Ground Source Geothermal Power Systems:

How well do they work?

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April 26, 2001

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Introduction

The increasing energy use by the citizens of the United States over the last few decades contributes greatly to global warming today. The United States has an overall impact 5 times the global per capita average - as 1/25th of the world's population it produces 1/5 of all carbon emissions. With increasing concerns and global efforts to decrease gas emissions, more efficient means of energy use need to be employed (2).

Space heating and air conditioning consume about 20% of the energy used in the United States. The heat pump increases the efficiency of providing thermal energy at room temperature by using low-grade ambient thermal energy. The heat pump that is used in Black Rock Forest's visitor center is an electric heat pump that warms the inside of the building by cooling the surrounding ground. It uses only 45% as much fuel as a furnace that is 75% efficient for the same amount of heating, even when correcting for the factor of 3 loss in generating the electricity at the generating plant. Ground source heating pumps can save up to 70% on space and heating costs (3).

According to the U.S. Environmental Protection Agency, ground-source heat pumps are the most energy-efficient, environmentally clean, and cost-effective means of space-conditioning in most climates within the United States (3). They are now being used by residential and commercial buildings in nearly every part of the United States. However, as of 1992, ground-coupled heat pumps provided only one-half of 1 percent of the total space-conditioning market (4). Market barriers such as most consumers' unfamiliarity with the technology, relatively high investment requirement, and lack of widespread infrastructure to support such advanced technology prevent a widespread use of the ground-coupled heat pumps (5).

There is also a significant lack of understanding regarding their energy efficiency. We have yet to experimentally determine the efficiency of the heat pump system when compared to conventional heating and cooling. Also, we do not know how the anticipation of the climate becoming warmer and more humid will affect energy use for heating and cooling of buildings.

Black Rock Forest Visitor Center and its Geothermal Heat Pump Unit

Black Rock Forest is a nature preserve dedicated to conservation of the ecosystem of the Hudson Highlands for public and private education and scientific research. Extending over an area of close to 4000 acres on the west bank of the Hudson River 50 miles north of the New York City, it contains the Black Rock Forest Center for Science and Education, which adheres to strict standards of environmental ethics so to reduce human disturbance of the nature preserve there. The center serves as a operative model of the ability of man to preserve and maintain the natural surroundings while also living in them. The visitor center uses solar panels that allow for passive solar radiation (8). The heating and cooling of the building is achieved by a geothermal heat pump (GHP) that was installed within five 500 foot (152 meters) bore holes in rock in 1999. It is a typical, medium-size heating and cooling system for a commercial building manufactured by Water Furnace International, Inc. There are 5 geothermal wells, a heat exchange unit, and a ventilation system for the heat distribution.

<u>The ground-source geothermal heat pump consists of three parts</u>:

1.) *An earth connection, which transfers heat from the ground to the fluid.* This consists of a series of pipes in either a horizontal, vertical ground closed loops or pond-closed loops, depending on the structure of the building and its needs. A closed earth connection is environmentally friendly because it prevents any leakage of the earth connection fluid into the environment. This fluid flows through the pipes and either absorbs heat from the ground or releases it, depending on the mode of operation.

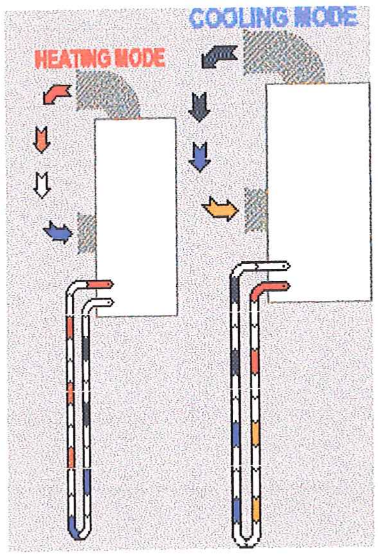


Figure I: Heating and Cooling Modes of Operation of GHP. This is made possible by a 4-way valve.

2.) *A heat pump which moves the fluid between the wells and the building.* A vapor compression cycle allows the heat pump to extract heat from the earth connection fluid. A cold fluid refrigerant first passes through a heat exchanger where it absorbs heat from the earth connection fluid. A fluid with a low boiling point is chosen so the heat from the earth connection fluid is enough to vaporize it. This gas then passes into a compression chamber where it is pressurized until it reaches a temperature of 180 F. Finally this gas enters the other refrigerent-to-air- exchanger where heat is released into a distribution system.

3.)*An earth connection distribution system that circulates air around the building.* This transfers the heat into the building's interior, after which the gas cools off and returns into a liquid form, and the cycle starts again. This is all reversed in a cooling mode during warmer months (6).

Thus, the ground, in essence, serves as a heat source during winter operation and as a heat sink for summer cooling. The energy-saving mechanism that such a heat pump uses is like that of a refrigerator. It takes low-quality heat, concentrates it into a higher-quality heat and moves that heat to another location in the cycle. A basic air-conditioning system takes low-quality (low-temperature) heat in a facility via the evaporator, then the compressor concentrates it, and then the heat is moved to the compressor concentrates it, and then the heat is moved to the condensor where it is removed from the facility. The basic heat pump operates similarly but can redirect the flow of the refrigerant, in this case, alcohol, and thereby allows the refrigerant system to exchange the operation of the condensing heat exchanger and the evaporating heat exchanger. This allows the heat pump to provide cooling during the summer and also heating during the winter, using a four-way reversing valve (7).

Temperatures below the ground surface remain relatively constant at 50 degrees Fahrenheit, unlike ambient air temperatures (7). An important aspect of the overall efficiency of the heat pump is the difference in temperature between the interior of the building and the ground. Due to the fairly constant temperature of the ground, this difference is reduced. Thus, the system is extremely efficient. According to the Department of Energy, ground-source heat pump systems (GHP) have the potential to reduce consumption of cooling energy by 30% to 50% and to reduce consumption of heating energy by 20% to 40% compared with typical air-source heat pumps. In looking at the efficiency of the GHP, we will be comparing the energy usage at Black Rock Forest and that at Lamont-Doherty Earth Observatory (LDEO) by comparing the power usage per square foot for the buildings at LDEO and that at the Black Rock Forest visitor center (1).

Due to this relatively constant temperature of the ground, the power usage at the hottest or coldest time of the day does not peak as much as it does for conventional furnace and air conditioning systems. This reduction of the peak power use, or the peak shaving, also adds significantly to the energy savings that ground source systems produce. It also reduces costs greatly. Peak power rates are the steepest for the power company and also determine the generating capacity it must build. We are interested in comparing the peak shaving of the ground source system at Black Rock Forest to that of the conventional heating and cooling system at LDEO. The energy usage at Black Rock Forest, when compared to the buildings at LDEO, will show smaller power usage per square foot.

Assessing Climate's Effect

Climate is a factor that affects the performance of the GHP system. We expect atmospheric variables monitored such as difference of outdoor temperature and indoor temperature, atmospheric humidity, and wind speed to affect the amount of energy expended by the ground source geothermal pump. Of these three variables, we will study the effect of the difference of outside temperature and inside temperature on daily power usage. As the difference in outside and inside temperature increases we expect daily power usage to increase also because more energy will be needed to resolve this difference in temperature. The GHP should be less dependent on this variable than conventional heating and cooling systems because of the relatively constant temperature of the ground source.

Although we do not expect GHP performance to vary with seasonal variation we do expect that, as the heating and cooling season progresses, the GHP becomes less efficient. Ground temperature changes as heat is dumped into or extracted from the ground. This will change the temperature of the heating or cooling reservoir. Thus the temperature gradient between the ground and the air inside the building will reduce throughout the course of a season which will, in turn, reduce flow of heat in either direction.

Approach/ Methods

At BRF, the monitored record of the outside temperature comes from local weather stations near BRF giving us hourly readings, of which we have produced an average on a daily and monthly basis. There are two weather stations at Black Rock Forest, Open Lowland Weather Station, and West Point Military Station, that record temperature, wind speed and humidity on an hourly basis.

We compared the geothermal ground source system to conventional systems at

LDEO in terms of overall power usage per unit area for heating and cooling. In order to do so, we used monthly gas and electrical use invoices from January through May, 2000. We converted the gas data into its power use in units of kWh and added the two factors to produce the total power usage. For purposes of comparison, we divided the total power usage by the square feet of the building. These calculations were performed for 5 LDEO buildings: Administration, Geo-Chem, Monell, Oceanography, and Seismology. For the BRF calculations, we used the hourly record from the sensors at the visitor center and divided by the area of the visitor center.

The two data sets were plotted against each other as bar graphs. There are some limitations to the data that, at this point, only partially validate the results. Firstly, corrections for the difference in location of the BRF and LDEO buildings must take into account the heating/ cooling degree days (HDD, CDD). HDD/ CDD factors in the ratio of the days that the building needed heating/ cooling. Using 65 degrees Fahrenheit as the indoor temperature, if the outside temperature exceeded it, the day would be described as a CDD, and vice versa. The ratio of HDD to CDD for both locations, BRF and LDEO, would determine the extent of the difference in outside temperature. At BRF, the outside temperature is generally colder than that at LDEO because it is at a higher elevation. Therefore, in the winter, the LDEO heat use per square foot would be multiplied by the ratio of the larger HDD value (from that of BRF and LDEO) over the smaller HDD value to produce the corrected value of the LDEO heat use. Similarly, in the summer, the BRF heat use per square foot would be multiplied by the larger CDD value over the smaller CDD value. Although we have monthly mean temperature data for LDEO (Jan – May 2000), we are missing data on temperature at BRF. Specifically, we need to obtain temperature record for February, March, and April 2000. Thus, the HDD/CDD correction has not been made for our results.

