GeoExchange at Water Tower Square

The Water Tower Square office complex is a 140,000 ft^2 refurbished warehouse located in Willamsport, Pennsylvania. The climate control system in the building consists of a GeoExchange system that uses treated effluent from the nearby municipal sewage treatment plant as the heat source and sink. Two plate frame heat exchangers interface the effluent with the building loop. Pumping energy was minimized through the use of variable speed drives on both the effluent pumps and building pumps. Variable speed operation reduced the annual effluent pump energy by 90% and the annual building pump energy by 57%. Comparison of the GeoExchange system to a similarly sized water loop heat pump system with a boiler and cooling tower resulted in annual operating cost savings of 15% over the water loop heat pump system.

The water loop heat pump concept offered the developer a means to reduce the initial capital investment, by only adding heat pumps as spaces are leased.

The building occupancy remained at 50,000 ft^2 throughout the monitored period. Annual building energy consumption was 970 MWh or 20.0 kWh/ft^2. Annual HVAC energy consumption was 360 MWh or 7.2 kWh/ft^2. HVAC energy consisted of 37% of the total building energy.

The measured heat extraction indicated building loads with a significant amount of simultaneous heating and cooling operation. The total heat extraction was reduced by 240 MMBtu (27%) due to building load diversity. The total building heat load consisted of 57% of heat extracted from the effluent, 22% from load diversity, and 21% from heat pump compressor operation.

The main objective in monitoring this site was to demonstrate the performance of this innovative use of treated municipal effluent as the heat source and sink for the building heat pumps. The project relied on the building control system to collect one year of performance data. Monitored points included effluent and building loop temperatures, pump and building energies, heat pump statuses, and outdoor air temperature.

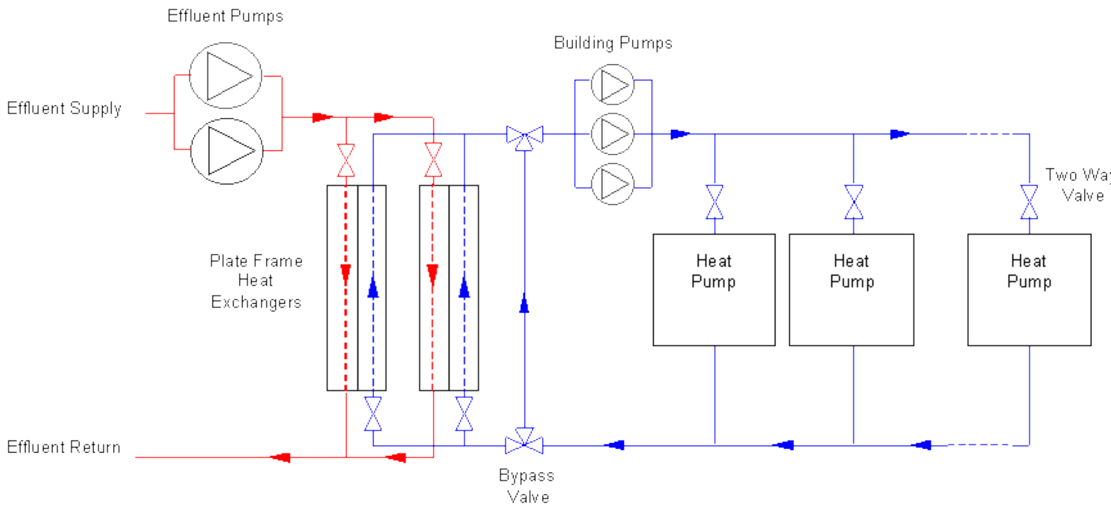


Figure 1. GeoExchange System Schematic

Heat Pumps

There are 51 extended range heat pumps installed in the 50,000 ft^2 of occupied space. Each heat pump operates in parallel as controlled by a zone thermostat through the DDC system. Most of the heat pumps have automatic 2 way valves to minimize part load pumping. Typically, blowers on each unit operate continuously to circulate air and introduce ventilation. Some zones cycle the blower with the compressor at the tenant's request.

Ground Heat Exchanger

Figure 2. Plate Frame Heat Exchangers

Two plate frame heat exchangers on the building loop extract and reject heat from effluent discharged from the Williamsport Sanitary Authority. The effluent is pumped 1,200 ft. from the discharge line to the heat exchangers and then returns back to the discharge line by gravity.

Effluent Pumps

Two 38 hp variable speed pumps extract effluent from the sanitary discharge line and pump it to the heat exchangers. Each pump is capable of delivering 1,000 gpm to the heat exchangers at distance of 1,200 feet. Their speed is set to maintain building loop temperature.

Figure 3. Effluent Pumps

Building Loop Pumps

Three 15 hp variable speed pumps circulate water through the building loop. Prior to August 12, 1998 the pump speed was controlled based on the static pressure on the supply side of the loop on the fourth floor. After August 12, the pump speed was controlled to maintain the differential pressure across the heat pump return and supply headers.

Ventilation

Six sensible heat exchangers supply fresh air to the return air plenum during occupied hours. A bypass damper maintains the air temperature at 55°F when the outdoor temperature drops below 50°F. The fresh air is distributed on each floor through a central duct that discharges near the heat pumps. The damper is closed above a 75°F outdoor temperature. The three feet of space above the drop ceiling is used for the plenum. The unducted returns of each heat pump draws air from the plenum. Return air enters the plenum through gaps around the light fixtures.

Monitoring Approach

Monitoring of the Water Tower Square office complex was accomplished through the building's existing control system. Since The DDC system controlled the pumping station and each heat pump, temperature and operating status data were readily available. Power transducers on the effluent pumps and building loop pumps were incorporated into the control system.

Data Points

Temperatures, pressures, flow rates, drive frequencies, power data, and equipment statuses were collected using the control software. The software was unable to total runtime, so an on/off status for the entire sample period was returned as a proxy for runtime. Analog data such as temperatures, pressures and flow rates were averaged over the sampling period. Heat pump status data were collected at 4 minute intervals. All other data were collected at 5 minute intervals. These data allowed the calculation of heat extraction and rejection on both sides of the heat exchangers. The heat pump operating status along with loop temperature and equipment specs provided a means to determine the energy use of each heat pump.

Performance

Loop Temperatures

The effluent temperature ranged from 45˚F to 75˚F. The system adjusted the building loop supply temperature by controlling the effluent flow rate. The building loop temperature shows the loop operated primarily at 50˚F in heating and 73˚F in cooling. At these temperatures the heat pump efficiencies were 4.5 COP in heating and 17 EER in cooling. The approach temperature distribution shows that for the majority of operation, the building loop was maintained within 5˚F of the effluent temperature.

