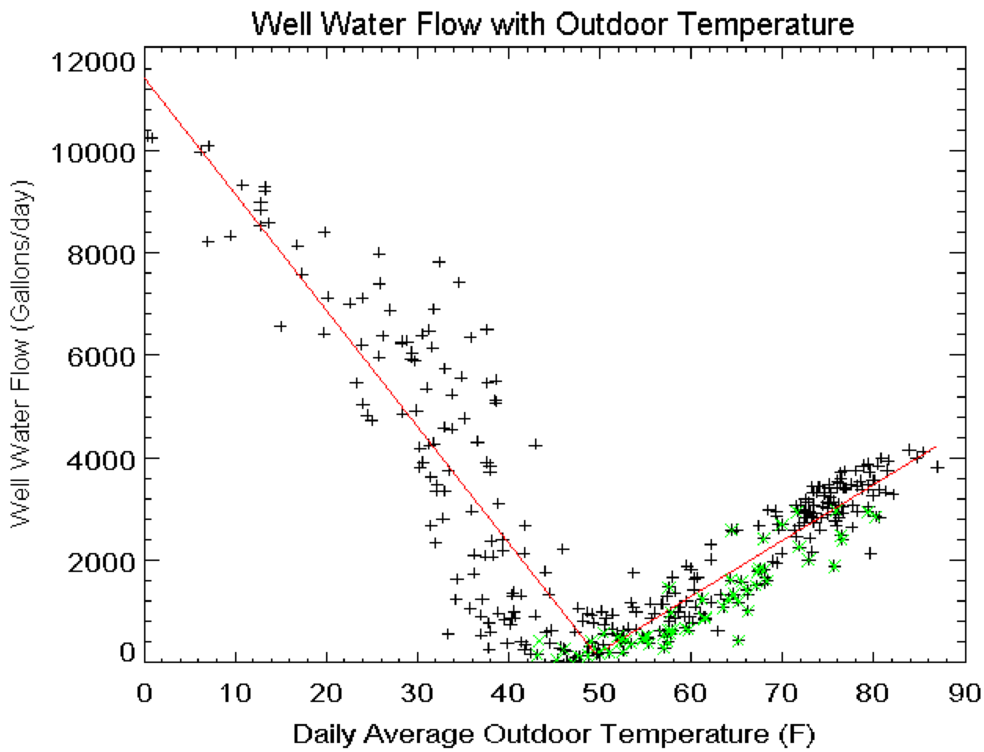


Figure 5. Well Water Use Relationship to Outdoor Temperature (Load)

The system maintained a constant flow rate of 265 gpm (2.65 gpm/ton) through the building loop. Over a year the system re-circulated 139 million gallons through the loop. A variable speed drive on a conventional piping system would have circulated only 32 million gallons.

Loop Load

The space conditioning load was dominated by the cooling load. Cooling was predominant from April through October as illustrated by the monthly net loop load in Figure 6. Over the 1998 calendar year, 1,250 MMBtu was rejected to the well water, and 223 MMBtu was extracted from the well.