Also, BRF data set presents the total power use, including the electrical use of other facilities not contributing to the heating and cooling of the building such as computers, lighting, and the caretaker's water-heating and personal use of electrical appliances. This power usage needs to be subtracted from the total power usage. At LDEO, the waste heat generated by electrical uses such as those of computers, and fluorescent lights has been considered. The percentage of the electrical facilities' power usage that is not wasted as heat was subtracted from the total power usage to obtain the corrected value of the power usage allotted to heating and cooling. On estimate, 20% of power usage of the electrical facilities goes into waste heat. Figures 1b to 5b represent the results using these rough corrections.

Daily Power Usage (kWh) and Change in Outside and Inside Temperature (degrees Celsius) for 1/1/00 - 1/5/01

Daily data from monitors that log total power usage (kWh), indoor temperature (degrees Celsius), and outdoor temperature (degrees Celsius) at the BRF Visitor Center was used for the second portion of our results. We determined the relationship between the difference in the daily outside and inside temperature and daily power usage at BRF through time. For Figure 6, we took an average of the difference of outside and inside temperature. There is a data gap for 7/1/00 - 7/31/00.

Hourly Power Usage: Average Hourly Demand for 12/23/99 - 6/31/00

We divided the data in monthly increments. The hourly data provided us with the power usage (kWh) every hour of each day. We took an average of the power usage at each hour for the month.

We then compared the plotted data for the 12/23/99 to 1/31/00 data with a metropolitan area analysis of medium office buildings that are electrically heated in Pittsburgh (9). We compared the discrepancy between January's 4 lowest and highest weekday hourly load values (kW) to the discrepancy between BRF's 4 lowest and peak hourly load values (kWh). Calculations are shown in Table 1.

Results

Comparison of Conventional Cooling and Heating and GHP's Power Usage: LDEO Buildings vs. BRF Visitor Center

Figure 1 compares the power usage per square foot in the Seismology- Marine Biology (LDEO) building complex to that at the BRF visitor center for January through May, 2000. The complex is 36,129 square feet and the BRF visitor center is 9000 square feet. The values of the kWh per square feet on the y-axis take into consideration the size of the building, giving us a value of the power usage allotted to heating a square foot in each building. The BRF visitor center used less than half the power during these months than the Seismology building complex. As the months progressed towards May, BRF used noticeably less power while the Seismology building, after minimal fluctuation, building increased power usage in April and May.

Figure 2 compares the power usage per square foot in Monell building (LDEO), 27,000 square feet in area, to the BRF visitor center. Monell uses about 1/8th less energy than BRF visitor center in January. An increase in power usage in February at Monell and a reduction at BRF leaves BRF using less power. The rest months of the study indicate Monell using more power. Yet, there is no trend in the power usage in Monell.

Figure 3 compares the power usage per square foot in the Administration (LDEO) building to that at the BRF visitor center for January through May 2000. The Administration building is 14,000 square feet. The BRF visitor center used significantly less power during these months than the Administration building. As the months progressed towards May, BRF used noticeably less power while the Administration building showed no such trend.

Figure 4 compares the power usage per square foot in the Oceanography (LDEO), which is 33,581 square feet in area with BRF visitor center's power usage per square

