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Analysis of Heating the Black Rock Forest Visitor Center Between November and March (2000-2001)

The Black Rock Forest Visitor Center is heated and cooled by a ground source geothermal heat pump. During the winter, heat is pumped from the ground into the building, whereas in the summer, heat is pumped out of the building and into the ground The Visitor Center also utilizes certain principles of passive solar heating in order to provide for the building's energy needs. Data collected between November 7th and March 21st, including the temperature inside and outside of the building, solar radiation, and the ground source power usage. Examination of the data indicated that the ground source geothermal power usage was more a function of ΔT than of solar radiation

Introduction

Heat is transferred in three ways, namely conduction, convection, and radiation. Conduction refers to heat transferred between molecules without significant movement of the molecules. This is the major mode of heat transfer in solids. Convection refers to the transfer of heat effected by the movement of a hot material to colder areas and is the major mode of heat transfer in liquids. Finally, radiation refers to the transfer of heat effected by the movement of electromagnetic radiation, and is the only method of heat transfer in a vacuum. Energy efficient building design should minimize all three of these methods of heat transfer[1]. The Black Rock Forest Visitor Center incorporates principles of passive solar design but cannot truly be considered passive since it utilizes a ground source geothermal pump to move heat in and out of the building via the ground.

Methods

Measurements were taken hourly of the temperature inside the Black Rock Forest Visitor Center, the temperature outside, the solar radiation and the ground source power use for each day between November 7-March 21 2001. The average ground source geothermal power use for each hour of the day was calculated for each month. The difference between the time of day with peak power use and the time of day with the least power use was calculated. The differences between the inside and outside temperatures were calculated for the entire dataset, which were then compared to the ground source power use. Finally, the solar insolation, temperature difference and ground source power use were compared between 7:30AM-4:30PM and from 4:30PM-7:30AM to determine which variable had a better correlation.

Results

The calculated hourly average ground source power use for each month is illustrated in figure 1. The difference between the peak average use and the least power use for each month

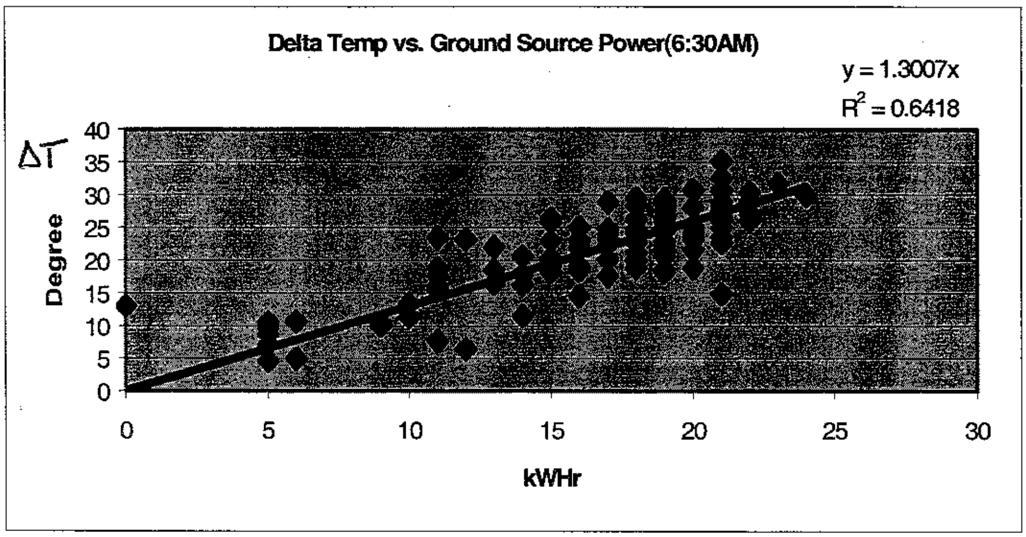
Hour	mean solar	mean Del. T	mean D.T./GSP
630	9.0284	21.81471429	1.22617854
730	55.450619	21.48366667	1.109720702
830	187.9541	20.5232	1.138935221
930	294.1395	19.6028	1.622623258
1030	402.32526	18.95047368	1.544735897
1130	460.05684	18.09463158	1.724796799
1230	450.95211	17.35068421	1.747553042
1330	393.27474	16.86163158	1.874381444
1430	293.4325	16.87075	2.255770527
1530	170.08065	17.22265	2.354649497
1630	73.2173	17.684	2.47015017

Figure 3: Calculated Mean Solar Insolation, ΔT, and Average ΔT divided by Ground Source Power for March 6:30am-4:30pm

The period of peak average power use for the month of March was determined to be 8:00am (7:30am), which, according to figure 3, has the lowest mean ΔT/GSP value (~1.11). This time period also has the second highest mean ΔT (21.48 °C) and the second lowest mean solar radiation (55.45 W/m^2).