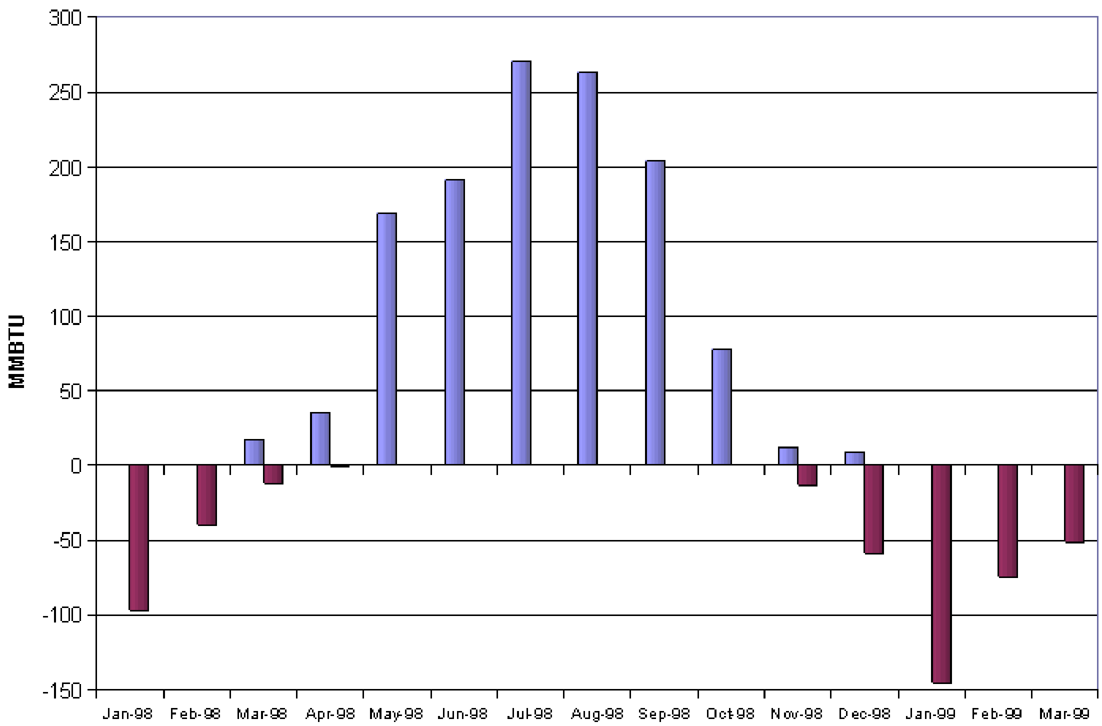


Figure 6. Monthly Net Loop Load

Heat Pump Energy

The heat pump energy use was estimated from the monitored total building power. Correlation of daily total building energy use with daily average outdoor temperature shows a strong weather dependence in Figure 7. Assuming all of the weather dependence in the total building energy use was caused by the heat pump operation gives an estimate of the heat pump energy use.

Applying the expected heat pump COP for a given loop temperature to the loop loads gives an estimate of the heat pump energy use, which is also shown in Figure 7 as squares at the bottom of the plot. The dashed lines represent the estimated heat pump energy use estimated from the total building meter.

The heat pump energy use amounted to 30 kWh/Day °F when derived from the total building meter.