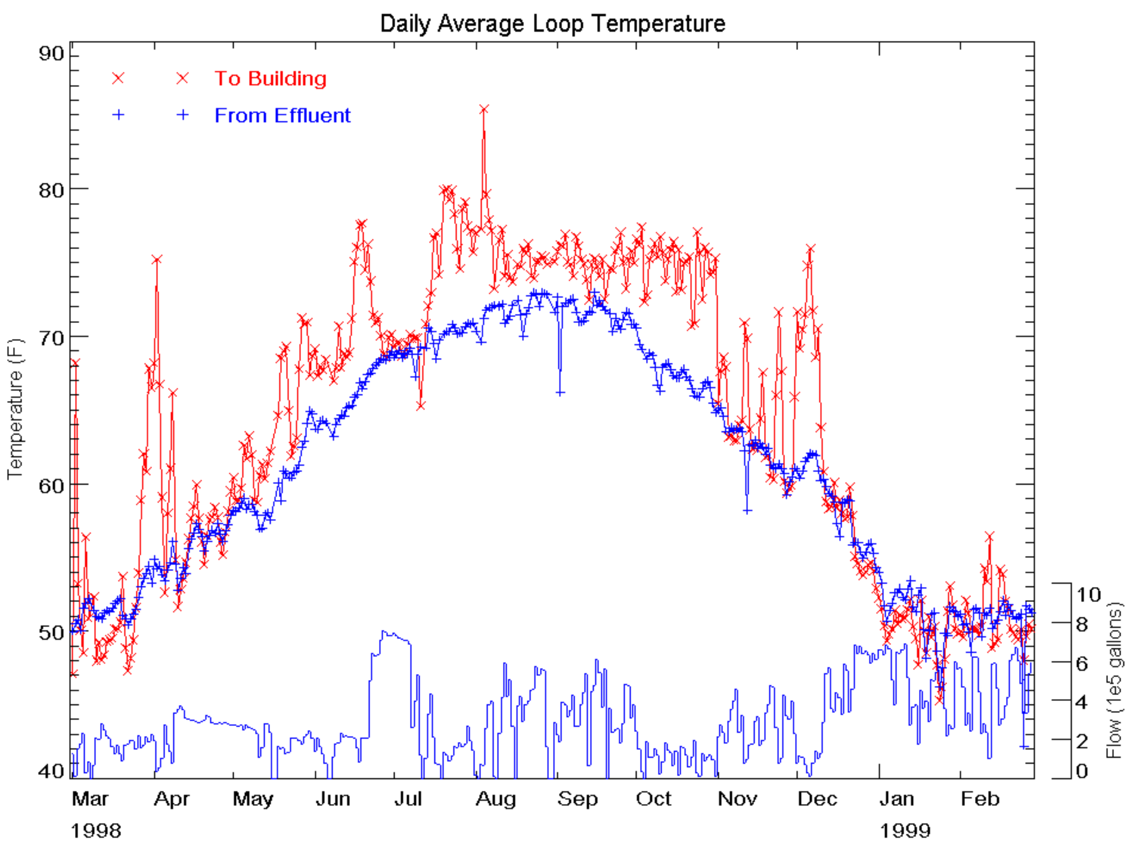


Figure 4. Daily Average Effluent and Building Loop Temperature

Daily effluent use ranged from 100,000 gallons to 700,000 gallons varying with load and approach. During the period from late June to early July daily effluent use was 700,000 gallons/day as the pump speeds were set manually while the controller was being serviced. During this period the building loop temperature matched the effluent temperature.

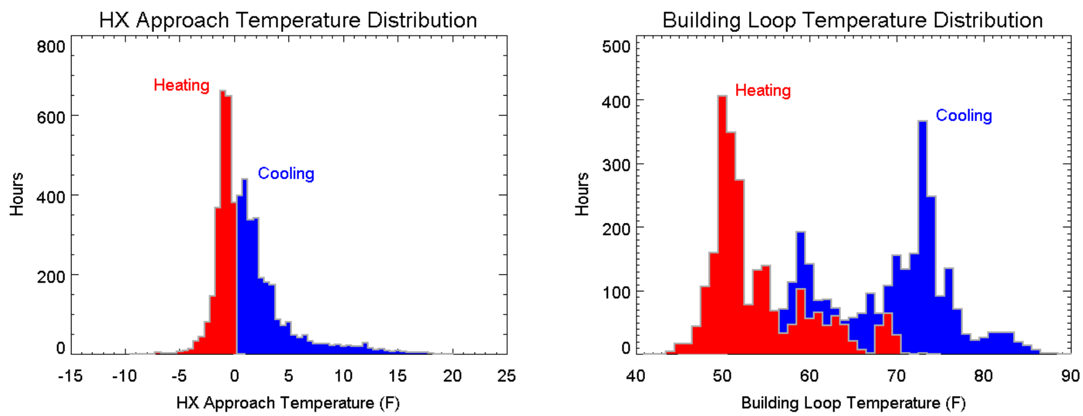
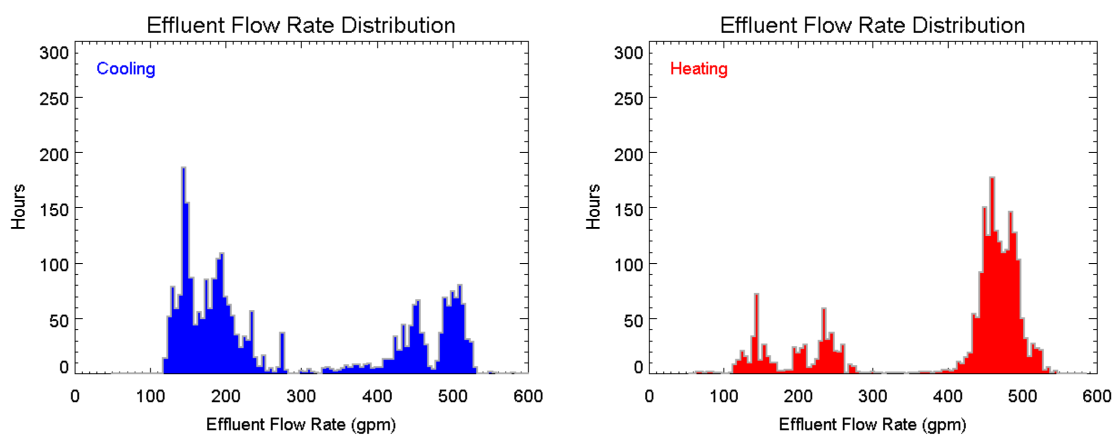


Figure 5. Building Loop Temperature Distributions

Pumping

Both the building loop and the effluent flow utilize variable speed pumping to minimize pump energy. The effluent flow rate displayed two distinct operating ranges as opposed to continuous variable flow control. The effluent was pumped at either a low speed of 150 to 200 gpm or a high speed of 450 to 500 gpm. There was significantly more high speed pump operation during the heating season as the building loop temperature was kept within 5°F of the effluent temperature. The larger temperature difference between the building loop and effluent during cooling operation allowed for significantly more runtime at low flow rates.



Effluent flow through the heat exchanger reached 709,000 gallons/day during the winter and 756,000 gallons/day during the summer. The total annual effluent flow was

122 million gallons. Variable speed operation reduced annual effluent pumping energy by 90% over continuous pumping operation, and 67% if the effluent pumps had cycled at full speed to maintain loop temperature.

The daily effluent flow varied 32 gallons/day/1000 Btu of heat rejection and 60 gallons/day/1000 Btu of heat extraction. Over the year the effluent flow averaged 60 gallons/Btu of heating load, and 35 gallons/Btu of cooling load.

At full occupancy, with approximately 400 tons installed (nearly twice the present installed capacity of 178 tons), the heat rejection and extraction from the building loop would double. The total daily effluent flow at full occupancy would reach approximately 1.5 million gallons per day at peak loads and annual effluent flow would reach approximately 250 million gallons.

The building loop flow rate ranged from 100 to 400 gpm throughout the monitored period. While the loop flow was being controlled to maintain static pressure on the supply side of the loop, the majority of operation was at 150 gpm. After August 12, 1998 when the loop flow was changed to maintain differential pressure across the heat pump headers, there was equal operation at flows of 110 gpm to 200 gpm.