Correlation: Delta T. vs. Ground Source Power

Figure 4 illustrates the correlation between ΔT and Ground Source Power Usage during each month between 6:30-7:30am



Power Use is the variable which should be fit and thus should be on the y axis.

Figure 4: Correlation Between ΔT. and Ground Source Power, March 6:30am

Figure 5 illustrates the correlation between ΔT and Ground Source Power Usage for March at 7:30AM. Notice that both the r^2 value and the slope of the line have decreased from those of 6:30AM.

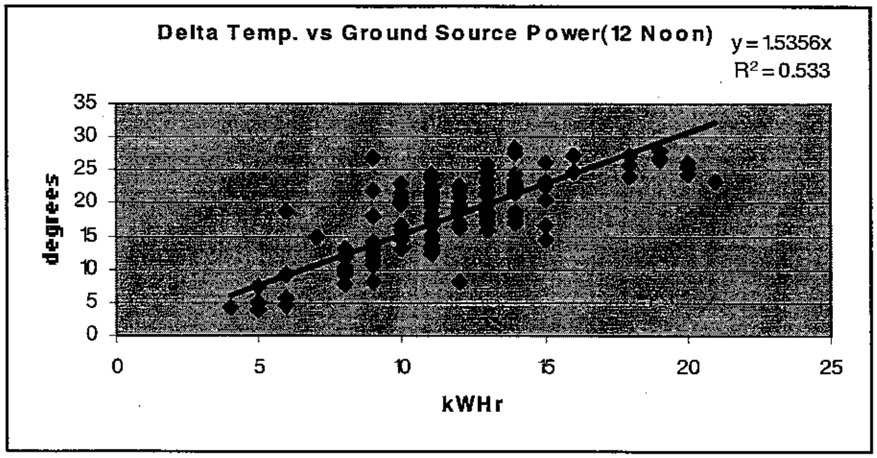


Figure 7: Correlation between ΔT and Ground Source Power Usage, March 12 noon

Figure 8 illustrates the correlation between ΔT and Ground Source Power Usage in March at 4:30PM. Notice the increase in slope of the line, but a decrease in the r^2 value.

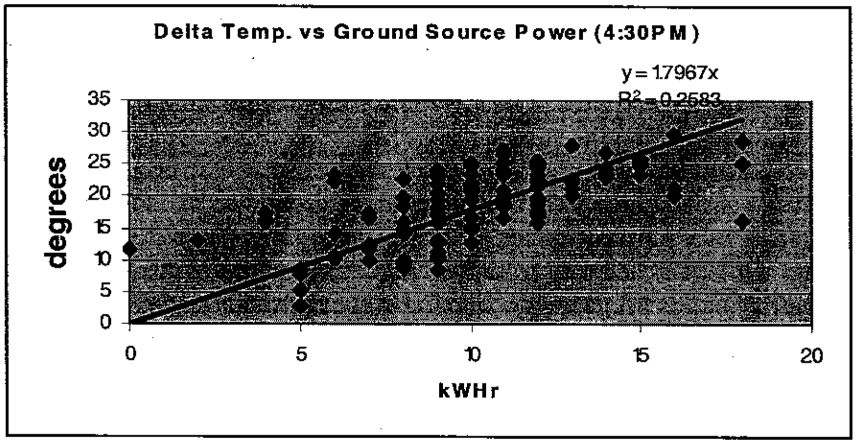


Figure 8: Correlation Between ΔT and Ground Source Power Usage, March 4:30pm

A multivariate fit was created for ΔT, ground source power use and solar insolation using all of the data with times between 7:30 AM and 4:30 PM, in order to solve for ground source power use as a function of both ΔT and solar insolation. A second multivariate fit was done utilizing all the data from 4:30PM to 7:30AM. The adjusted r^2 values of the multivariate fits between 7:30AM-4:30PM and 4:30PM-7:30AM are both displayed in figure 9.

Summary of Regression Statistics (Multivariate Fit)	
7:30AM-4:30PM	4:30PM-7:30AM
Adj. R^2 value: 0.517146	Adj. R^2 value: 0.195309

Figure 9: Adjusted R^2 Values for Multivariate Fits (7:30am-4:30pm, 4:30pm-7:30am)

Notice the lower r^2 value for the period between 4:30PM-7:30AM. Figure 10 illustrates the resulting p-values of solar radiation and ΔT for both multivariate fits.

figure 10 shows, ΔT is the more significant variable in both time periods, but is more significant in the time period from 7:30am-4:30pm.