Figure 1: Power Usage (kWh) per Sq. Foot: BRF vs. Seismology

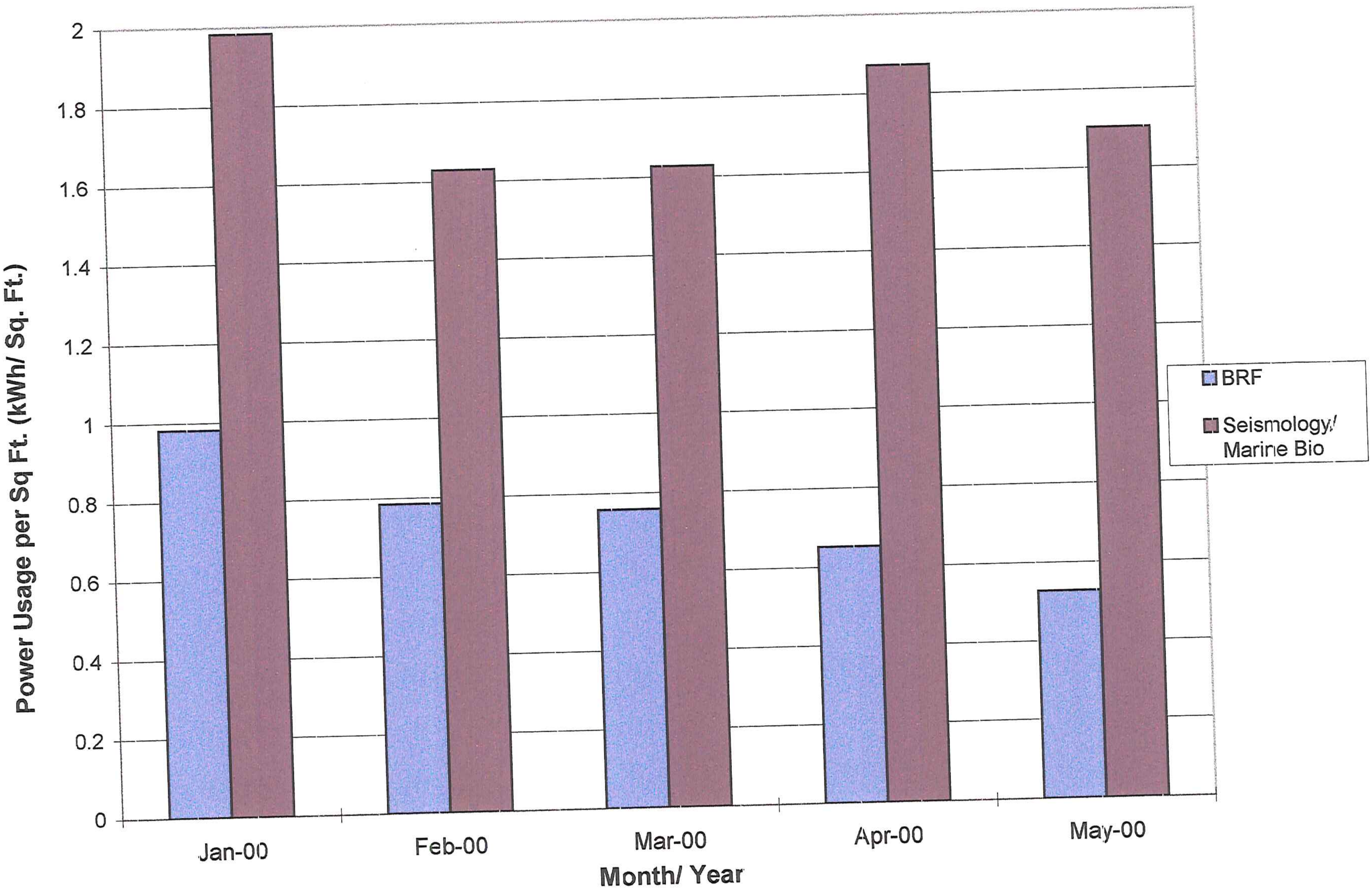


Figure 2: Power Usage (kWh) per Sq. Ft.: BRF vs. Monell

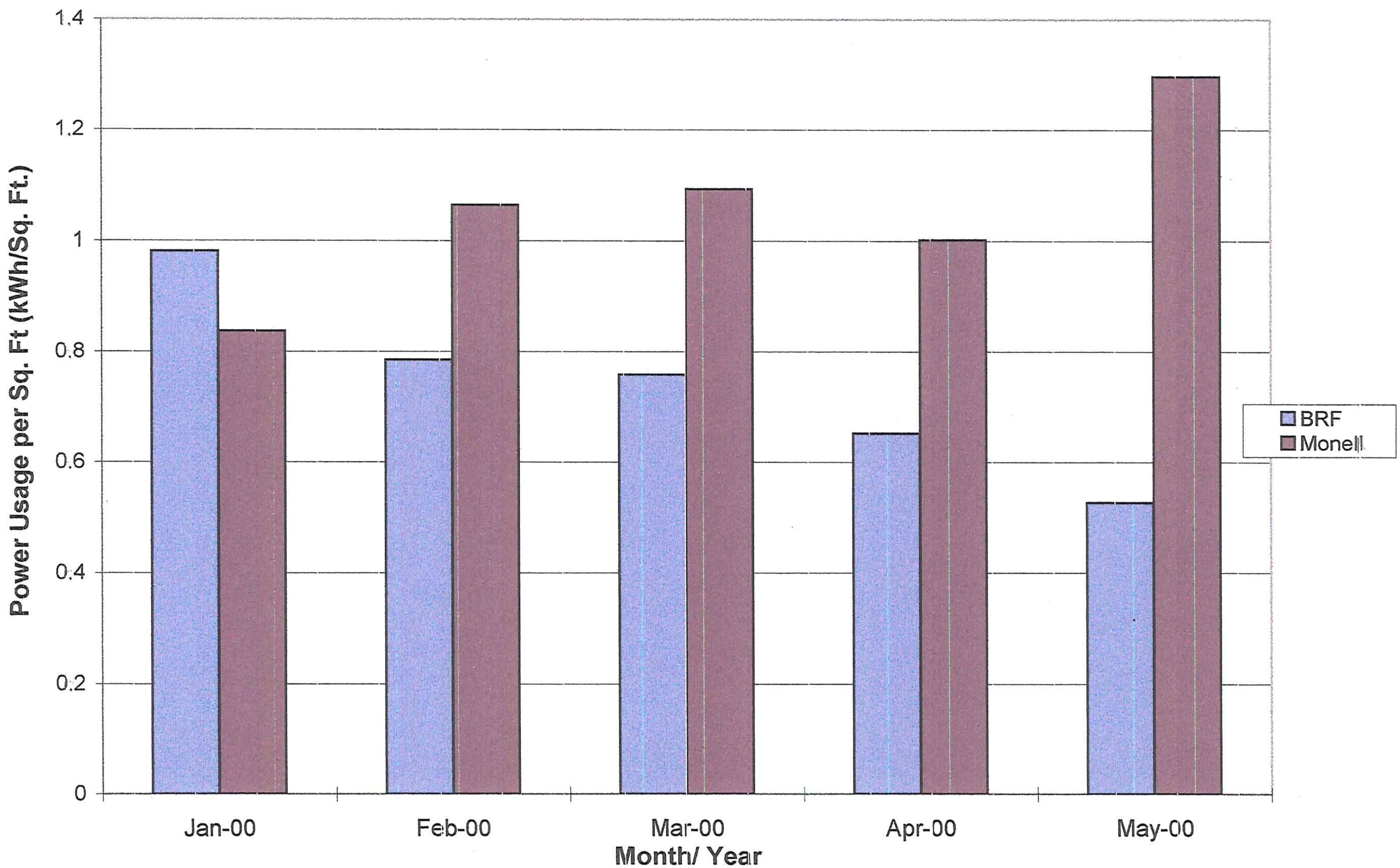


Figure 3: Power Usage (kWh) per Sq. Ft.: BRF vs. Administration

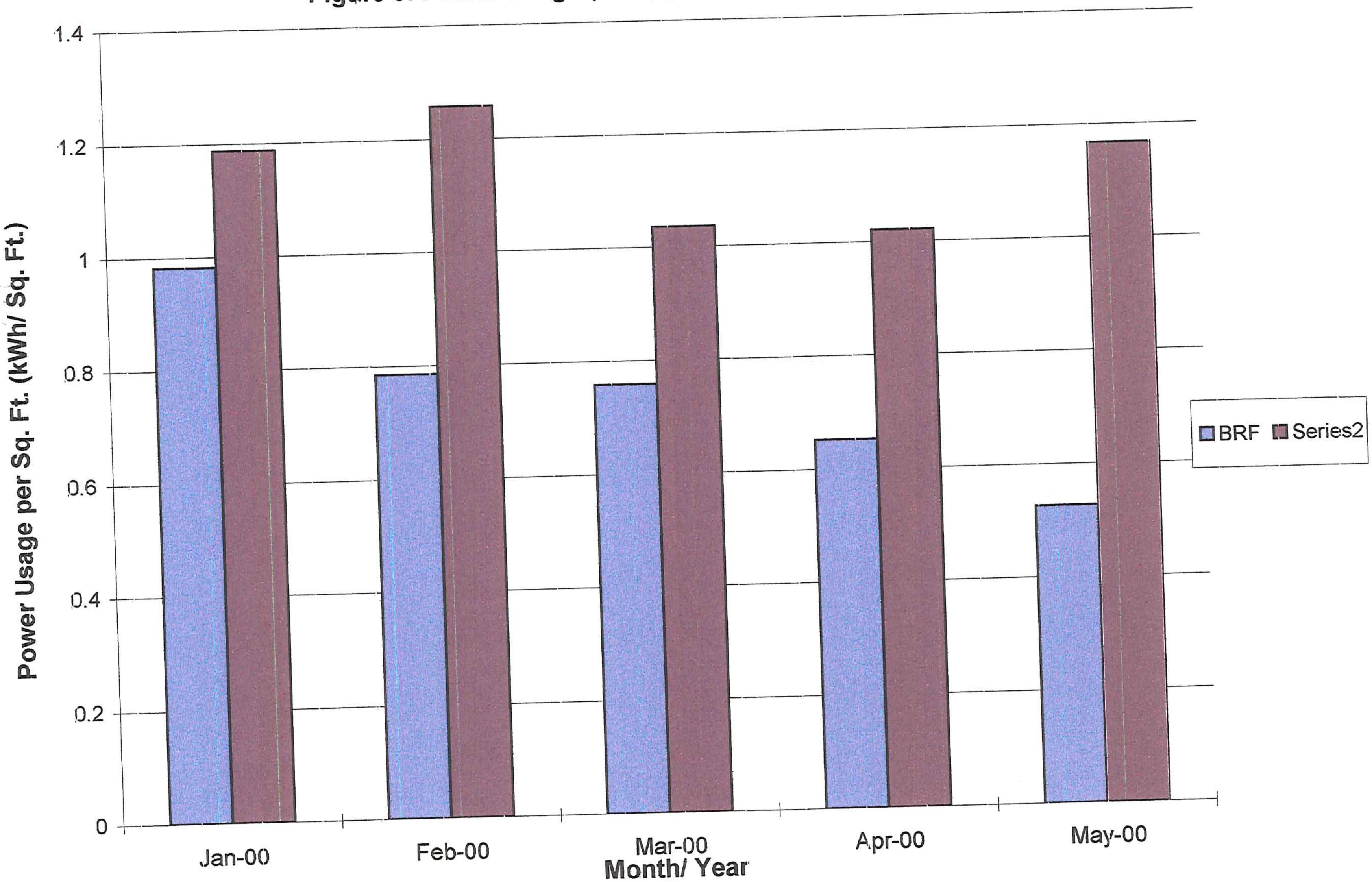
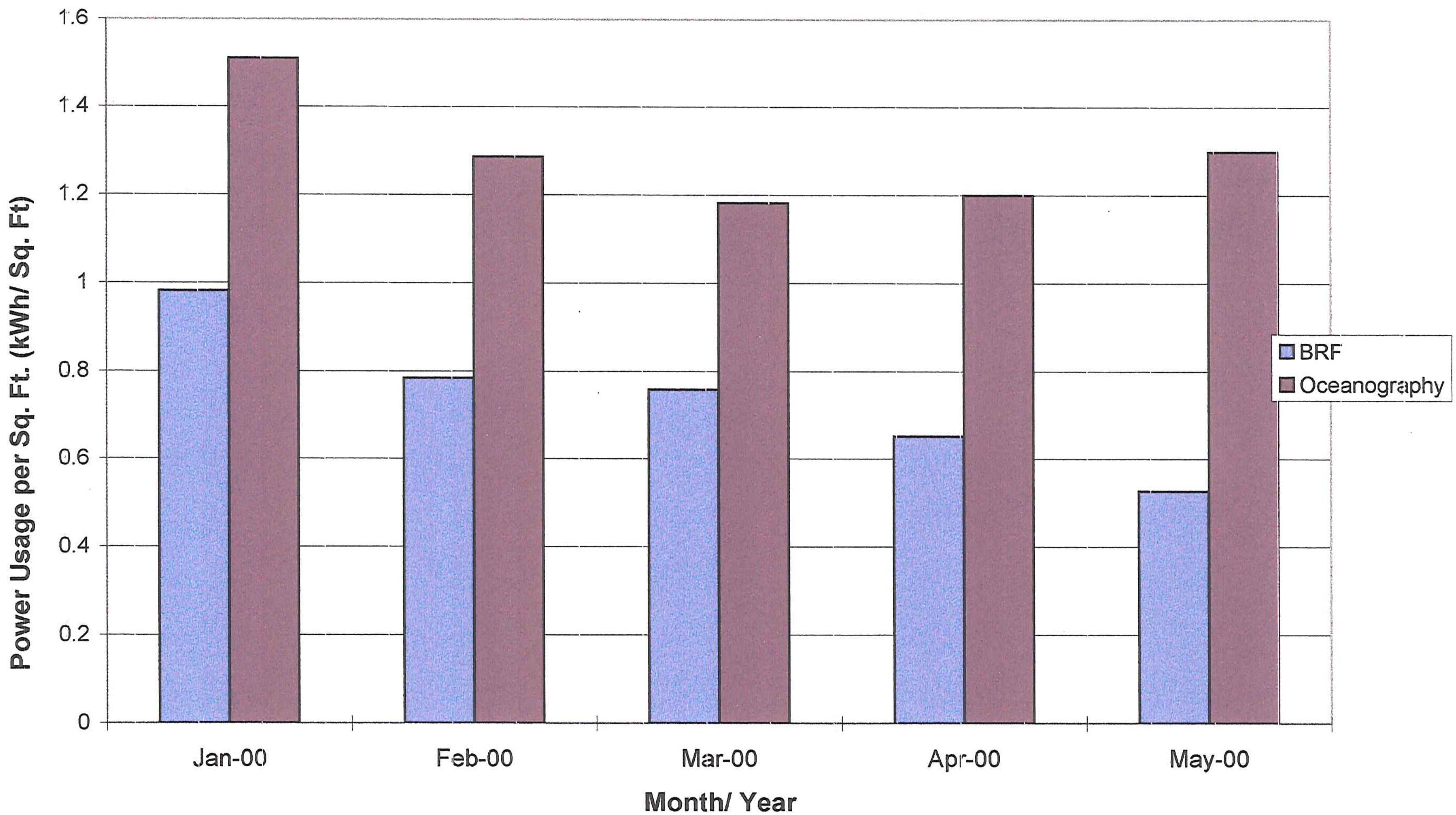


Figure 4: Power Usage (kWh) per Sq. Ft: BRF vs. Oceanography



foot. Oceanography used more power than BRF, Monell, and Administration. BRF used about half the power per square foot during the months studied than Oceanography. Oceanography steadily uses less power through the months and leveled off in April. As with Geo-Chem, Administration, and Monell, Oceanography power usage in May increased noticeably from April.