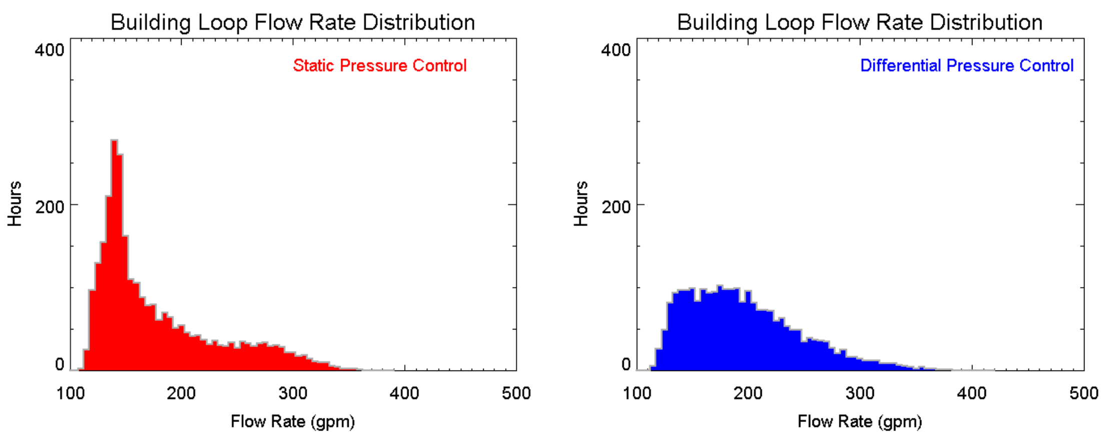


Figure 6. Building Loop Flow Distribution

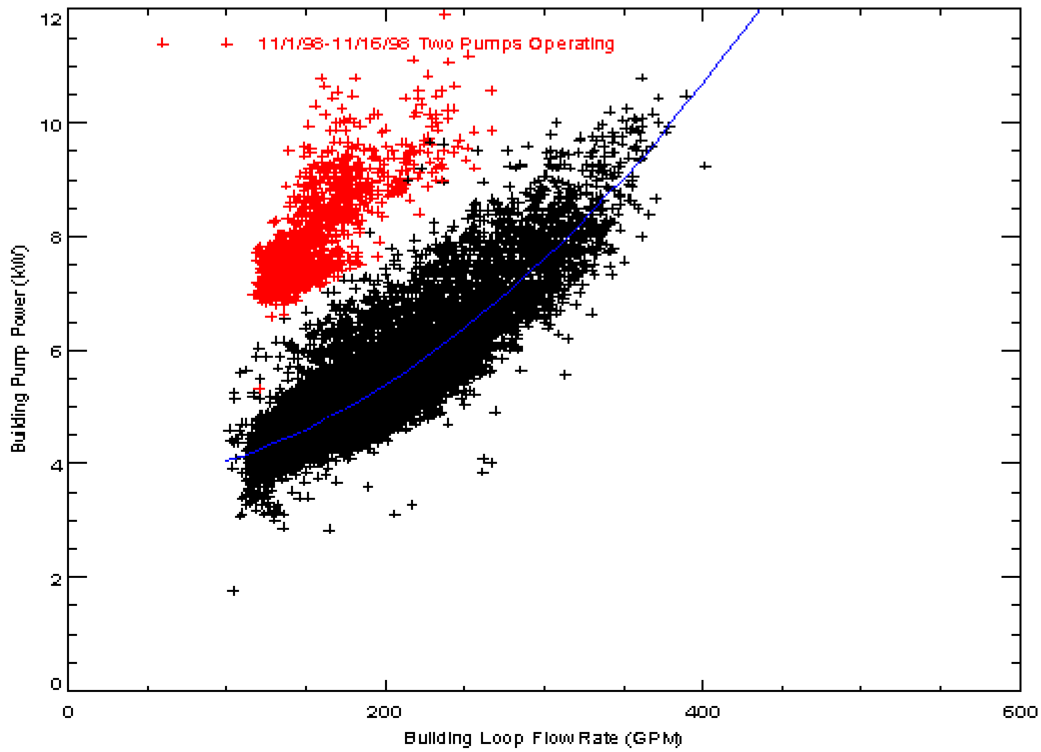


Figure 7. Building Pump Power Relation to Flow Rate

The building pump energy use illustrates the benefits of a variable speed drive. The building loop circulated 89 million gallons through the building, a reduction of 62% from a constant speed pumping system. The variable speed drive was able to reduce the building pump energy by 57% over a constant speed pumping system at the present design flow rate of 2.5 gpm/ton.

The building load, which is a function of outdoor air temperature, drives both the effluent pump energy and building pump energy. The relation of pumping energy to outdoor air temperature is shown in Figure 8. Combined pumping energy for the system totaled 3 kWh/day °F. For days with little building load, with no effluent pump operation, the minimum daily pumping energy was 100 kWh/day due to pumping the system bypass of 100 gpm through the building loop.

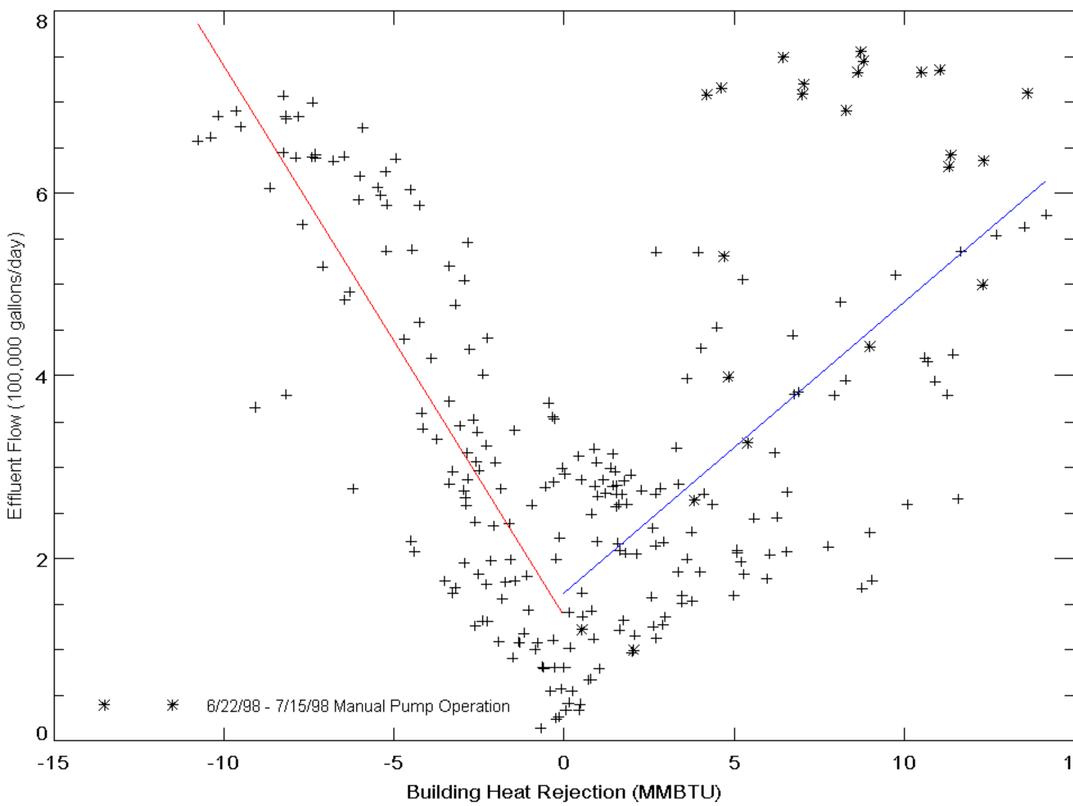


Figure 8. Daily Combined Pump Energy Relation to Outdoor Air Temperature

Loop Load

The space conditioning load was dominated by the cooling load. Heat rejection to the effluent was predominate from April through October as illustrated by the monthly net loop load in Figure 9. During the monitored period of March 1998 to February 1999 1,190 MMBtu was rejected to the effluent and 640 MMBtu was extracted from the effluent.