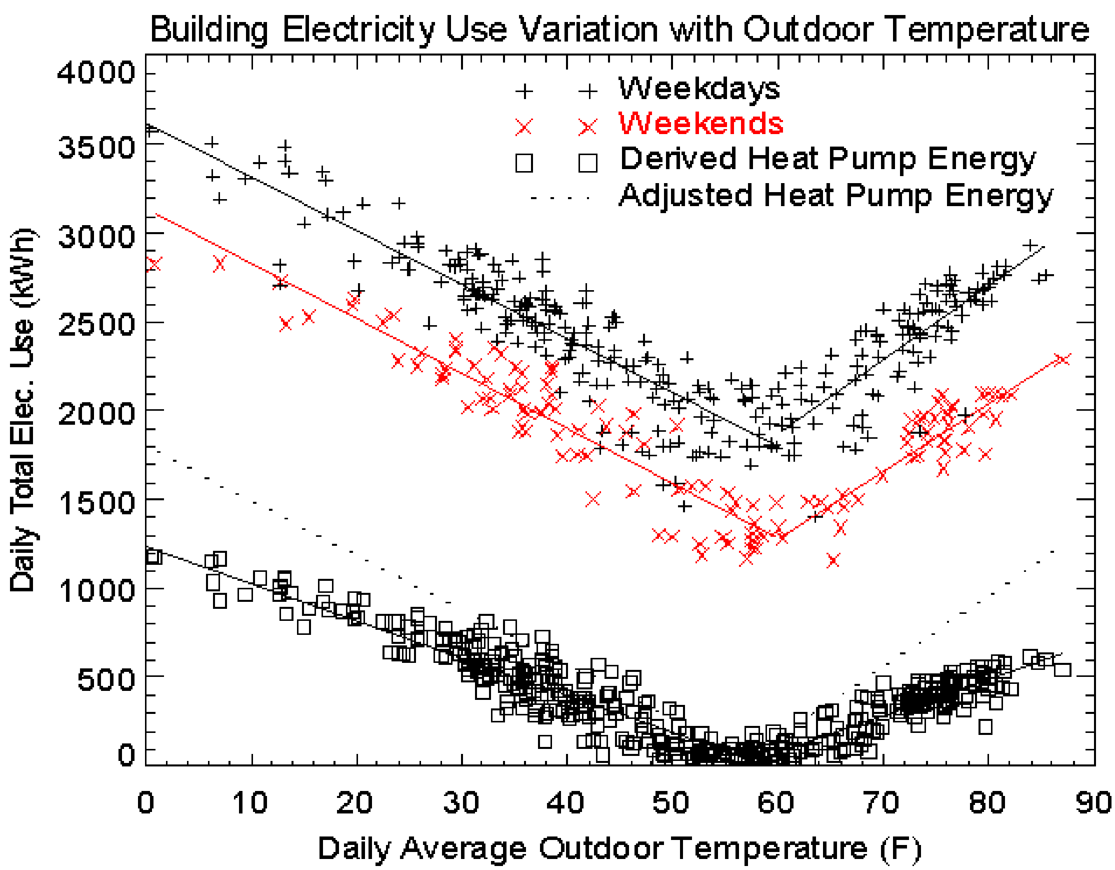


Figure 7. Total Building Electricity Use Relationship to Outdoor Temperature

Electricity Use

The HVAC system used 54% of the total building energy as shown in Figure 8. Nearly half of the HVAC energy was used for pumping. The constant operation of the building's circulating pumps and booster pumps increased the energy use of this system. As the monthly energy use shows in Figure 9, the pumping energy reached nearly triple the heat pump energy use in fall and spring months. Beside the constant operation of the pumps, the series configuration of the heat pumps increased the pumping power. In this system as many as twelve heat pumps are in series so the pressure drop across the heat pumps as much as twelve times greater than in a standard system with all heat pumps in parallel.

The well pump energy use illustrates the benefits of a variable speed drive. The variable speed drive was able to reduce the well pump energy by 47% to 87% depending on the design flow rate that would have been used with a constant speed well pump. Had a standard building loop piping configuration been possible, booster pumps would not have been necessary, eliminating 93 MWh (12%) of the total building energy use. In addition, a variable speed drive in a standard piping arrangement could have potentially reduced the circulating pump energy by at least 77% (75 MWh). In total, without the compromises made to accommodate this historical building, the system could have reduced the total energy use from 794 MWh to 626 MWh (21%).