One of the major principles of passive solar design involves the location of the building with respect to sun directions and wind[1]. Although the Black Rock Forest Visitor Center is not a completely passive solar system, it does utilize aspects of a passive system. Overhangs over the windows on the south side let sun in during the winter, and block it during the summer. Based upon the analysis of the data from November through March 2001, ΔT is more significant in the ground source power usage than solar radiation, although solar radiation is significant as well.

References

1.Menke, W. Environmental Data Analysis. Energy 3: Controls on Energy Use of Ground Source System at Black Rock Forest.
http://www.ldeo.columbia.edu/users/menke/energy3/stuff.html

2.Black Rock Forest. Black Rock Center for Science and Education.
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3. Franklin Energy Services, Inc. 2001. Geothermal Heating Systems
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Abstract

The objective of this lab was to determine if there is a relationship between outdoor temperature and geothermal power usage. The data set spans a 5-month period from November to March, although there are some gaps which are likely due to equipment failure.

Introduction

The Black Rock Forest Visitors' Center was constructed with a number of environmentally friendly features, chief among which is the building's heating and cooling system. As described on the website of the firm that designed the building,

> "The rectangular footprint and east/west orientation maximizes solar exposure while minimizing the building mass. Individual southern window overhangs minimize summer heat gain...a highly efficient geothermal heat pump system provides heating and cooling within the well-insulated envelope…the final design is projected to consume 45% less energy annually compared to a traditional structure meeting all applicable codes."

Geothermal systems take advantage of the Earth's ability to store vast amounts of heat. This heat energy is maintained at a constant temperature (50°F to 70°F depending on latitude) in the soil and near-surface rocks. Geothermal heating systems, also called ground-source heat pumps, capture this steady supply of heat energy and "move" it from the Earth through a home or building.

A heat pump is a mechanical device that transfers heat from one source to another. Ground-source units pull heat from the earth and transfer it to homes or buildings. Heat pumps can provide both heating and cooling; the cooling process is simply the reverse of the heating process: heat is taken out of a building and returned to the Earth.

Typical ground-source heat pumps transfer heat using a network of tubes, called "closed loops." Basically, the loops are filled with water, refrigerant or an anti-freeze solution. They run through the ground in the vicinity of a building and the liquid absorbs the Earth's heat energy. Then, this warmed liquid is pumped back through the system into the building. This process provides heat to the building space. Once the fluid passes through the building and transfers its energy, it flows through the loop system back to the Earth and the process repeats itself. In the summertime, these systems "reverse" into cooling mode. A series of valves enables the system to transfer the heat from the building to the liquid in the loop and this liquid is pumped back into the ground. When the ground source heat pump is in cooling mode, it usually has an excess of warmed liquid in the system. This liquid can heat water for the building and basically eliminate the use of the hot water heater during the summer months.

Ground-source heat pumps can use 25%-70% less electricity than conventional electric heating and cooling systems, and don't pollute like systems that use fossil fuels. It is interesting to note that ground source heat pumps produce more heat energy output than they require in electric energy input. By way of comparison, conventional electric heaters don't produce as much heat output as electric input.

This can translate into significant savings for homeowners. A ground source heat pump system, including the underground loops, costs about $2,500 per ton of capacity, or roughly $7,500 for a 3-ton unit (typical residential size). Approximately half of this cost is related to the geothermal loop configuration. The system can be expected to last from 20 to 30 years with minimal maintenance. Although the upfront cost is greater than that of a conventional heating and cooling system (which typically runs up to $4,000), the total expenditure over the life of the system will be much less. Given that energy costs are expected to continue to rise, installing a geothermal system can be a good investment that protects the consumer from energy price shocks.

Methods

Using the data set provided on the course website, we first sorted the data by month and then sorted each month by the time of day. We then averaged the power use by the ground source geothermal power unit for each hour of the day, using the data for the entire month, and found the time of day that mean peak power use occurs for each month. [results below].