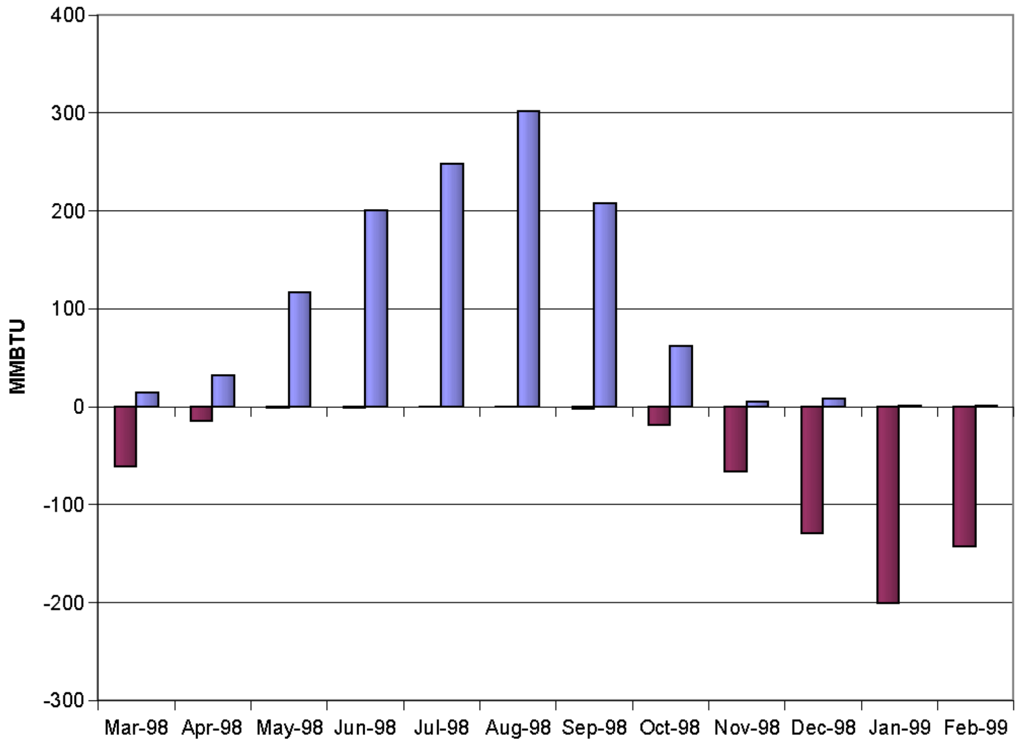


Figure 9. Monthly Net Loop Load

Space Load

The building space load was calculated from the individual heat pump runtimes, building loop temperature and manufacturer's performance curves. Figure 10 shows the monthly space conditioning loads. The heating load for the monitored period totaled 1,125 MMBtu, and the cooling load totaled 1,560 MMBtu. The building required small levels of cooling operation throughout the year, as shown in both the monthly total cooling load in Figure 10 and the hourly load plot in Figure 11. Both the peak hourly cooling and heating loads never exceeded 60% of the total installed capacity of 178 tons. Annual heat extraction from the loop was reduced by 27% from 880 MMBtu to 640 MMBtu due to simultaneous heating and cooling operation by the heat pumps.

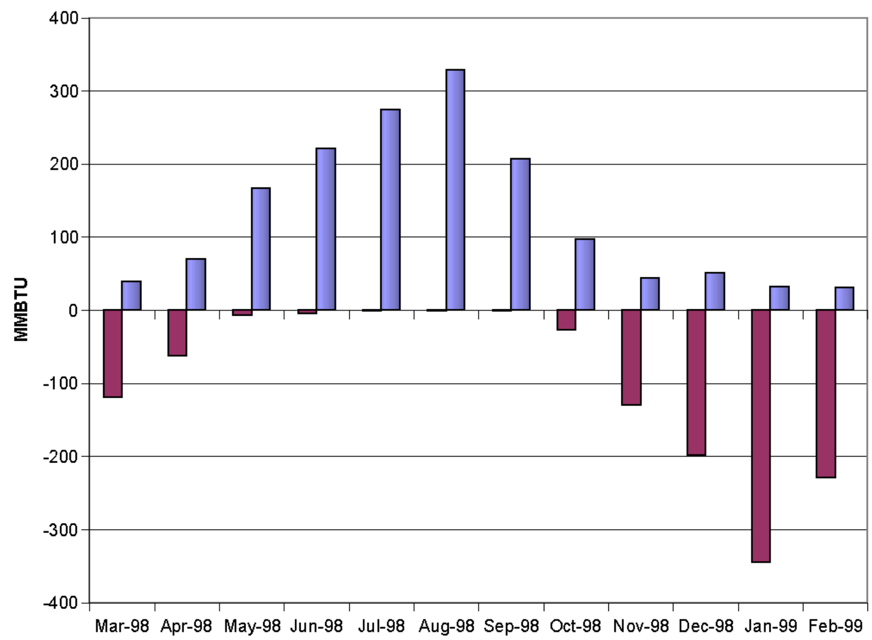


Figure 10. Monthly Building Load

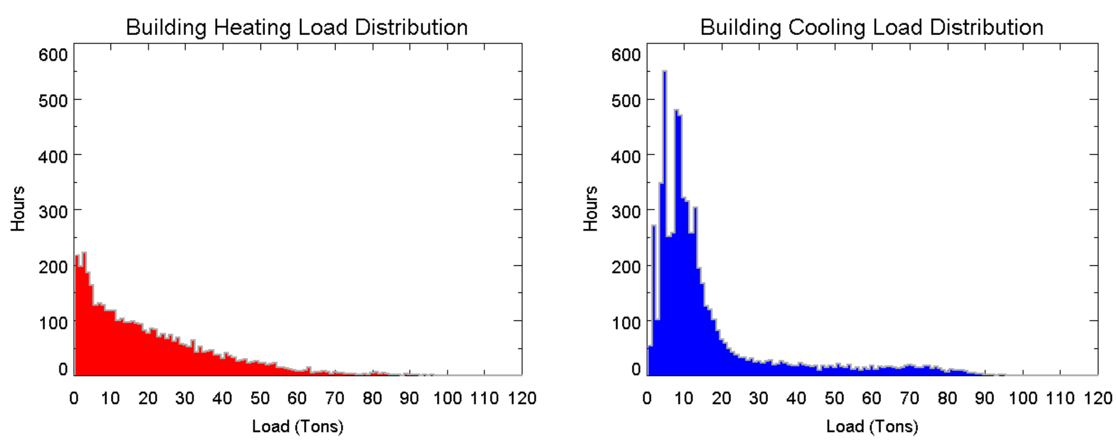


Figure 11. Building Load Distributions

In the heating mode, a heat pump extracts heat from the building loop and supplies heat to the building through operation of the compressor. The building heating load therefore consists of heat extracted from the building loop and heat from operation of the heat pump compressor. The expected heat extraction from the building loop based on heat pump status and loop temperature was 880 MMBtu while the measured heat extraction totaled only 640 MMBtu. The difference in the total heat extractions was caused by heat that was removed from spaces in the building and rejected to the building loop while other heat pumps in the building were concurrently extracting heat from the loop and supplying heat to the space. This simultaneous heating and cooling of separate spaces illustrates the advantage of a water loop system's ability to move heat around a building as opposed to providing the energy to meet the building's full heating and cooling load. Building load diversity causes return loop temperatures to be more moderate, and reduce the need for high levels of heat extraction.