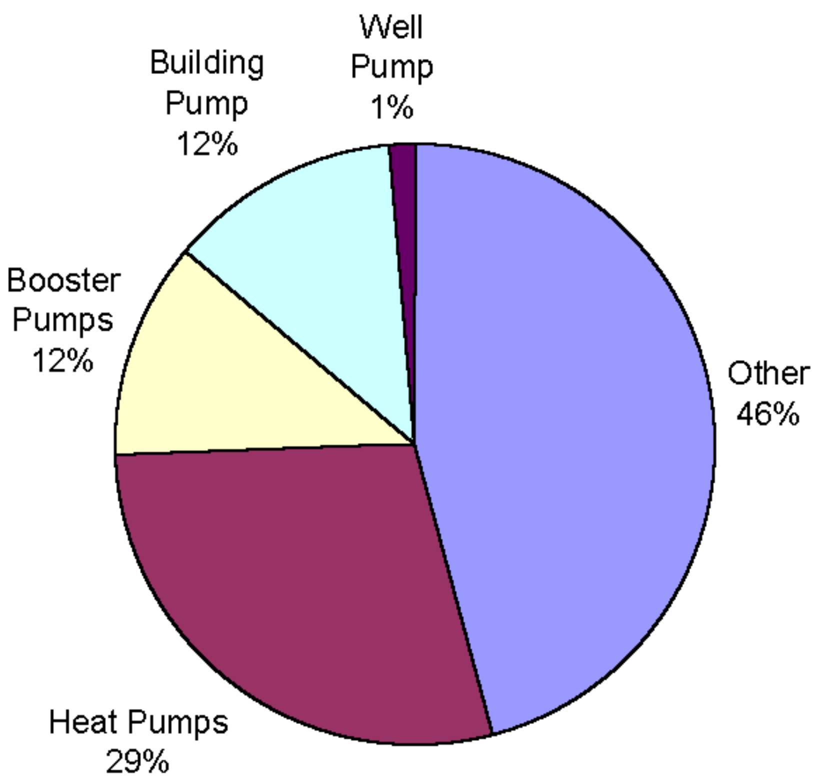


Figure 8. Total Building Annual Electricity Use 1998

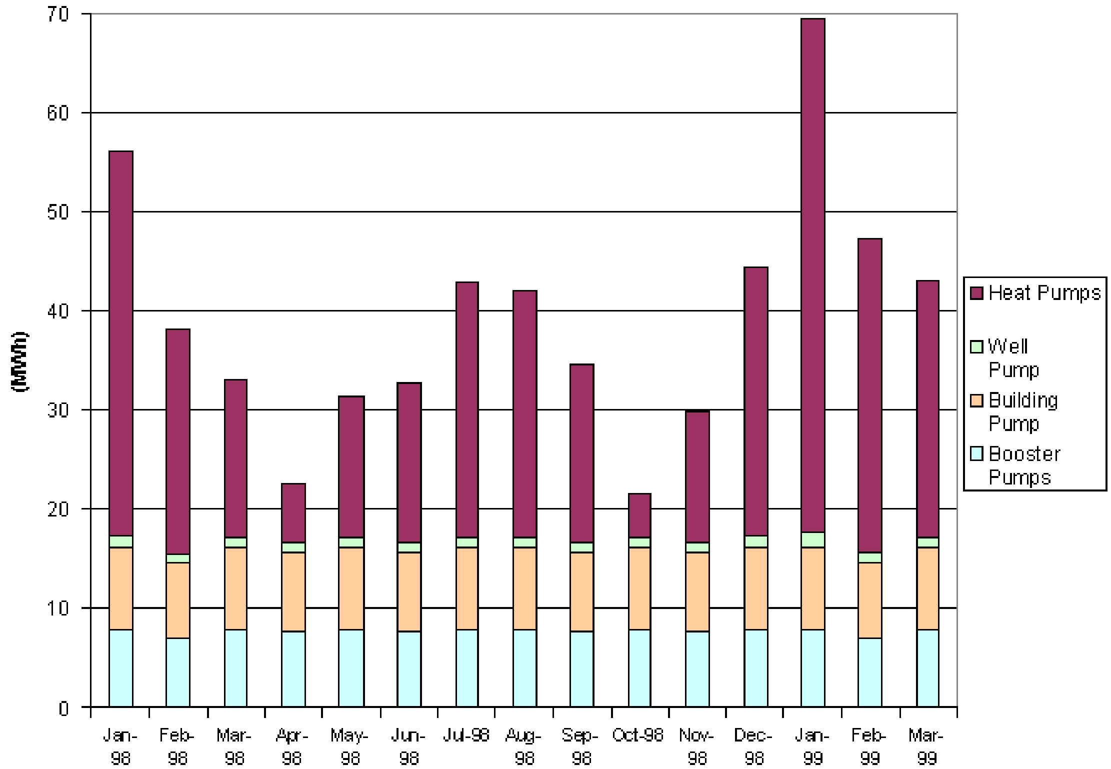


Figure 9. Monthly HVAC Electricity Use

The electricity use of the building followed a typical pattern for an office building; peaking during normal weekday business hours. The shade plot in Figure 10 shows periods with higher use as darker shades of gray. Each day is depicted as a vertical stripe. The days progress horizontally to show the entire 15 month data collection period. A white area in March 1998 indicates that no data were collected during that period. Times were not adjusted for daylight savings time, so the pattern between April and October are shifted one hour from local time.