Finally, Figure 5 compares Geo-Chem's power usage with that of BRF. Geo-Chem used significantly more power than any of the buildings studied. Whereas most buildings' usage ranged from .82 kWh/ sq. ft. (Monell, January/00) to 1.8 kWh/ sq. ft (Seismology, January/00), Geo-Chem used an average of 4 kWh per square foot. There is no noticeable trend in Geo-Chem's power usage per square foot over the months but, as in most of the other LDEO buildings, we do notice an increase in power usage from April to May.

Corrections Made for Power Usage Allotted to Electrical Appliances

The results of the corrected values are proportional with the uncorrected values. That is, the trends are the same for both BRF and LDEO: BRF gradually reduced power usage as the months progressed and LDEO buildings mainly increased power usage in May from April without showing any other trends. Figures 1b to 5b show the corrected power usage of LDEO, taking into account only 20% of the total electrical power usage (kWh). Seismology (Figure 1b) saved more than twice the energy as BRF in January. Even though BRF gradually reduced power usage by May, Seismology still saved up to 1/3 energy. Monell (Figure 2b) uses only about 20% of the power that it takes to heat or cool BRF. The Administration building (Figure 3b) uses only about 1/3 the power of BRF throughout the course of the five months. Oceanography (Figure 4b) uses close to 1/3 of the power at BRF in January. As BRF decreases power usage and Oceanography fluctuated minimally through the months, Oceanography uses more than half of the power at BRF. Finally, Figure 5b shows that Geo-Chem conserves more energy only in January. From February to May, it increasingly used more power that by May BRF used only about 5/8 of the power at Geo-Chem.