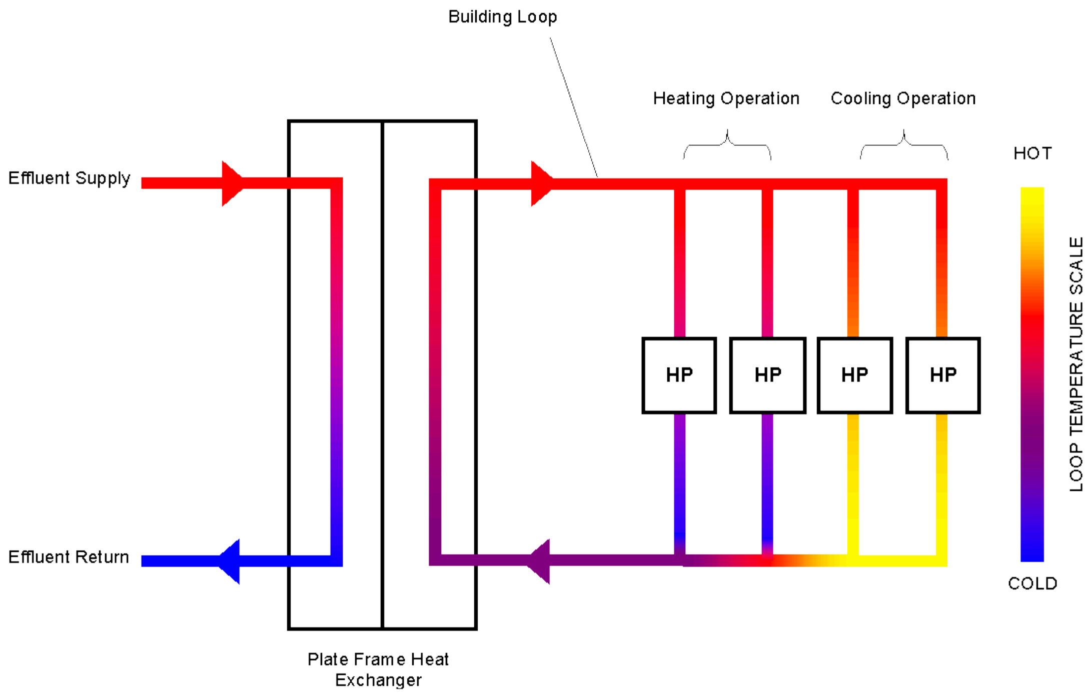


Figure 12. Schematic of Diversity Effect on Loop Temperature

The annual heating load consisted of 640 MMBtu from the effluent (57%), 245 MMBtu from compressor operation (22%) and 240 MMBtu from building diversity (21%).

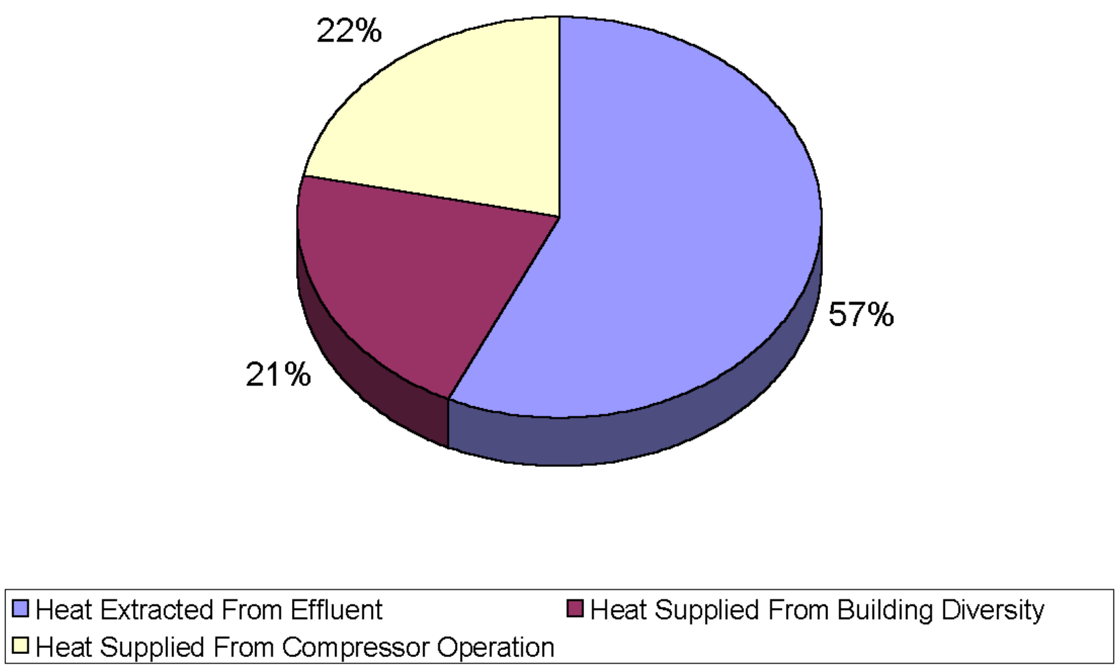


Figure 13. Heating Load Component Distribution

Heat Pump Energy

The status of each heat pump was used in conjunction with the loop temperature and the heat pump performance specifications to determine heat pump energy use. The daily total heat pump energy showed strong correlation with outdoor air temperature as shown by the squares in Figure 14. The same trend with outdoor air temperature can be observed in the total building energy data.

The heat pump energy use amounted to 17 kWh/Day °F. The total building energy use amounted 20 kWh/Day °F. The building pumps and effluent pumps energy use are indirectly driven by outdoor air temperature. Total pump energy variation with outdoor air temperature was 3 kWh/Day °F. The pumping energy was not included in the heat pump energy and well explains the variation between the heat pump energy variation and the total building energy variation with outdoor air temperature. Heat pump energy and pumping energy are the only building energy use components that are dependent on weather.