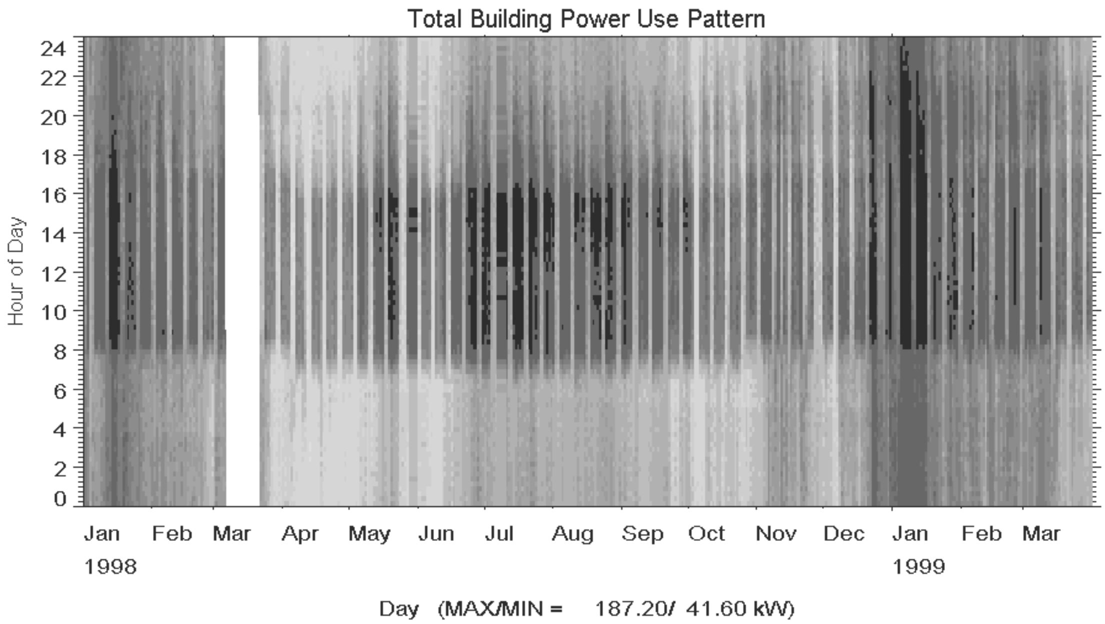


Figure 10. Total Building Power Use Pattern

The shade plot in Figure 11 shows the energy use pattern in more detail. The low electricity use on the weekends is clear. Energy use increased each day between 8 a.m. and 9 a.m. and decreased near 5 p.m. then tails off through the evening.