Figure 5: Power Usage (kWh) per Sq. Ft: BRF vs. Geo-Chem

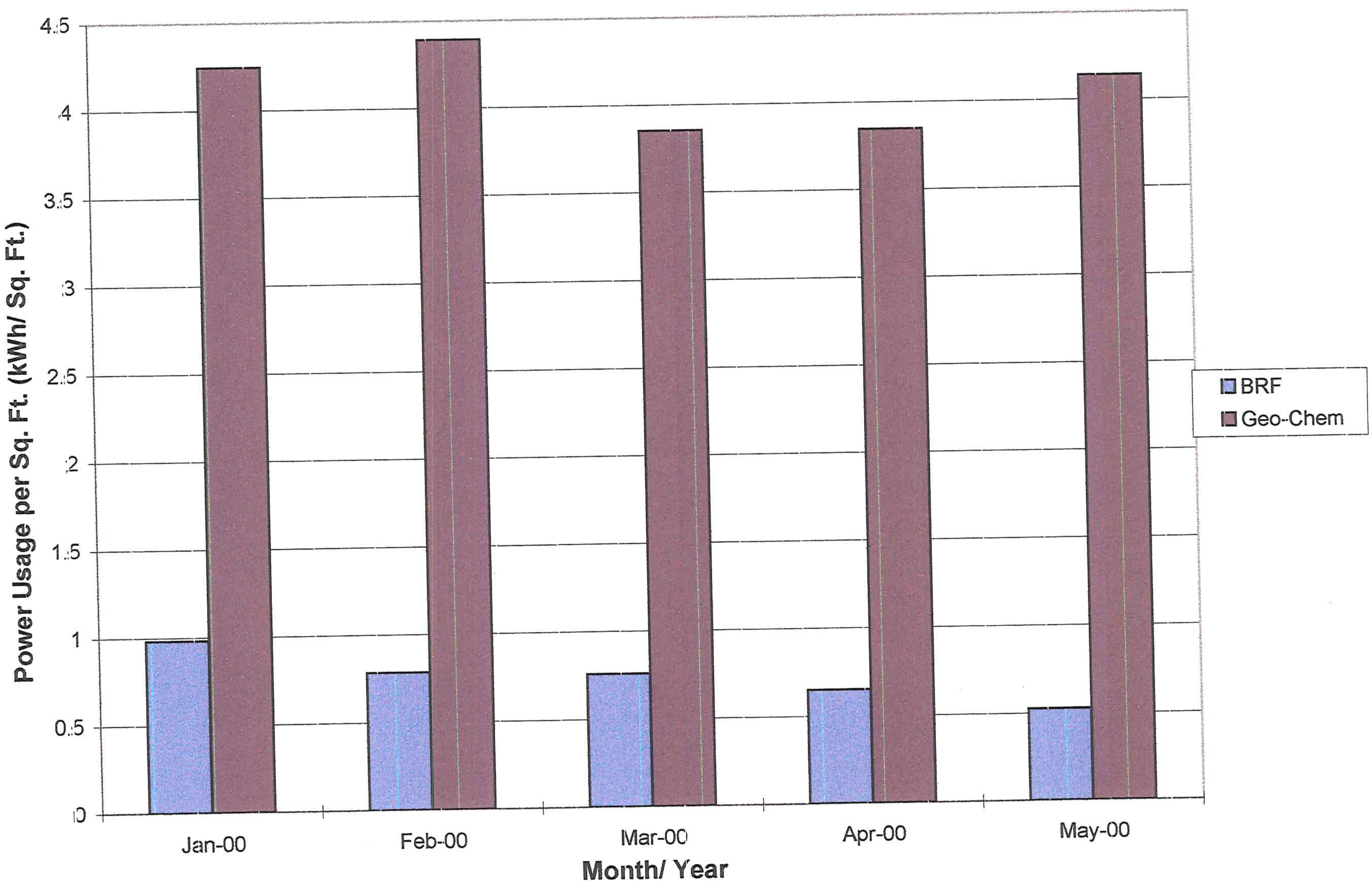


Figure 1b: Corrected Power Usage (kWh) per Sq. Foot: BRF vs. Seismology

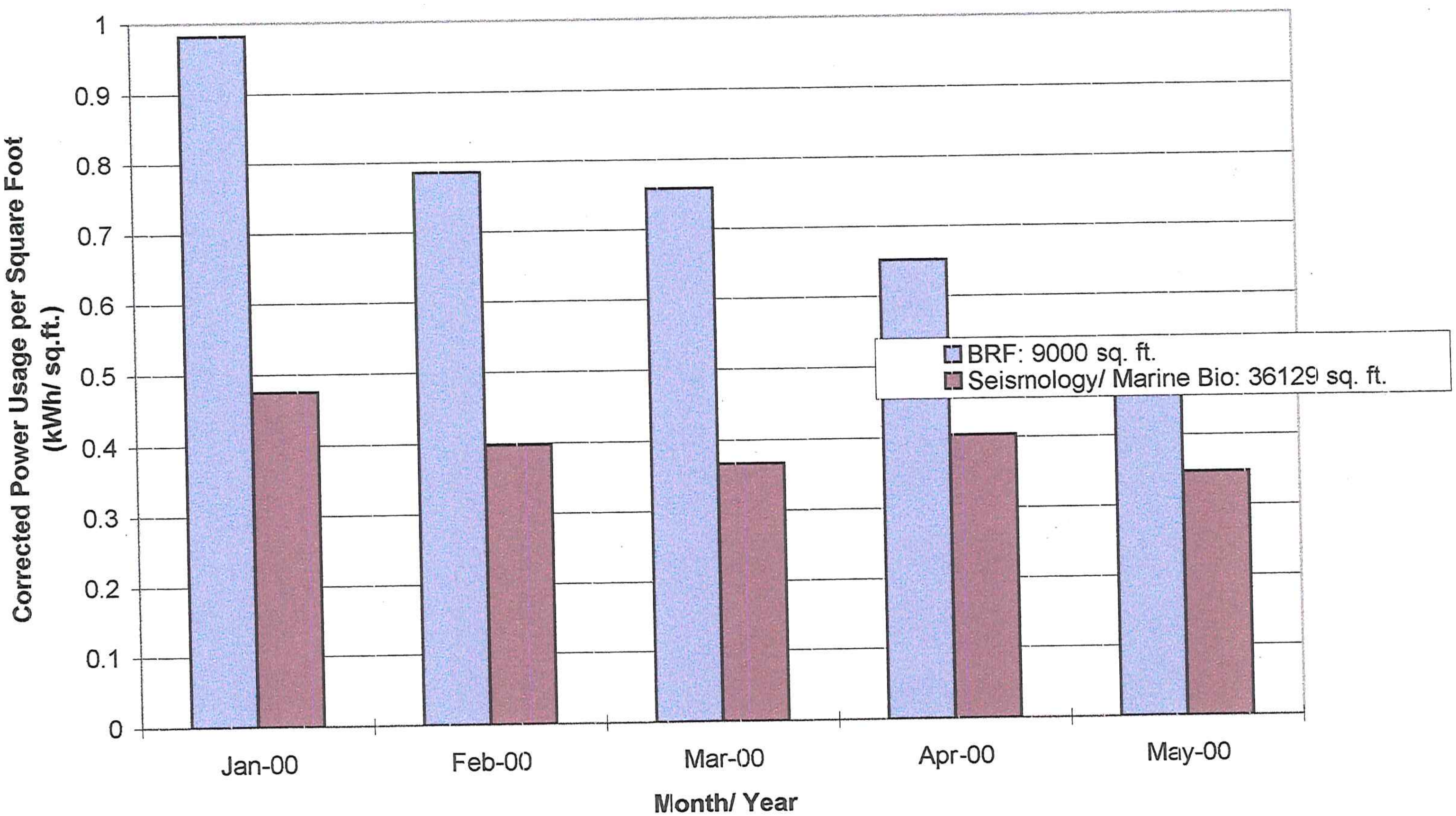


Figure 2b: Corrected Power Usage (kWh) per Sq. Ft.: BRF vs. Monell

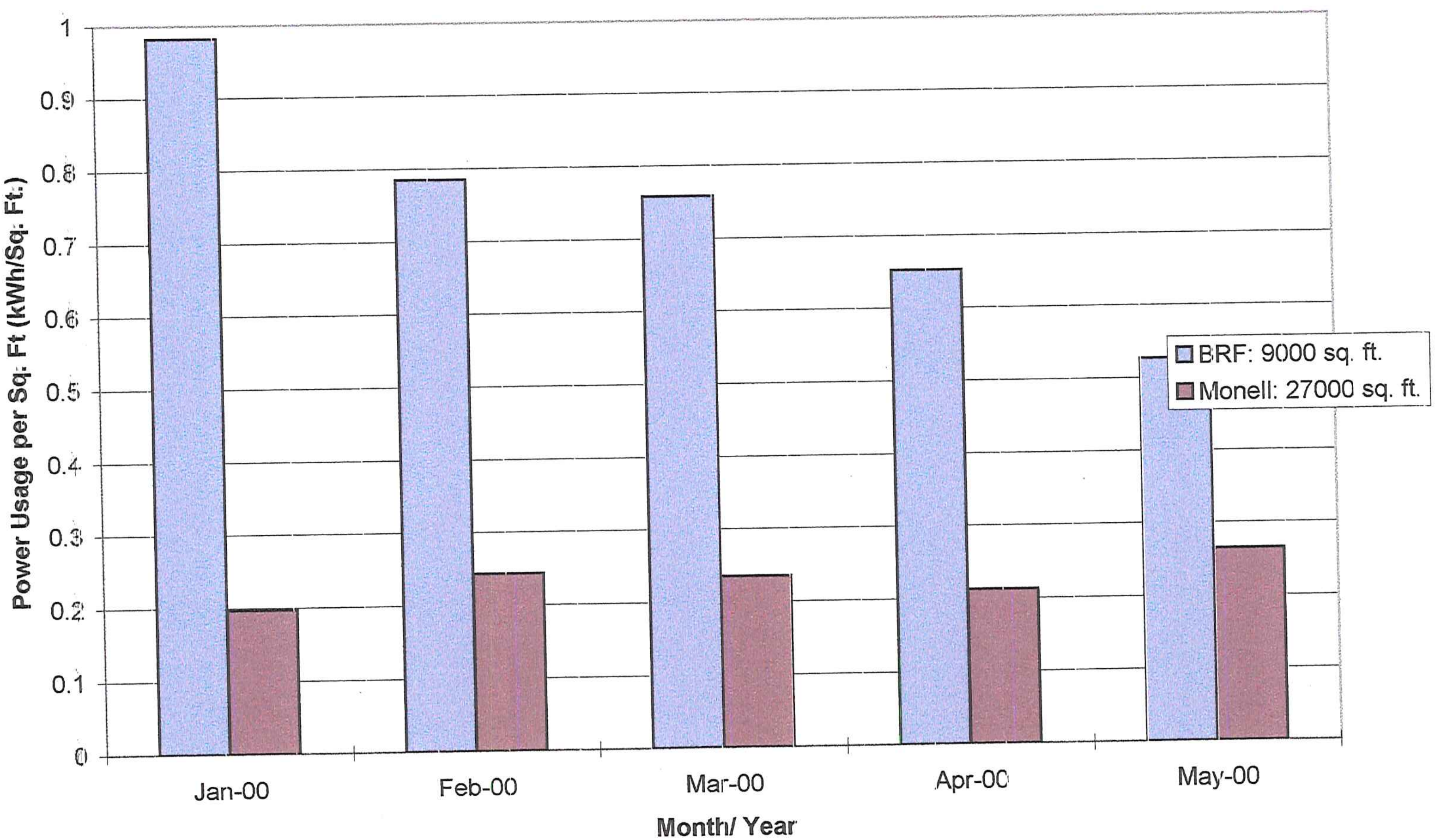


Figure 3b: Corrected Power Usage (kWh) per Sq. Ft.: BRF vs. Administration

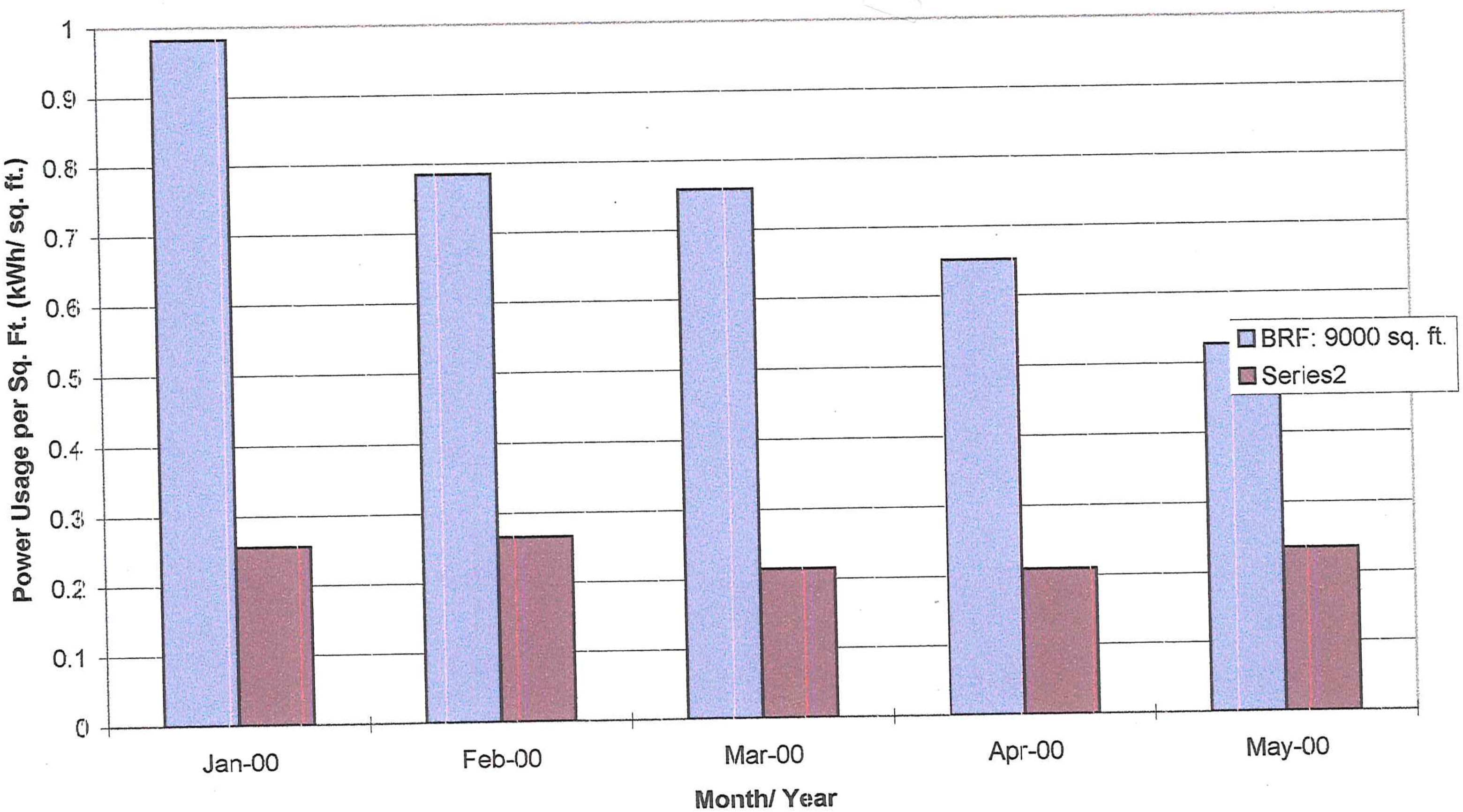
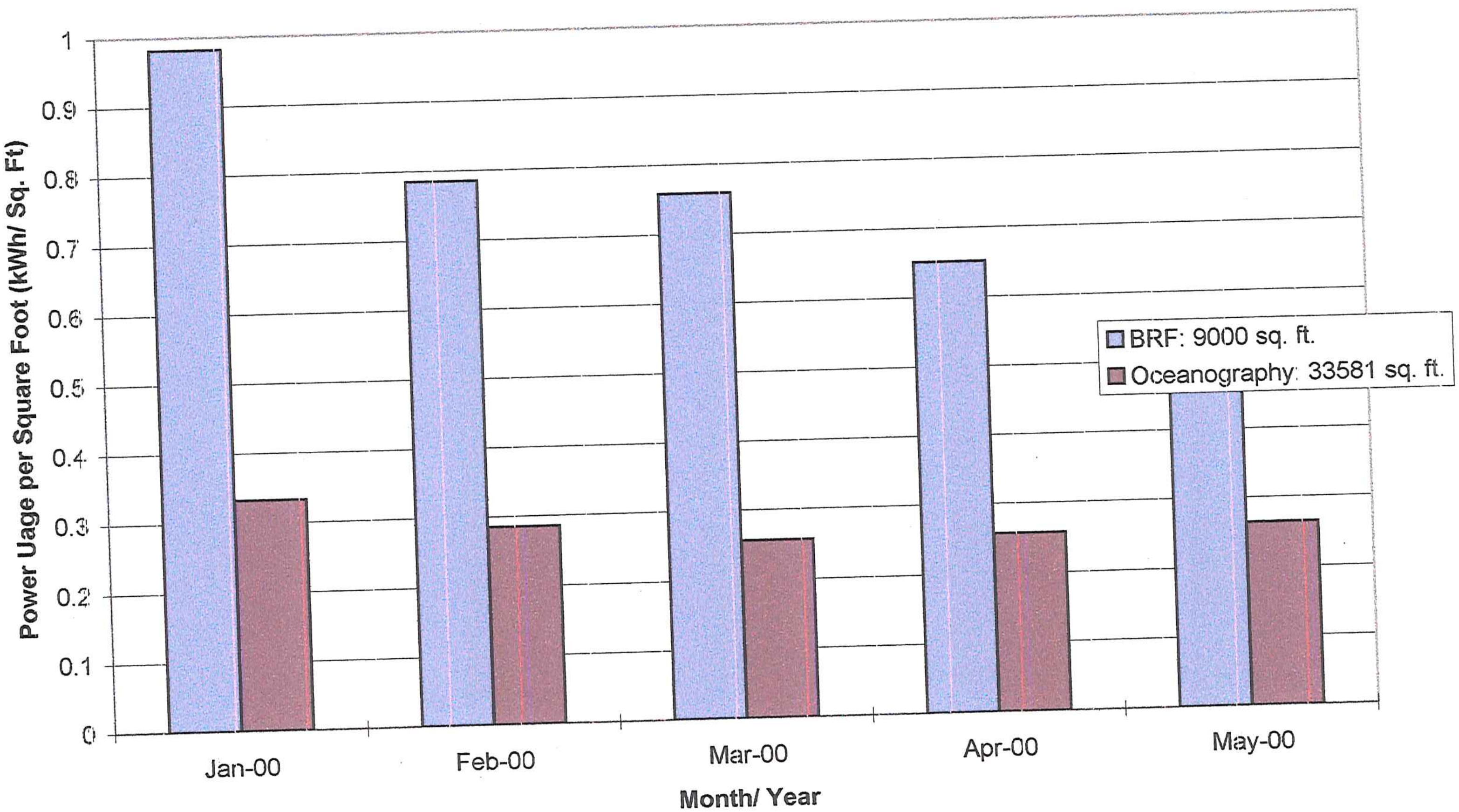