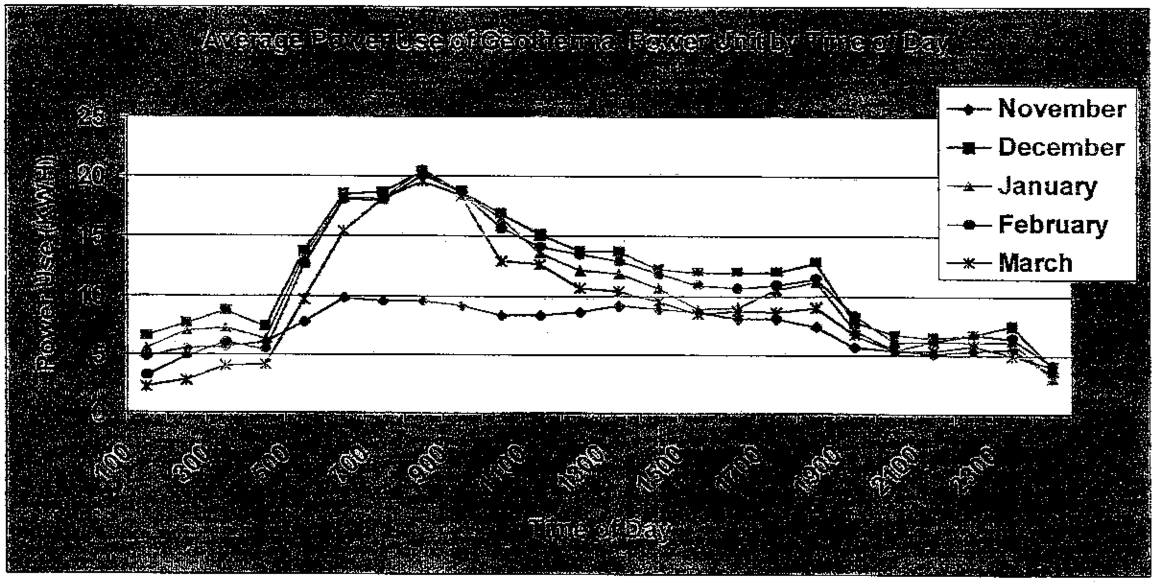
Next, we calculated the difference between the inside and outside temperature and used it to calculate the temperature differential divided by the power use of the ground source geothermal power unit. We then investigated why there are time lags between different variables such as power usage, insolation, and temperature differentials. [results below].

The third step was to sort the data by time of day and plot the indoor-outdoor temperature differential against power use of the geothermal power unit. [results below].

Lastly, we performed a multivariate fit of the indoor-outdoor temperature differential, ground source power use, and insolation using all of the data with times between 7:30 am and 4:30 pm, solving for ground source power use as a function of insolation and the temperature differential. [results below].

Results

Average Power Use



As shown in the above graph, the peak power usage for every month with the exception of November occurs at 9:00 am. November's second highest usage occurs at this time, but the peak is at 6:00 am.

The differences between maximum and minimum power use for the 5 months are:

Month	Max	Min	Difference
November	9.88	3.38	6.5
December	20.39	4.10	16.29
January	20.50	3.10	17.40
February	20.21	3.18	17.03
March	21.48	2.33	19.15

T-tests for statistical significance in peak and lowest power use:

We then calculated the Performing t-tests on the power source usage for the times of day when usage was highest and lowest. Use of the T-test is appropriate because the number of observations is relatively small. The number of degrees of freedom (df) is equal to the number of observations less 2.

The main assumptions of the *t*-tests are the following:
1. Individuals are randomly sampled from a population with a normal density.
2. In the 2 sample tests, populations sampled have equal parametric variances.
3. Also in 2-sample tests, the samples are independent. That is, the values obtained in one sample have no effect on the values in the other

In all cases, the p-values that were returned we extremely small. Our null hypothesis is there is no significant difference in the power source usage, so small p values mean that we will reject this null hypothesis. The data values are significantly different. Below is an example of the values returned for November:

NOVEMBER

	Variable 1	*Variable 2*
Mean	9.875	3.375
Variance	19.15761	5.722826
Observations	24	24
Pooled Variance	12.44022	
Hypothesized Mean Difference	0	
df	46	
t Stat	6.383958	
P(T<=t) one-tail	3.84E-08	
t Critical one-tail	1.678659	
P(T<=t) two-tail	7.68E-08	
t Critical two-tail	2.012894	

Statistics for the month of March:

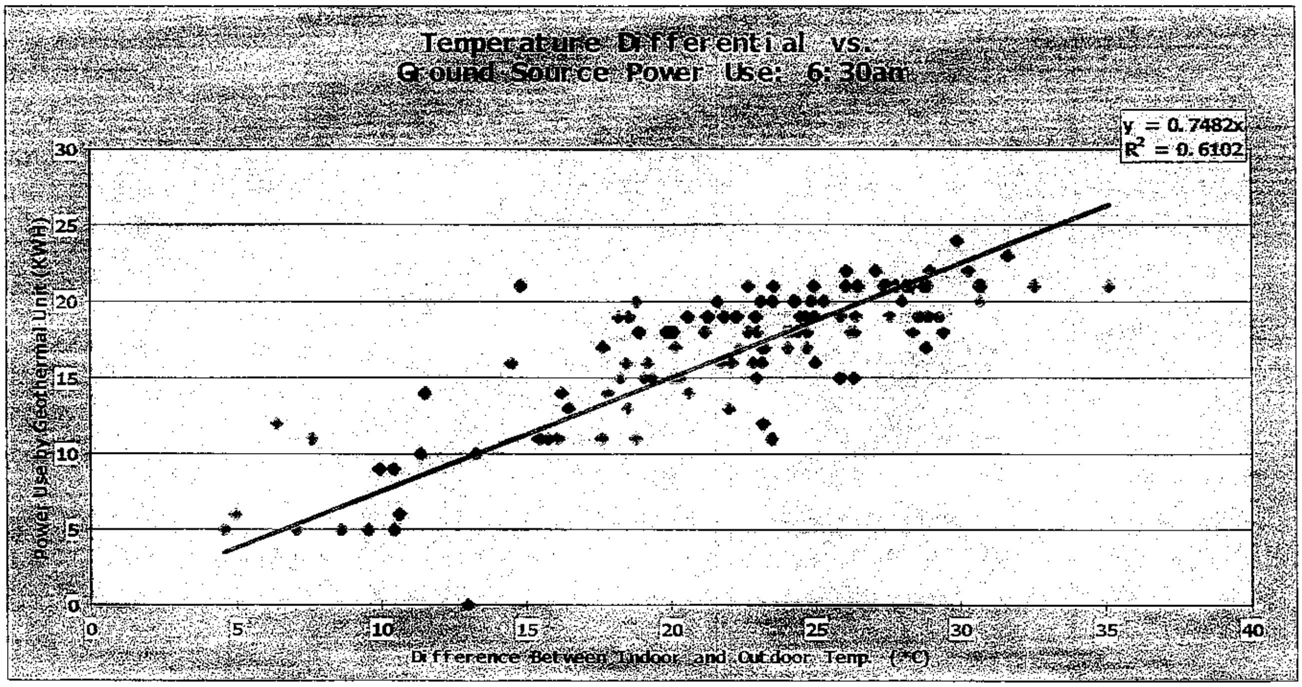
Time of Day	Difference Between Indoor and Outdoor Temperature (*C)	Change in Temperature Over Power Usage	Insolation (w/m$^{2)}$
630	21.81	1.23	9.32
730	21.48	1.11	55.45
830	20.52	1.14	187.95
930	19.60	1.62	294.14
1030	18.95	1.54	402.33
1130	18.09	1.72	460.06
1230	17.35	1.75	450.95
1330	16.86	1.87	393.27
1430	16.87	2.26	293.43
1530	17.22	2.35	170.08
1630	17.68	2.47	73.22

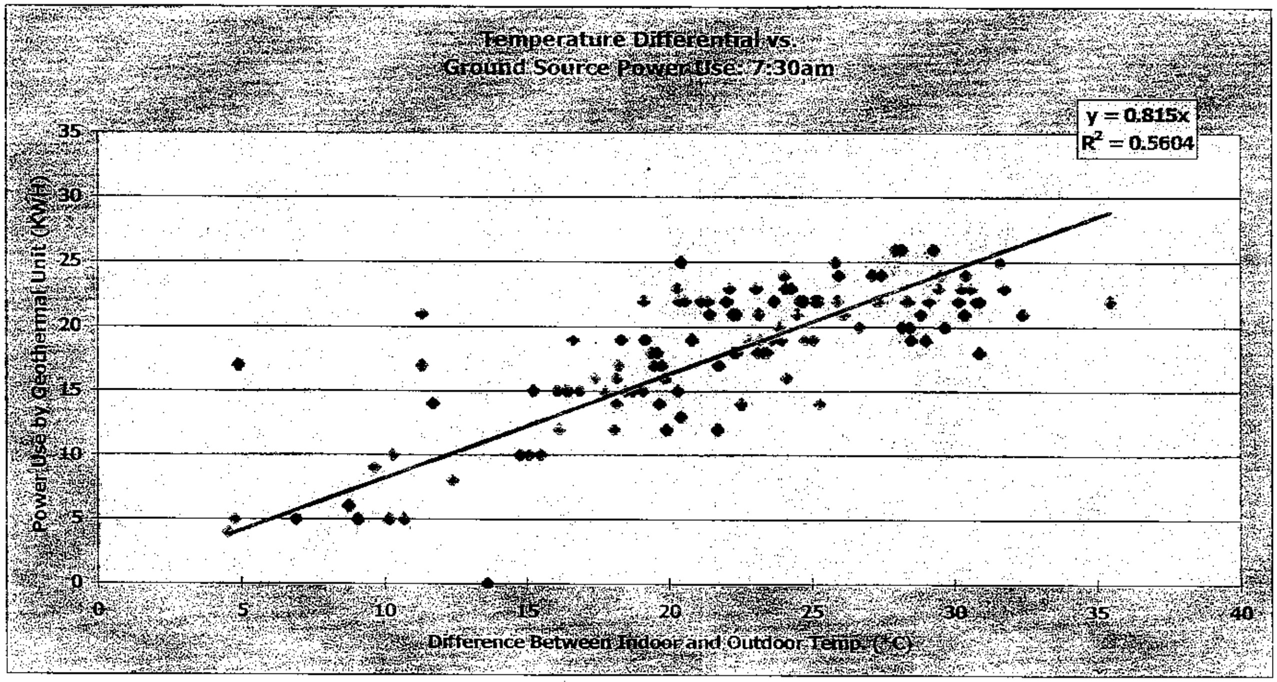
As shown in the above table, maximum temperature difference occurs at 6:30 am, and maximum insolation occurs at 11:30 am. Maximum power usage, as stated above, occurs at 9:00 am.