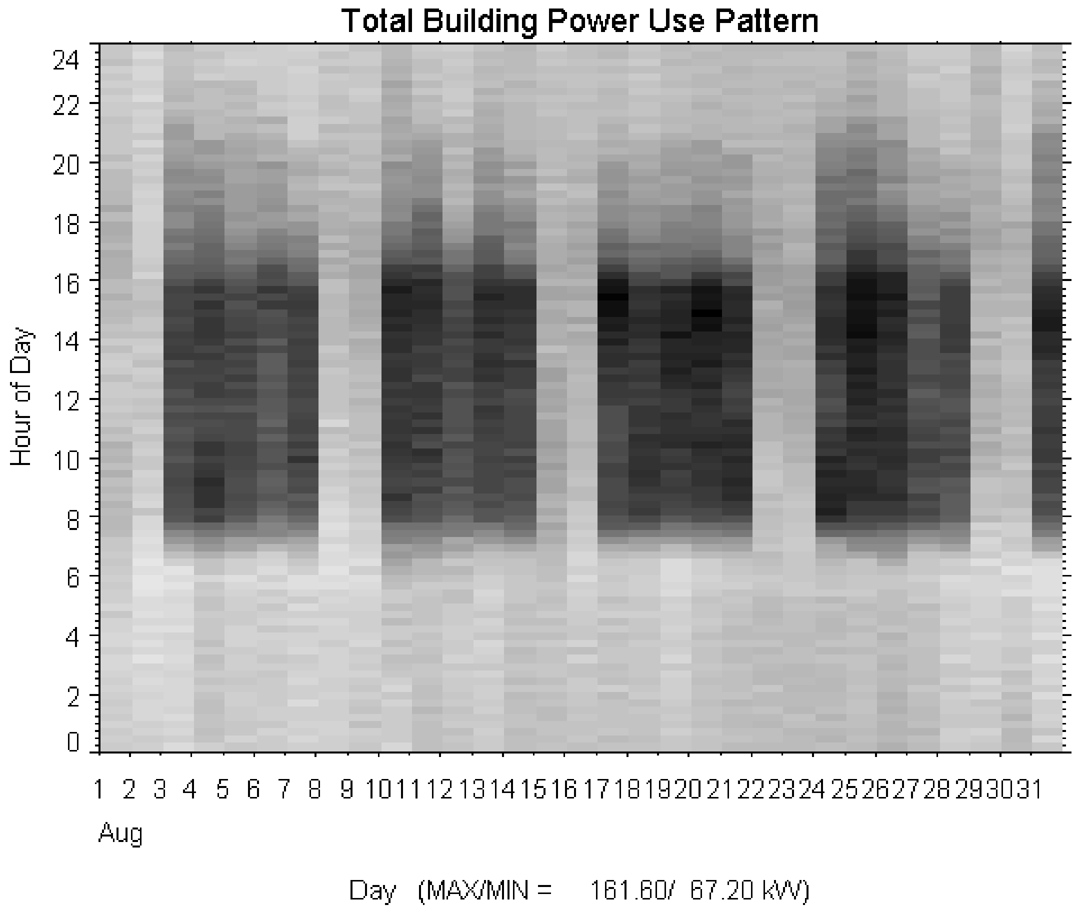


Figure 11. Total Building Power Use Pattern - August 1998

Summary

This application of GeoExchange is an example of an open well retrofit in an historic building. The boiler and tower were replaced with a well and heat exchanger. All of the heat pumps in the building were also replaced. Compromises were made in the system design to minimize disruption within the building, namely using the existing one-pipe building loop system. While the GeoExchange system reduced energy cost by 20% over the previous boiler/tower system, a new piping arrangement along with variable speed pumping could have eliminated another 21% of the energy use.

The adjustable speed drive on the well pump illustrated the savings available from variable speed pumping. Depending on the base case constant flow design the variable speed drive reduced well pumping by 47% to 87%. The lower savings correspond to a design at typical well flow rates for the installed heat pump capacity. The higher savings correspond to the actual installed well flow capacity. This application also illustrates how the variable speed drive saved energy when the design conditions were significantly above actual conditions. The drive reduces energy use in cases where the system has excess capacity for future expansion plans or design safety margins.

This demonstration also showed the potential for savings associated with the loop temperature control. With the variable speed well pumping, it was possible to maintain the building loop temperature. Originally the loop was maintained at 80° F in cooling. Reducing the loop temperature to 75° F reduced the system energy use by 4.8%. This control change increased the amount of well water used along with pump energy, but the improvement in the heat pump efficiency was more significant.

The owners and occupants are pleased with the system and comfort levels. They were able to reclaim the boiler and cooling tower space, reallocate maintenance personnel time to other priorities and reduce operating and maintenance costs with the GeoExchange system.