ABSTRACT

A 1681 ton (cooling) Heating, Ventilating and Air Conditioning (HVAC) retrofit installed at the Richard Stockton College of New Jersey in 1993 and began operation in January 1994. During the first four years of operation, the system extracted 3100 Megawatt-hours (Mwhr) of energy from the well field for heating and dumped 12,200 Mwhr of excess heat into the well field for cooling. The annual average temperature of the supply water coming from the well field to the heat pumps has remained at 18.2 ±0.4 °C (64.8 ±0.7 °F) while the daily average temperature has ranged from about 13 °C (55 °F) up to 29 °C (84 °F). Additional analysis is needed to understand how these figures relate to the temperatures measured in the well field itself.

1. INTRODUCTION

In 1993, a ground-coupled closed-loop water-source heat pump Heating, Ventilating and Air Conditioning (HVAC) system was installed at the Richard Stockton College of New Jersey in Pomona, New Jersey. A well field of 400 wells, each 130 meters (425 feet) deep was installed under a 16,000 m$^2$ (4 acre) parking lot. A U-tube of 1 ¼ inch diameter high density polyethylene plastic pipe in each well carries up to 250 liters/second (4000 gallons per minute) of water through the well field to supply the heat pumps, extracting heat from the ground during the heating season and dumping unwanted heat into the ground during the cooling season. This system heats and cools 40,000 square meters (400,000 square feet) of the 50,000 square meter (500,000 square foot) academic complex of buildings. The total cooling capacity of this HVAC

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system is 1681 tons (2.2 \times 10^6 \text{ BTU/hr or 5.91 MW}). The technical details of this installation are given elsewhere.

A monitoring system was designed to measure the energy into and out of the well field and has been operating since the system started up in January 1994 [SEP +94a]. In this paper, we present results from this monitoring system for the first four years of operation - January 1994 through December 1997.

2. **THE ENERGY ANALYSIS**

To measure the energy into and out of the well field, difference, $\Delta T$, between the temperature of the water returned from the heat pumps to the well field, $T_R$, and the temperature of the water coming from the well field to supply the heat pumps, $T_S$, is determined:

$$\Delta T = T_R - T_S$$

The mass flow rate of the water in the main loop, $\frac{dm}{dt}$ is also determined. Then if $C$ is the specific heat of the water in the loop, the power dumped into the well field is:

$$P = \Delta T \times C \times \frac{dm}{dt}$$

Using the engineering units commonly used for this installation:

$$P \ (\text{kW}) = .0264 \times \Delta T \ (°C) \times \frac{dm}{dt} \ (\text{Gal/min})$$

The data analysis methods using these power values are described in section 4 on page 2.

3. **DATALOGGER AND ANALYSIS HARDWARE**

As described in earlier reports [SEP +94a], [SEP +94b], the temperature and flow data are measured each minute and 10-minute averages are computed and saved in the raw data files. There are nominally 144 data points recorded for each day. The datalogger is a Hewlett-Packard HP-75000 unit taking a total of 160 channels of data including the temperatures and flow measurements used for this report. These files are uploaded weekly to our internet connected computer network running the Linux operating system where the analysis is carried out using c and fortran programs.

These computers are now pentium based PCs though they have been upgraded several times since their initial installation in early 1994. These networked machines make access to our data possible from anywhere on the internet. Daily plots of the raw data are available from our WEB site:

http://vulcan.geo-phys.stockton.edu
4. DATA ANALYSIS

The data analysis is done in several stages. First the power is calculated as described in section 2 above and saved along with the temperatures and flow rates from which it is computed in a set of daily power files which are much smaller than the raw data files. These files are then collected into 3-month quarterly power files so there become four files for each year. From these files of ten-minute averages, the following daily values are calculated:

1. The day number starting with January 1, 1994 as day 1
2. $T_S$, Average Temperature of supply water coming from the well field in degrees C.
3. $T_R$, Average Temperature of the return water going to the well field in degrees C.
4. $P$, Average power into the well field in kW.
5. $P_{RMSE}$, The root mean square deviation of the power into the well field in kW.
6. $N$, the number of points in the averages.
7. $E_{IN}$, the Total energy deposited into the well field (cooling) in Mwhr.
8. $E_{OUT}$, the Total energy extracted from the well field (heating) in Mwhr.
9. $E_{NET}$, the net energy deposited into the well field ($E_{NET} - E_{OUT}$) in Mwhr.