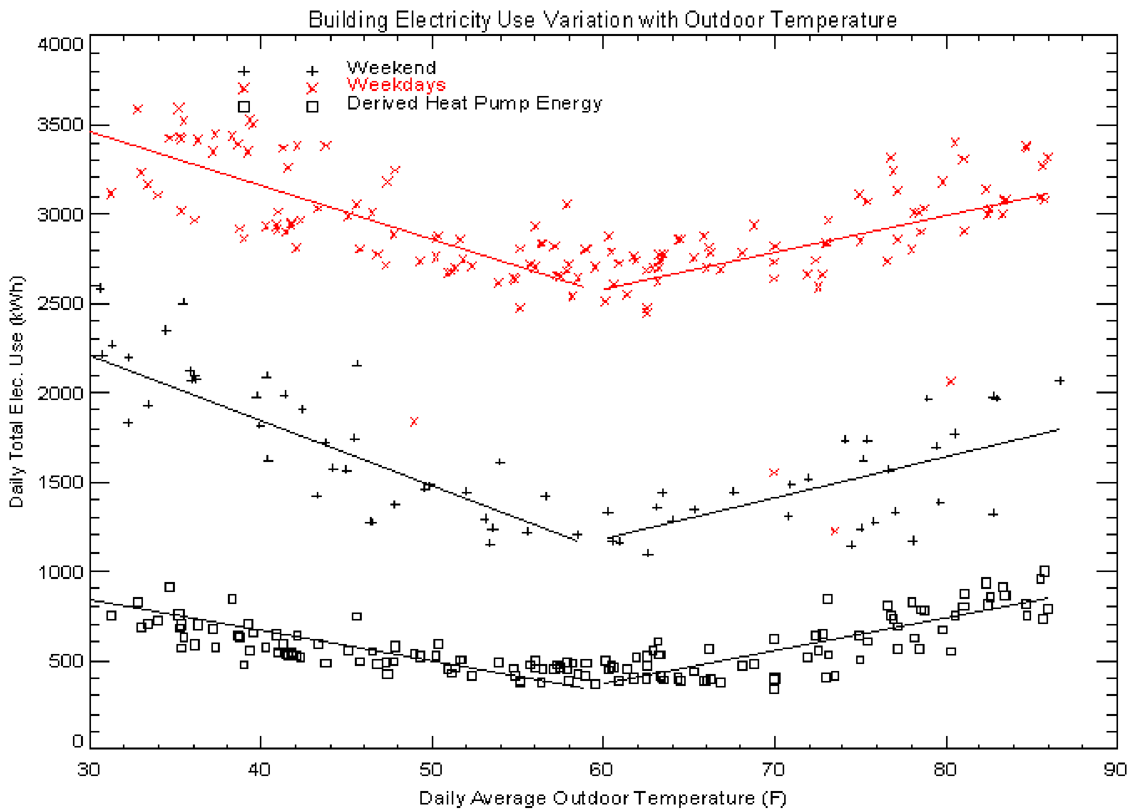


Figure 14. Total Building Electricity Use Relationship to Outdoor Temperature

The heat pump energy in Figure 14 indicates that the heat pumps consume a minimum of 500 kWh/day. Constant operation of the fans during occupied hours makes up 160 kWh of this base load. The remainder is due to significant amounts of mixed heat pump operation across a day.

The heat pump operating pattern in Figure 15 is typical of mild weather operation. The vertical red band at 6:00 AM indicates morning recovery from night setback. Shortly thereafter several units have switched to cooling while intermittent heating continues throughout the day.

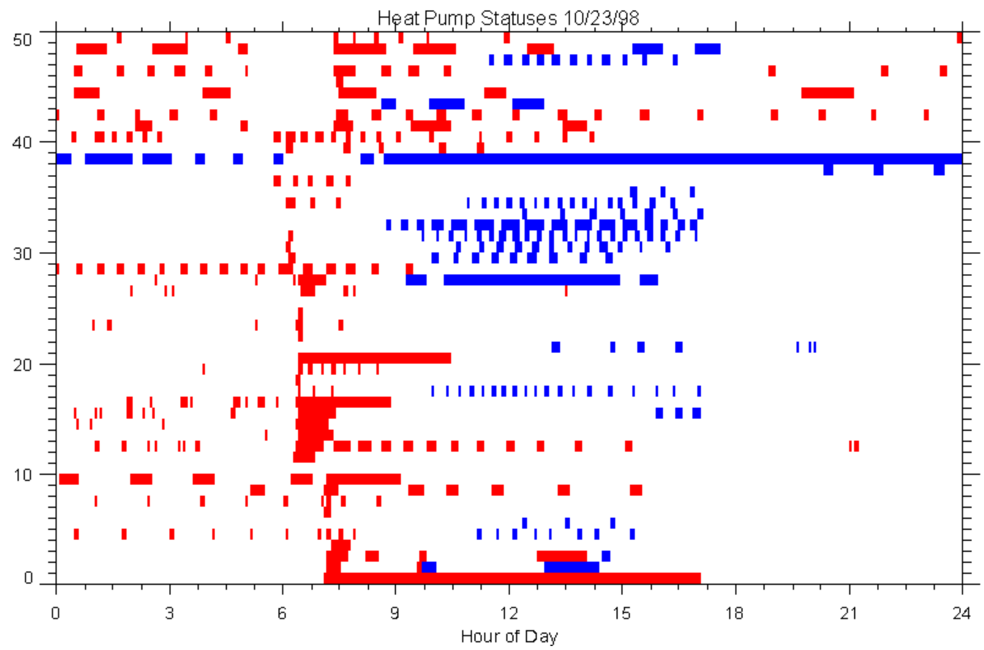


Figure 15. Heat Pump Operating Pattern

Electricity Use

Over the monitored period the total building used 970 MWh. The annual electricity cost for the building was $85,500 at the average utility rate of $0.08/kWh. The effluent pumps are on a separate utility service, with an average rate of $0.13/kWh. The normalized building energy use was 20.0 kWh/ft2 of occupied floor area and the normalized energy cost was $1.70/ft2of occupied floor area.

The HVAC system used 37% of the total building energy as shown in Figure 16. Heat pump operation totaled 280 MWh (29%) and pumping energy totaled 80 MWh (8%).

Pumping energy consisted of 22% of the HVAC energy. During the spring and fall months, the effluent pump energy shows good reduction with loading as shown in the monthly energy use Figure 17. The effluent pumps operated less as the building temperature was allowed to float between 50° F and 80° F during this period.

Heat pump compressor and blower operation each totaled 39% of the HVAC energy. Fan operation during occupied hours for ventilation purposes totaled 50% of the total heat pump energy and caused a 130% increase in annual fan energy if the fans were only allowed to cycle with the compressor. Fan energy was estimated at 100 watts of fan power per nominal ton of heat pump capacity. Fan energy was considered to be a constant 17.8 kW (178 installed tons x 100 watts/ton) during the hours of 8:00 AM and 5:00 PM. During unoccupied hours fan energy was determined using the same rule of thumb and the measured nominal heat pump tonnage operating based on the status data.