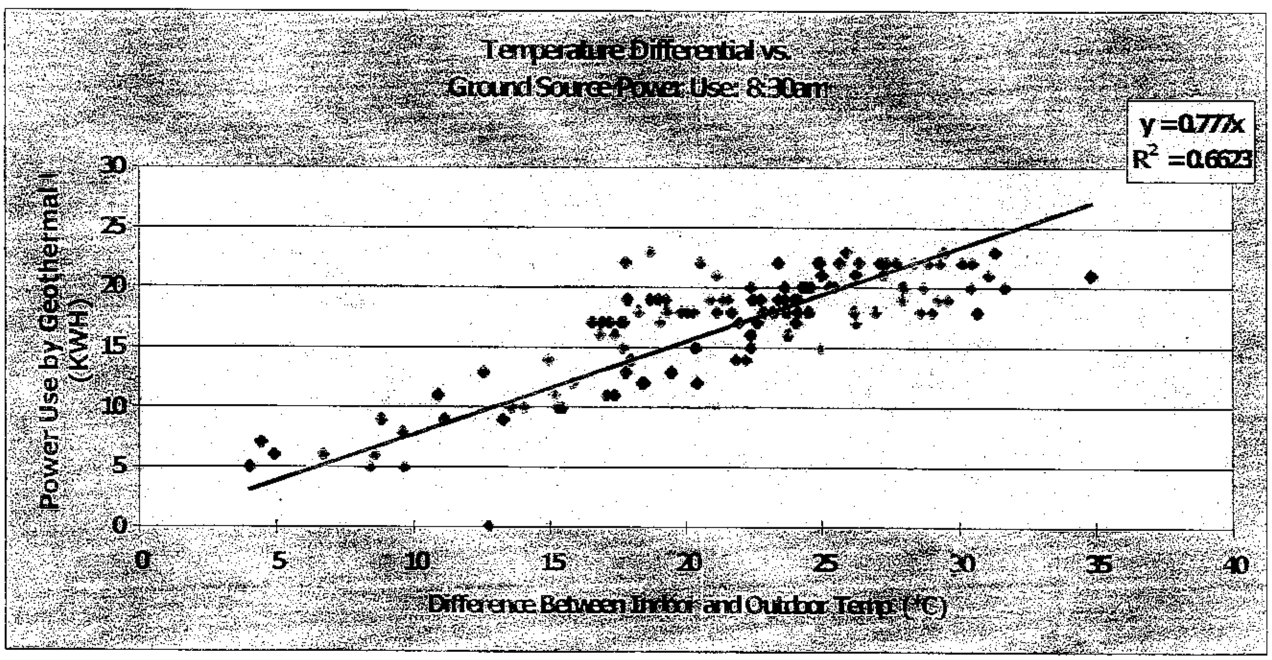
We can theorize that although the temperature dips lowest at 6:30 am, the building retains its thermal mass for a few hours. As the thermal mass decreases by 9:00 am, power use is at its peak. As insolation then begins to increase, power usage gradually declines and although peak insolation occurs at 11:30, it takes a few hours for the thermal mass of the house to reflect this in reduced power usage, which is at its lowest around midnight.