Figure 4b: Corrected Power Usage (kWh) per Sq. Ft: BRF vs. Oceanography



Assessing Impact of Atmospheric Variables on Performance of GHP: Temperature (Data from 1/1/00 to 1/5/01)

Figure 6 deals with the relationship with change in outside temperature, taken at Open Lowlands weather station, and indoor temperature, monitored by sensors inside the BRF visitor center. As the *average* difference between the outside and inside temperature (degrees Celsius) increased, the daily power usage (kWh) also increased. The slope of the curve is 4.078.

Relationship between Power Usage and Seasonal Variation

Figure 7 shows that as heating season 2000 progressed from January to May, the daily power usage (kWh) decreased. Then, from June to the end of October, there is a yearly low, excluding the uncertainty of the data gap for 7/00. From November to the end of the year, daily power usage steeply increased.

Effect of Change in Outside and Inside Temperature on Daily Power Usage (kWh)

Figure 8 combines the relationship between time (month/2000) and power usage seen in Figure 7 with relationship between time and change in outside and inside temperature (degrees Celsius). We do not notice a significant correlation between the temperature discrepancy and the demand for power usage. In the colder months such as December and January, the inside temperature understandably exceeded the outside temperature. Here, there was a relatively high demand of power usage. However, the rest of months showed no such trend.

Average Hourly Power Usage for 12/99 to 6/00

Figures 9 shows the relationships between power usage of (kWh) and hour of day. Figure 16 is a compilation of data for six months. As the heating season progressed, from December to June, power usage significantly reduced. All the curves are relatively flat. That is, there was not great variation in the power usage throughout the day. At approximately 5:00 AM, power usage suddenly increases in the warmer months (March,

Figure 6: BRF Power Usage (kwh) vs. Change in Daily Outside and Inside Temperature