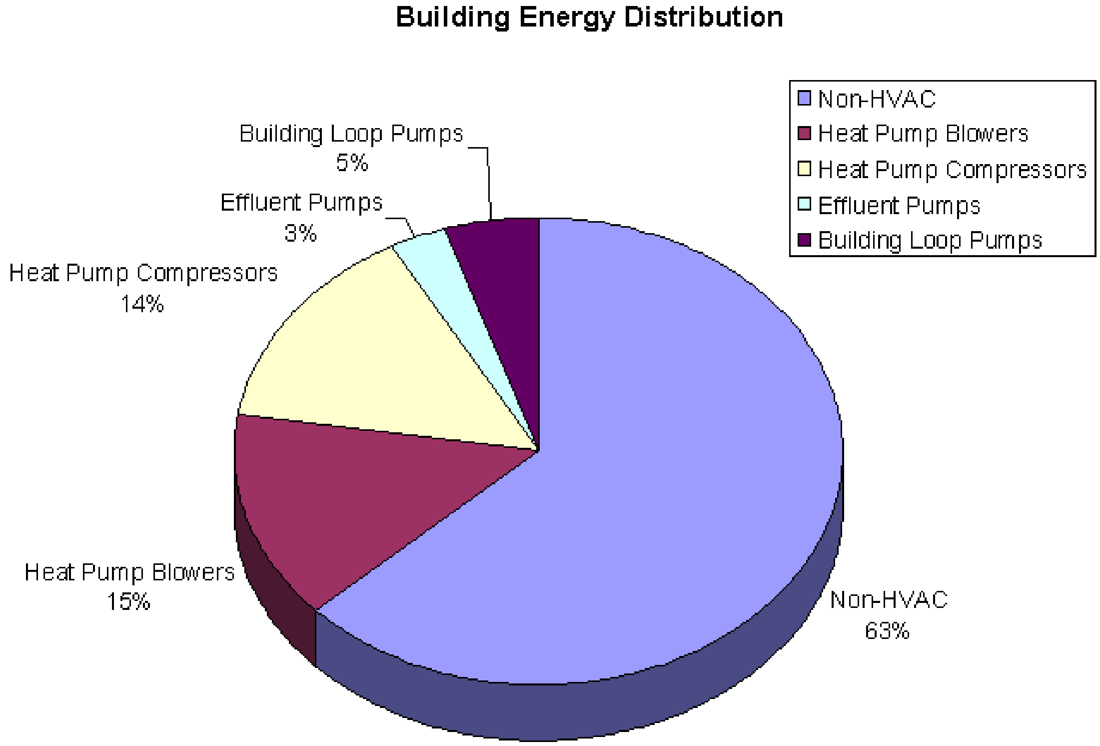


Figure 16. Total Building Annual Electricity Use 1998

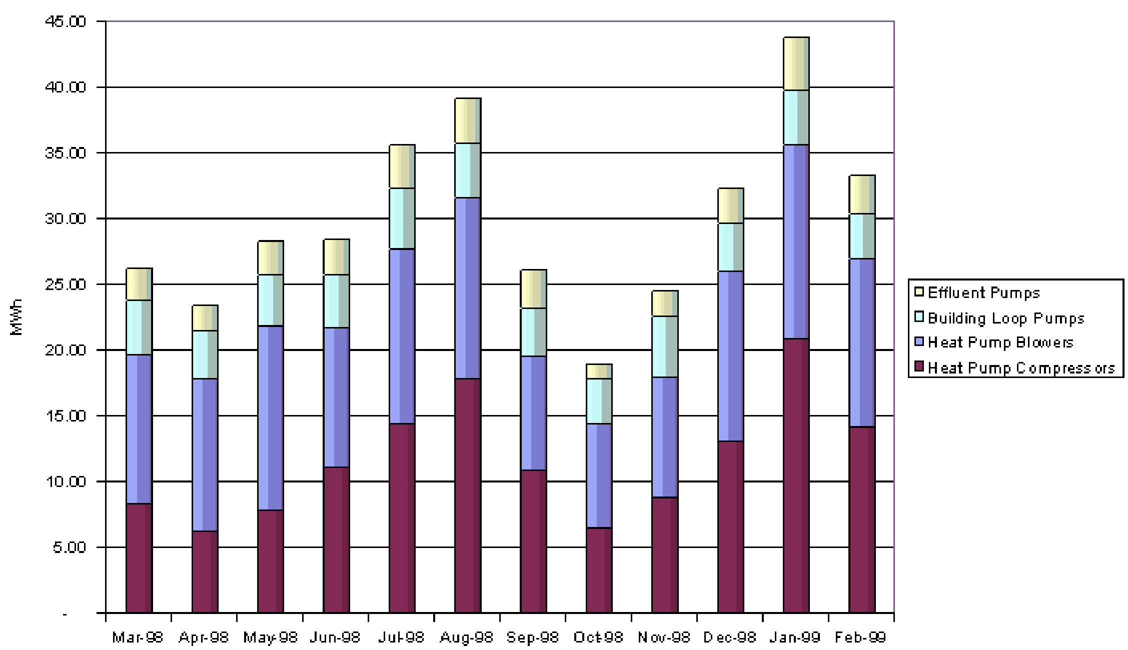


Figure 17. Monthly HVAC Electricity Use

The shade plot in Figure 18 shows periods with higher electricity use as darker shades of gray. The electricity use pattern is characteristic of an office building, peaking during normal weekday business hours.

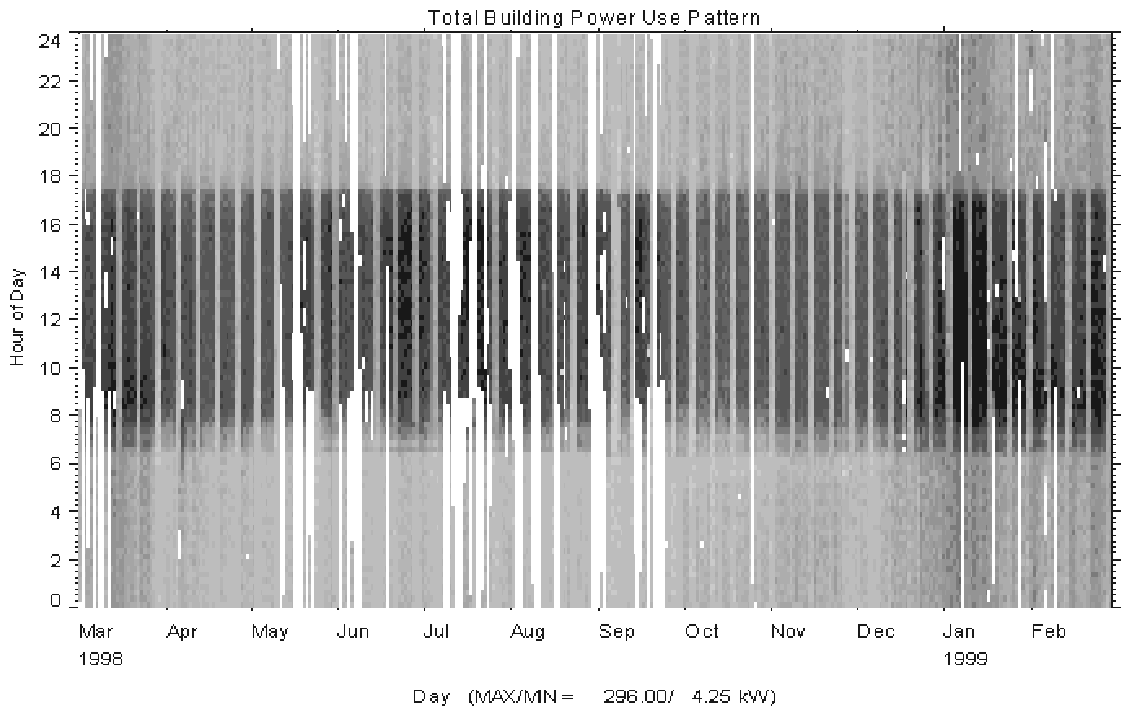


Figure 18. Total Building Power Use Pattern

The weekday demand profile indicates an average daily demand of 200 kW during occupied hours, and 80 kW during unoccupied hours. Constant fan operation during occupied hours totaled 18 kW of the demand.