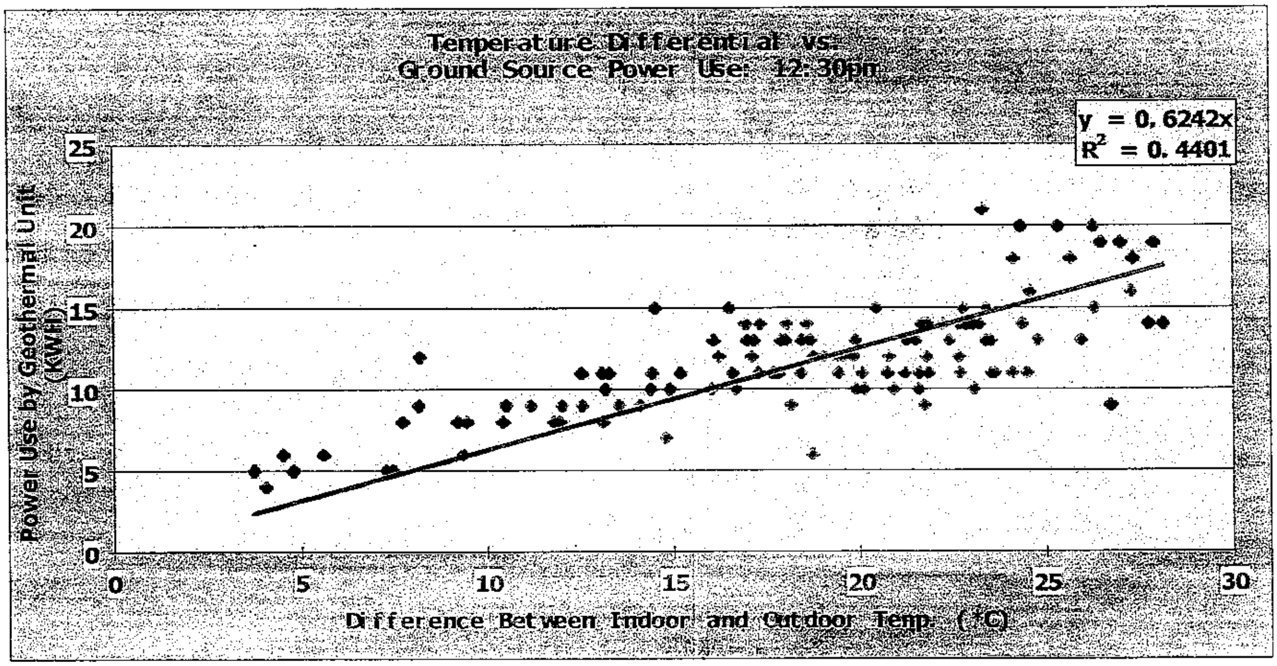
Simple Regressions

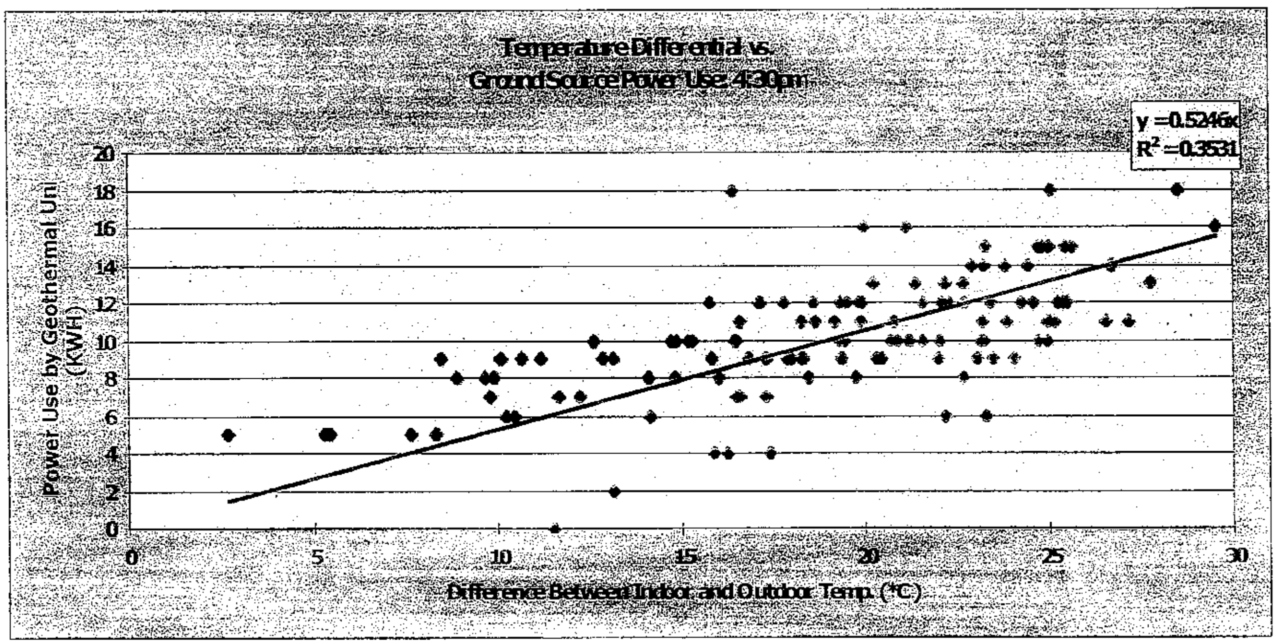
The R-square value is also known as the coefficient of determination, and it measures the percentage of variation in the values of the dependent variable (in this case, the ground source power use) that can be measured by change in the independent variable (here, the difference between indoor and outdoor air temperature).