The daily average temperatures are plotted in Figure 1. These daily average data show clearly the seasonal swing in the temperature of the loop as the load goes from heating to cooling. The size of this swing is somewhat asymmetric, being about 10 °C up from the average calculated below while only going down about 5 °C from the annual average. (The lower temperatures in the first year are explained by the start up conditions noted below.) From these daily average data the annual summary data are calculated using the following procedures:

1. Averaging the temperature, $T_S$.
2. Finding the maximum and minimum daily averages for $T_S$.
3. Calculating the net energy dumped into the well field by multiplying the daily average power by 24 hours to get $E_{NET}$.
4. Summing the daily total energy into the well field values to get $E_{IN}$.
5. Summing the daily total energy out of the well field values to get $E_{OUT}$.

When data are missing the energy values are interpolated from the last good value before the data gap and the first good value after the data. Overall about 80% of the possible ten-minute
averages are present in the data. Table 1 gives the annual temperature averages and Table 2 gives the annual energy results.

Over these four years, the temperature averages 18.2 ± 0.4°C (64.8 ± 0.7°F). The minimum daily average temperature of 8.8°C (48°F) seen in the first year occurred in the first month of operation. The first scheduled day of classes after the retrofit, January 18, 1994 was the day of a snowstorm sufficient to cancel classes and the next day, when students were first present with the new system, was called by AccuWeather meteorologists “the coldest day of the century”. The system managed to keep the buildings warm in spite of rolling power outages imposed by the electric company in their desperate efforts to meet demand. This resulted in an initial depression of the temperature in the main loop which has not re-occurred in the years since.

Figure 1: Daily average temperatures for the water being supplied to the heat pumps from the well field, T_s.
Table 1: Annual average, maximum and minimum values for the temperature of the water from the well field supplied to the heat pumps.

<table>
<thead>
<tr>
<th>Year</th>
<th>$T_s$ (°C)</th>
<th>RMSD (°C)</th>
<th>$N_{DAY}$</th>
<th>$T_{MAX}$ (°C)</th>
<th>$T_{MIN}$ (°C)</th>
<th>Good</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>17.44</td>
<td>4.35</td>
<td>345</td>
<td>27.20</td>
<td>8.80</td>
<td>87%</td>
</tr>
<tr>
<td>1995</td>
<td>18.62</td>
<td>4.34</td>
<td>343</td>
<td>28.80</td>
<td>12.70</td>
<td>90%</td>
</tr>
<tr>
<td>1996</td>
<td>18.44</td>
<td>4.12</td>
<td>285</td>
<td>26.40</td>
<td>12.70</td>
<td>76%</td>
</tr>
<tr>
<td>1997</td>
<td>18.33</td>
<td>4.15</td>
<td>271</td>
<td>29.10</td>
<td>13.00</td>
<td>72%</td>
</tr>
</tbody>
</table>

Table 2: Annual summary value of the net energy dumped into the well field together with the separate totals of the energy dumped into the well field for cooling and the energy extracted from the well field for heating.

<table>
<thead>
<tr>
<th>Year</th>
<th>$E_{NET}$ (MWhr)</th>
<th>$E_{IN}$ (MWhr)</th>
<th>$E_{OUT}$ (MWhr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>2253</td>
<td>2752</td>
<td>656</td>
</tr>
<tr>
<td>1995</td>
<td>3032</td>
<td>3306</td>
<td>453</td>
</tr>
<tr>
<td>1996</td>
<td>2238</td>
<td>2770</td>
<td>785</td>
</tr>
<tr>
<td>1997</td>
<td>2750</td>
<td>3403</td>
<td>1209</td>
</tr>
<tr>
<td>Total</td>
<td>10272</td>
<td>12231</td>
<td>3103</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS

The annual average temperatures of the supply water for the heat pumps obtained here show no significant change from year to year though each year of operation the system has dumped an average of 2568 MWhr into the well field. With the (volumetric) heat capacity of water 1 cal/cm$^3$/°C and the specific heat of stone about three quarters of this, the heat capacity of the well field is about 1250 MWhr/°C so the dumping of an excess of 10,272 MWhr of heat into the well field should produce a temperature rise of about 8°C/° or about 2°C/° per year. The fact that this is not seen in the temperature of the supply water might be due to an operating strategy which limits the rise in the loop temperature or to some heat exchange outside the well field due to the flow of ground water or a combination of these and other effects. Direct measurements of the well field temperature show a temperature rise of about half this amount or about 1 °C per year. (See paper 1 in the technical research and development section of this conference by Dr. Claude Epstein entitled: ‘Impact of Groundwater Flow on the Stockton Geothermal Wellfield’.) Further research is needed to understand this apparent discrepancy.

REFERENCES

[SEP+94b]

[TSH98]