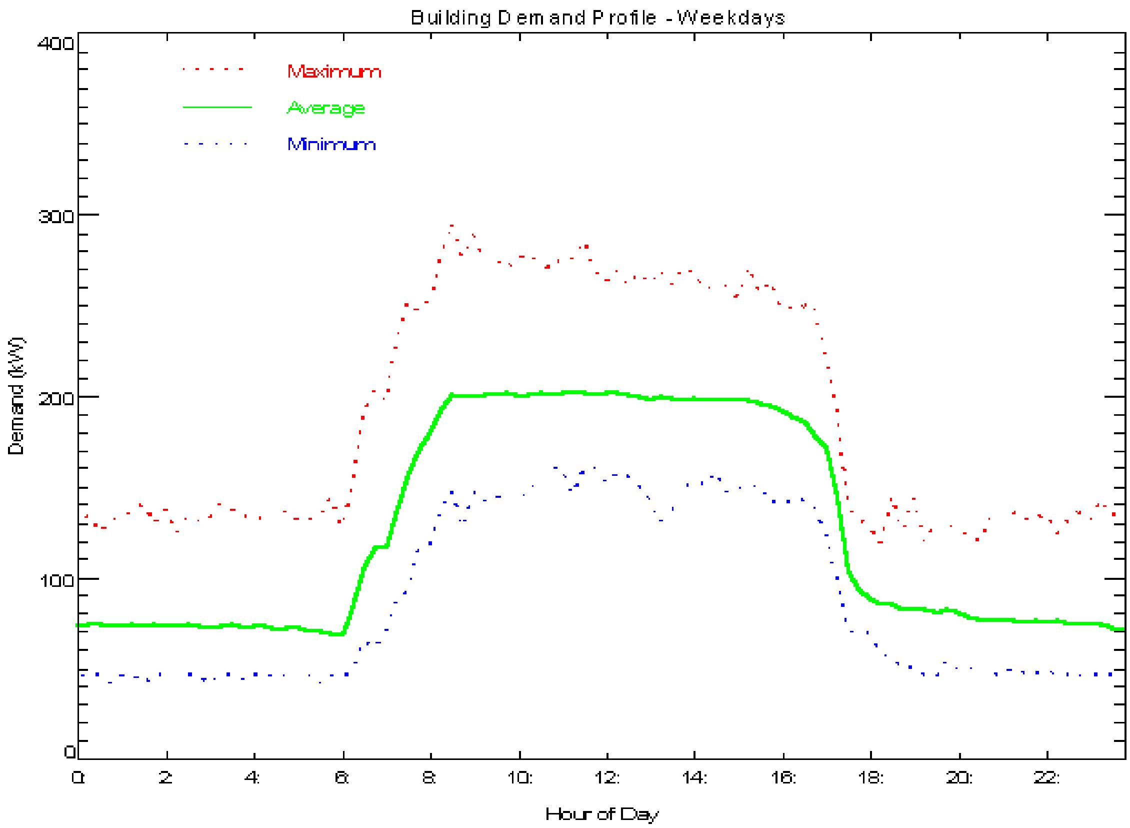


Figure 19. Daily Building Demand Profile

The weekday demand profile indicates an average daily demand of 200 kW during occupied hours, and 80 kW during unoccupied hours. Constant fan operation during occupied hours totaled 18 kW of the demand.

The shade plot in Figure 20 shows the energy use pattern in more detail. The low electricity use on the weekends is clear. Energy use increased each day between 7 AM and 6 PM then tails off through the evening.

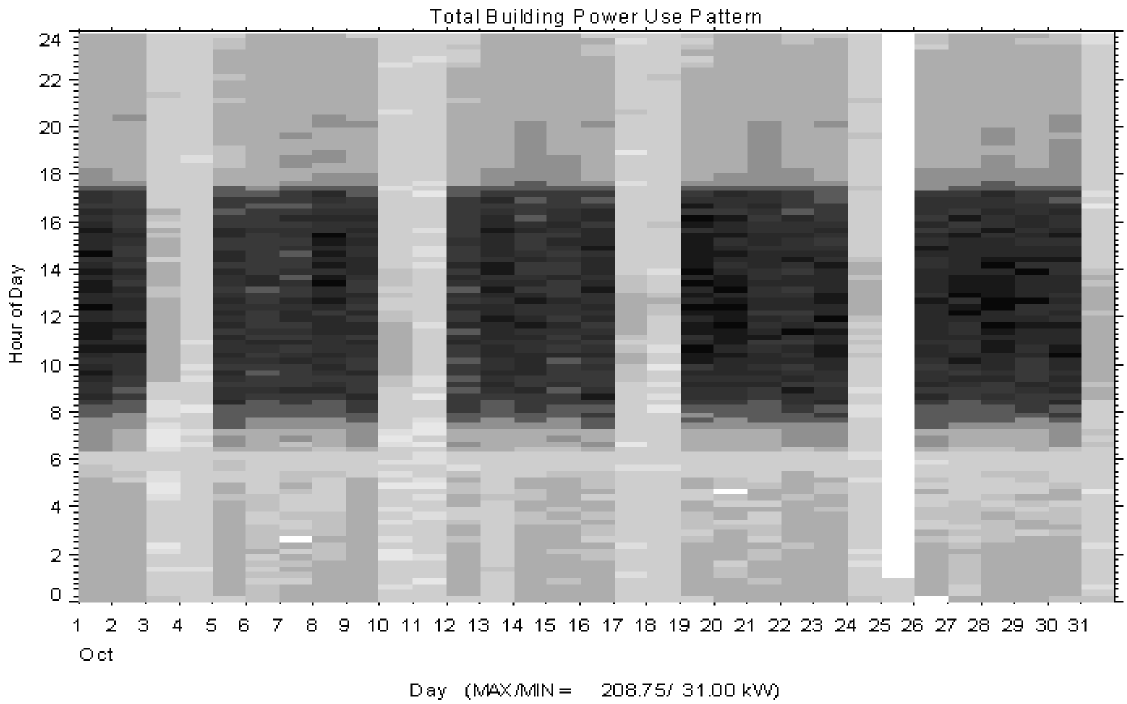


Figure 20. Total Building Power Use Pattern - Octoer 1998

Comparison to Other Systems

To gauge the performance of the effluent system in relation to a more conventional system, the monitored performance of the effluent system was compared to a model of a water loop heat pump system. The water loop heat pump system used a natural gas fired boiler to add heat to the building loop, and a closed circuit cooling tower to remove heat

Operating the effluent system resulted in an annual energy savings of 10,000 kWh and 8,500 therms. The effluent system showed an annual operating cost savings of 15% over the water loop system operating at the same loop temperatures. The electricity rate for all equipment excluding the effluent pumps was $0.08/kWh. The effluent pump rate was $0.13/kWh. The natural gas rate for the boiler was $0.60/therm.

The water loop system was capable of providing loop temperatures equivalent to those measured over the monitored period, as well as the standard 50˚F heating 80˚F cooling loop temperatures often observed in water loop operation. All three models were run at both sets of loop temperatures. Operating the water loop system at loop temperatures of 50˚F in heating and 80˚F in cooling provided little difference in operating cost from operating the water loop system at the monitored loop temperatures. In cooling, operating the building loop at 80˚F instead of 75˚F as observed over the monitored period caused an increase of 8,100 kWh in heat pump energy. This energy increase was offset by a reduction in cooling tower energy of 8,200 kWh.

Summary

This application of GeoExchange is a demonstration of the innovative use of treated municipal effluent as the heat source and sink for the building heat pumps. Effluent is pumped through two plate frame heat exchangers from the treatment station discharge line and returned to the discharge line via a gravity drain.

The effluent pumps provided 122 million gallons of effluent over the monitored period, peaking at 750,000 gallons/day, and consumed 32 MWh or 3% of the total facility energy use. Variable speed operation reduced annual effluent pumping energy by 90% over continuous pumping operation, and 67% if the effluent pumps had cycled at full speed to maintain loop temperature.

The building pumps circulated 89 million gallons through the building loop and consumed 47 MWh or 5% of the total facility energy use. Variable speed operation reduced annual building pumping energy by 57%.

The annual heat extracted from the effluent totaled 640 MMBtu or 57% of the total building heating load. Simultaneous heating and cooling operation supplied 240 MMBtu of heat and reduced the amount of heat extracted from the effluent by 27%.

The total building consumed 970 MWh (20 kWh/ft2) over the monitored period. HVAC energy amounted to 37% of the total building energy use. Pumping energy totaled 22% of the HVAC energy. Due to constant fan operation during occupied periods, annual heat pump blower energy, equaled the annual heat pump compressor energy.

The effluent pumping system was estimated to have saved 10,000 kWh and 8,500 therms over an equivalently sized water loop heat pump system. The annual energy cost was reduced by 15% over the water loop boiler/tower system.