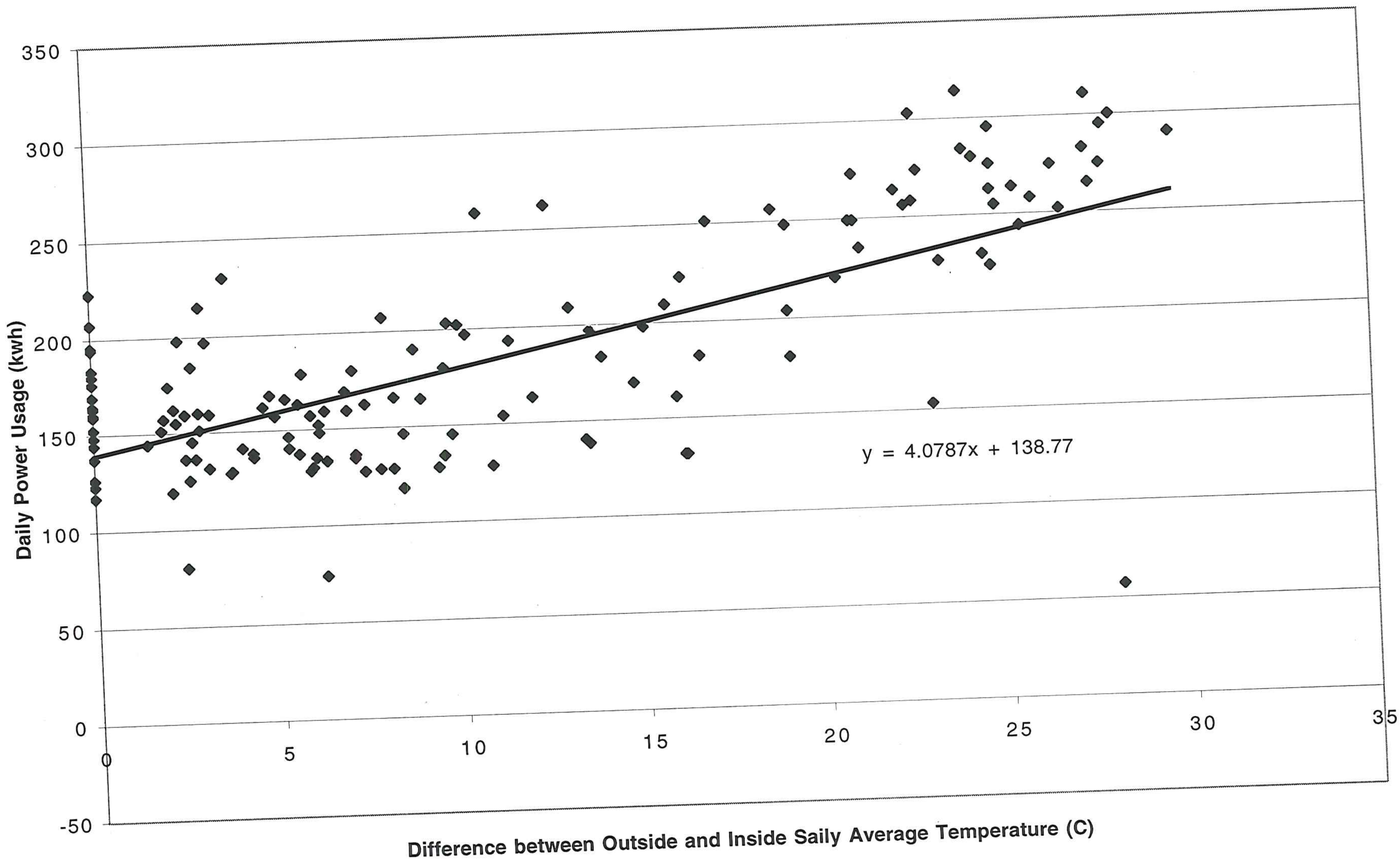


Figure 7: DAILY POWER USAGE (AVERAGE) in kWh throughout the year at BRF

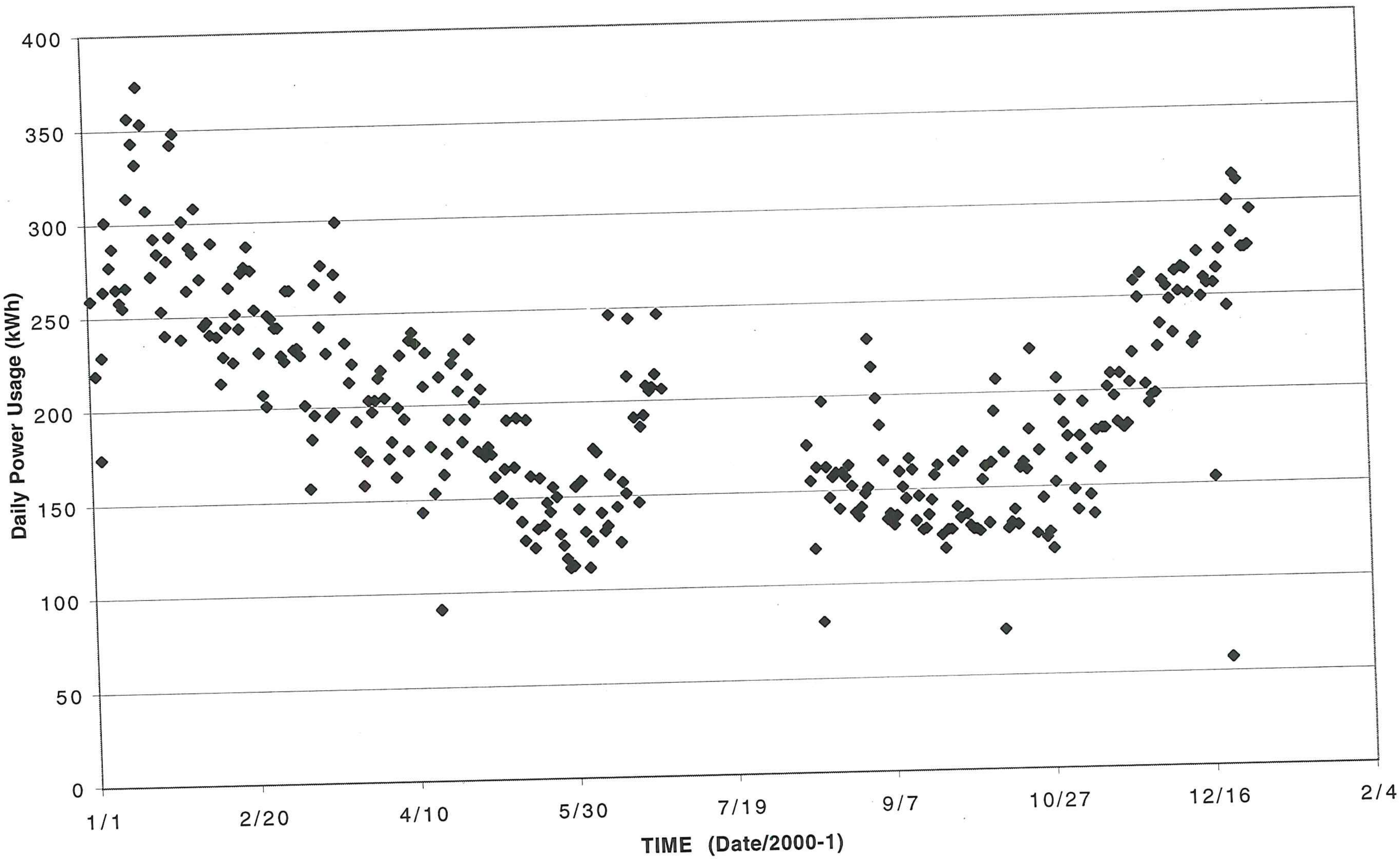
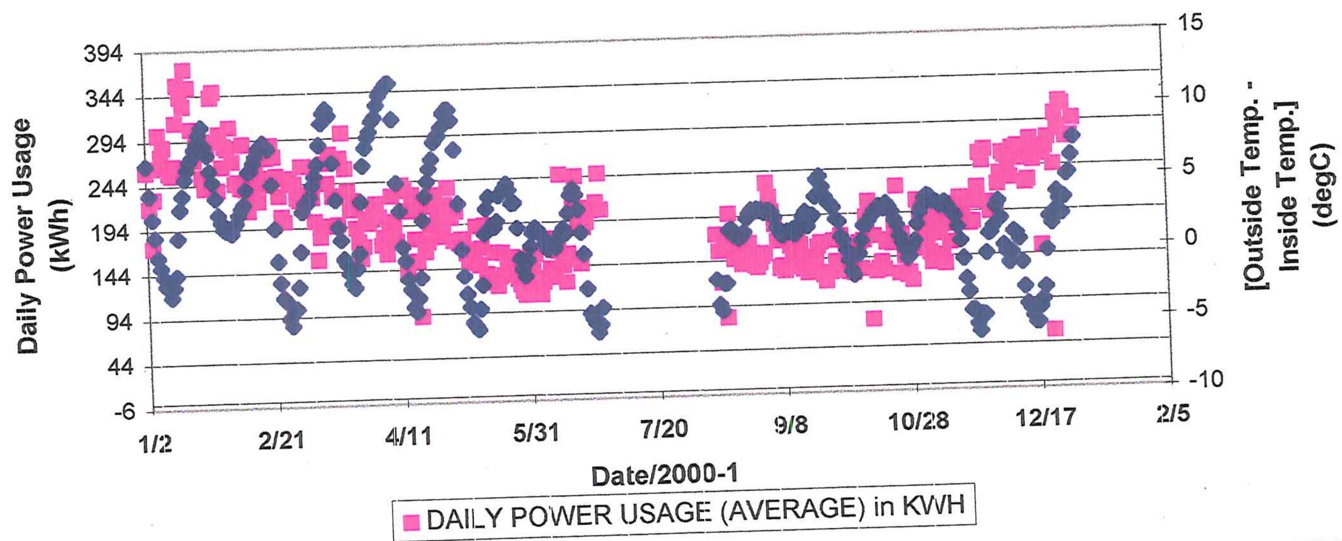


Figure 8: Daily Power Usage (kWh) Change in Inside and Outside Temperature (C) through Time



April, May). January and February show a moderate increase at about 6:00 AM. Also, there are peaks in all the months except January at 8:30 PM to 9:00 PM. Table 1 shows the calculation of the discrepancy between the peak and lowest average daily power usage in January for the Maisy Database Daytype and the BRF hourly average power usage (Figure 10). The range for the BRF hourly power demand varied by roughly 19.3348%. The Maisy daytype load, which is an example of a medium-sized building in that is electrically heated, showed a discrepancy of 93.8776%.

TABLE 1:Estimated Calculation of Peak Shaving

Average Hourly Power Usage for Dec99 - Jan00 at BRF (All days) kWh

Average of 4 lowest values:

11.1731 kWh

Average of 4 highest values:

13.3333 kWh

19.3348% Discrepancy between peak and lowest values

Metropolitan-Area Analysis (Pittsburgh) January Daytype Loads (Weekdays) kW*

Estimated Average of 4 lowest values:

490 kW

Estimated Average of 4 highest values:

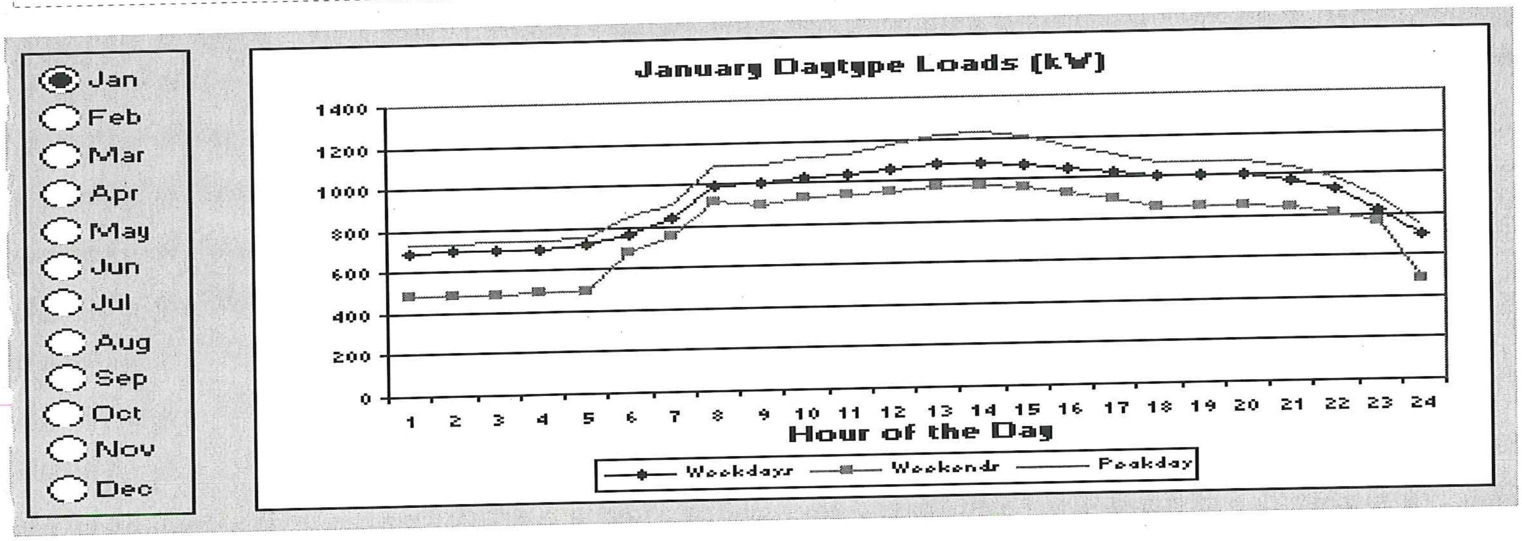
950 kW

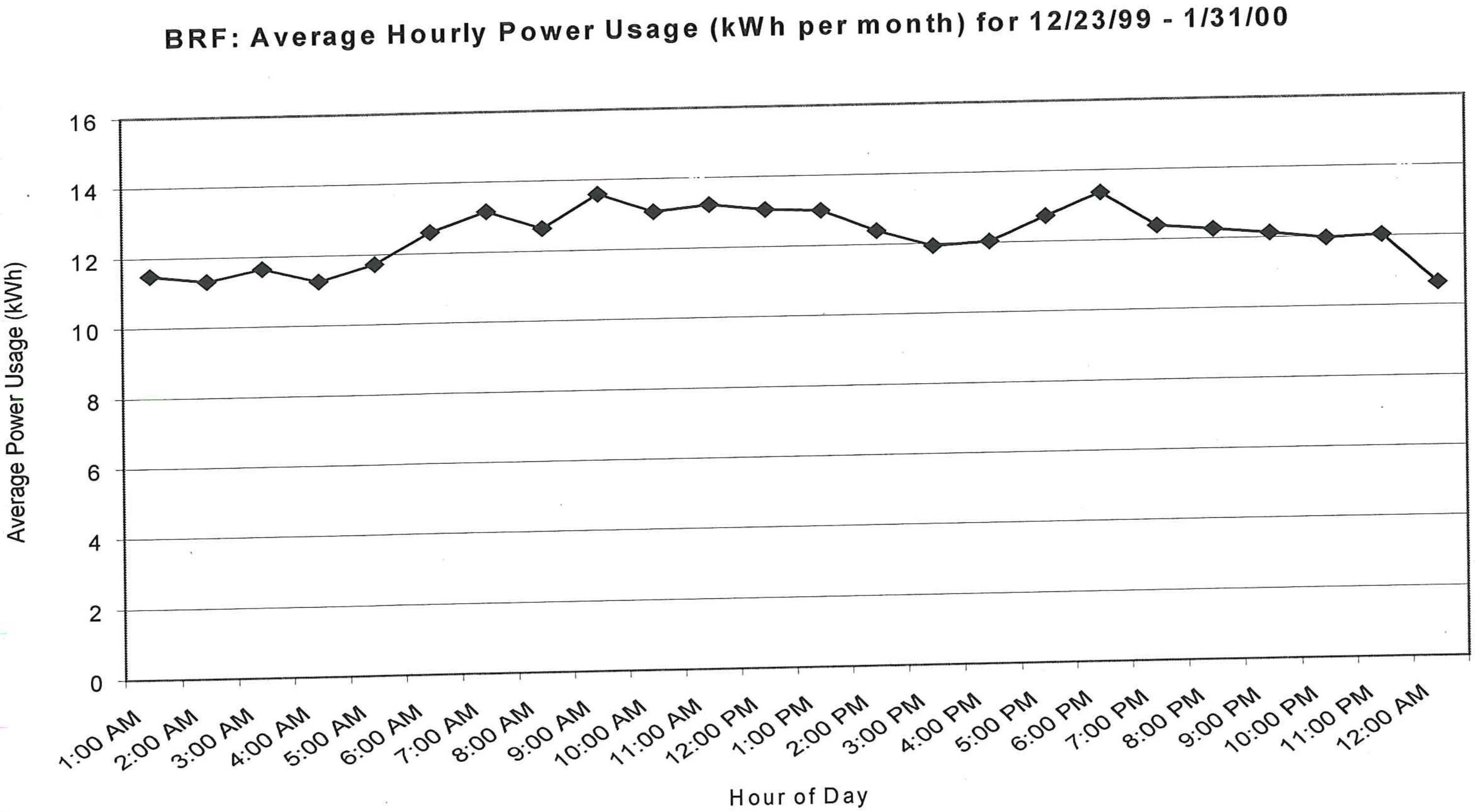
93.8776% Discrepancy between peak and lowest values

*http://www.maisy.com/mdbase.htm

Figure 10: Comparison of Peak Shaving *

*January Daytype Loads – Source: www. //www.maisy.com/mdbase.htm





Discussion

Assuming that most of electrical usage is allotted to space heating or cooling at BRF and LDEO, the comparison of power usage between LDEO buildings and BRF points to BRF using less energy per square foot (Figure 1 to 5). Having not yet calculated the CDD/HDD ratios for the power usage and separated the electricity allotted to the heating our results point to the greater efficiency of GHPs over conventional heating and cooling. The magnitude of the discrepancies of power usage between the two types of energy use is, in some cases, more than 100%. That is, the GHP used less than half the energy to heat or cool its visitor center than did the furnaces and air conditioning at LDEO.

With the significantly increased number of electrical facilities, however, LDEO buildings require the calculation of wasted heat that contributes to space heating. Figures 1b to 5b show how the power usage of LDEO compares with BRF if we only account for 20% of the electrical power usage at LDEO. This is the amount that, in the *heating season*, goes to the heat produced by the burning of electrical appliances such as lights, computers and other facilities. The results based on these calculations show that BRF saves less energy than LDEO. In fact, in many cases, the GHP uses more than twice the energy that LDEO buildings use to heat BRF's space. The range of our results, excluding the calculations and including them, shows that the rough corrections may be an intricate part of the comparison and thus need to be more precise. A deeper understanding of where electrical use is allotted is crucial in providing a more reliable comparison of power usage at LDEO and BRF.

The new Monell building is more efficient than other LDEO buildings. Monell (see Figure 2) used the least power per square foot of the LDEO buildings. Although Monell is designed to primarily to reduce energy usage with features that incorporate passive solar design, the design differs significantly from the energy conservation design of the Black Rock Forest visitor center. We cannot assess the effect of this design but we can deduce, looking at the uncorrected results, that it may not be as efficient as the cumulative use of the GHP, passive solar design, and increased building insulation.

Interestingly, Seismology and Administration are made from the same manufacturer but the Administration building uses considerably less power. This is probably because there is much more lab equipment and computers in Seismology. Similarly, Geo-Chem reports using the highest amount of power. This may be explained by the fact that it is filled with mass spectrometers that utilize relatively great amounts of power to operate.

For both comparisons Black Rock Forest Visitor's Center saved the most energy in the warmer months. Power usage decreased from January to May for BRF. The buildings at LDEO, that use conventional heating and cooling, did not show such a trend. All, except the Seismology-Marine Biology building, increased their power usage from April to May. Heating attributed to waste heat from computers, lighting and other facilities may have increased the indoor temperature thus requiring more energy to cool the interior on the CDD's.

Contrastingly, the GHP at BRF significantly reduced power usage in the warmer months (with the uncertainty of July 2000) (Figure 7). The steady drop in the heating season and the June to November sink in power usage cannot be attributed to the increased use of lighting in the colder months because the magnitude of the drop, from 300 kWh to 150 kWh, is too great. Figure 6 shows a direct relationship between the change in outside and inside temperature (degrees Celsius) and power usage. It would be interesting to compare the slope of Figure 6 with that of a similar analysis at LDEO. Thus, the GHP may be, to some degree, dependant on the outside temperature. Figure 8, which adds a temporal element to Figure 6, reveals that during the warmer months (June to October, 2000) there is the least discrepancy between the outside and inside temperature. It is also during these months that we find the lowest values of power usage. In this way, the decrease in power usage can be attributed to the change in outside and inside temperature. However, the progressive reduction of power usage through the heating season (approximately November to June) does not correlate with the change in outside and inside temperature. For example, on April 11th there is a peak in the change in outside and inside temperature yet we notice a low value of power usage. Here, then, the July 2000 data would be a crucial addition to our results because it would be able to show the trend in the summer that we are not able to deduce with the data gap.

We had hypothesized that as the heating or cooling season progresses, the pump becomes less efficient because the reservoir changes, and thus the temperature gradient between the sink and the source of heat decreases. However, our results only show the opposite: as the season progressed, BRF only used less energy. This can further be tested by determining the difference between the temperature of the circulating fluid as it enters the system (input temperature) and as it exits the system (exit temperature). If the difference becomes smaller for same fluid pumping rate and system residence time then there is a significant change in the temperature due to dumping or extraction of the heat. Considering the volume of the reservoir is relatively expansive that the amount of heat exiting and entering the reservoir may be insignificant.

Finally, the analysis of the hourly power usage correlates with our results indicating the reduction of power usage at BRF through the progression of the heating season. Figure 9 clearly shows this progression. The trends that we see in many of the curves for the various months can be attributed to the every-day activities of the care-taker at BRF. For example, from 8:30 to 9:00 PM, the peak in power demand could be because he is taking a shower. Thus, water-heater would be using this power. At 5:00 AM and 6:00 AM we often find peaks. This could be the spurt of heat provided at the beginning of the day in a central-heating facility. We have noticed a trend in our results of BRF saving more energy in the warmer months. So, the fact that the colder months (January and February) show less hourly power usage variation than the warmer months is left without an explanation

The comparison of the Maisy daytype load and the BRF average hourly power demand for January provides a rough estimate of the peak shaving of a GHP (Table 1 and Figure 10). The peak demand is almost twice that of the lowest power usage for the Maisy case while at BRF the discrepancy between the peak and the lowest demand is less than 20%. This peak shaving is due to the relative constant temperature of the ground, which prevents the need to raise the power usage during the hottest or coldest time of the day.

Conclusion and Recommendations

To what extent the GHP at BRF, as opposed to the conventional heating and cooling at LDEO, is an energy-conserving feature is left uncertain due to imprecise corrections we have made. In warmer seasons the GHP saves more energy. Corrections that account for the elevation difference between BRF and LDEO, and the electrical use of lighting, computers and other facilities must be done in a more precise manner for us to reach any conclusions. A data gap for 7/00 would be crucial to fill in order for us to ascertain if the GHP saves more energy in warmer months.

Generally speaking, difference in outside and inside temperature directly impacts the power usage at BRF but when we take a closer look at heating season 2000, the correlation it is questionable. As the heating season of 2000 came to a close, we noticed significant discrepancies in this relationship. However, in the summer of 2000, when there is minimal power usage, there is a lesser degree of fluctuation in outside and inside temperature.

The GHP at BRF may achieve peak shaving. Again, monitors that report the power usage allotted to heating and cooling the space at BRF would ascertain the effect of GHP on peak shaving. Also, more comparisons of the peak shaving at BRF with conventional heating and cooling systems in order for us to measure the degree of the peak shaving.

Acknowledgements

I want to express my gratitude for the great effort and patience that Dallas Abbott has shown towards my work with this thesis. Also, I would like to thank Chris Scholz for his helpful comments and support. And, I would also like to thank Sidney Hemming for her enthusiasm and encouragement. I am very grateful my friends' and family's attentiveness and constant support.

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