Temperature Differential vs.
Ground Source Power Use: 6:30am
y = 0.7482x
R^2 = 0.6102
Power Use by Geothermal Unit (KWH)
Difference Between Indoor and Outdoor Temp. (°C)
0
5
10
15
20
25
30
35
40


Temperature Differential vs.
Ground Source Power Use: 7:30am
y = 0.815x
R^2 = 0.5604
Power Use by Geothermal Unit (KWH)
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
Difference Between Indoor and Outdoor Temp. (°C)


Temperature Differential vs.
Ground Source Power Use: 8:30am
y = 0.777x
R^2 = 0.6623
Power Use by Geothermal (KWH)
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
Difference Between Indoor and Outdoor Temp (°C)

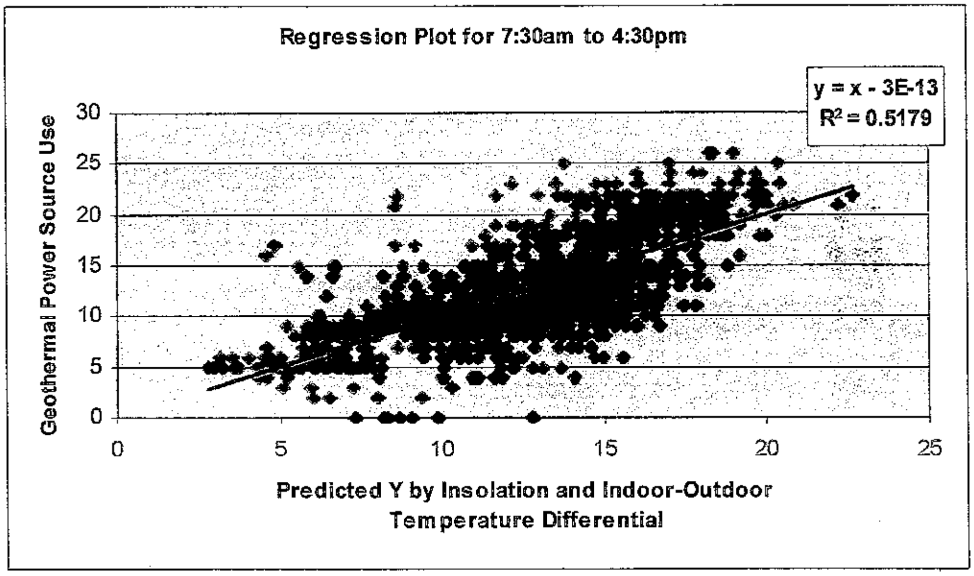

Temperature Differential vs.
Ground Source Power Use: 12:30pm
y = 0.6242x
R^2 = 0.4401
Power Use by Geothermal Unit (KWH)
25
20
15
10
5
0
0
5
10
15
20
25
30
Difference Between Indoor and Outdoor Temp. (°C)


Temperature Differential vs.
Ground Source Power Use: 4:30pm
y = 0.5246x
R^2 = 0.3531
Power Use by Geothermal Uni (KWH)
20
18
16
14
12
10
8
6
4
2
0
0
5
10
15
20
25
30
Difference Between Indoor and Outdoor Temp. (°C)

In the above graphs, we can see that the R squared values and slopes change with the time of day, decreasing as the day proceeds. We can hypothesize that this is due to the thermal heat capacity of the building—it takes a while for the sun to warm the building, but as it does, the geothermal unit uses less power. It is also very likely that while the indoor-outdoor temperature differential over night and first thing in the morning is probably relatively constant, the differential in the day could vary widely depending on weather, atmospheric conditions, etc. Thus, the correlation weakens later in the day. It might occur, for example, that the temperature is very cold, but solar insolation could still be very high.

So, this would appear that there is no immediate temporal correlation between indoor-outdoor temperature differentials and ground source power usage. We do know however that the temperature differential changes over the course of the day, and power usage does as well; thus, any difference in the R-squared values and slope of the above plots is likely due to the different times of day.

Multivariable Regressions



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.719669253
R Square	0.517923834
Adjusted R Square	0.517145664
Standard Error	3.441179485
Observations	1242

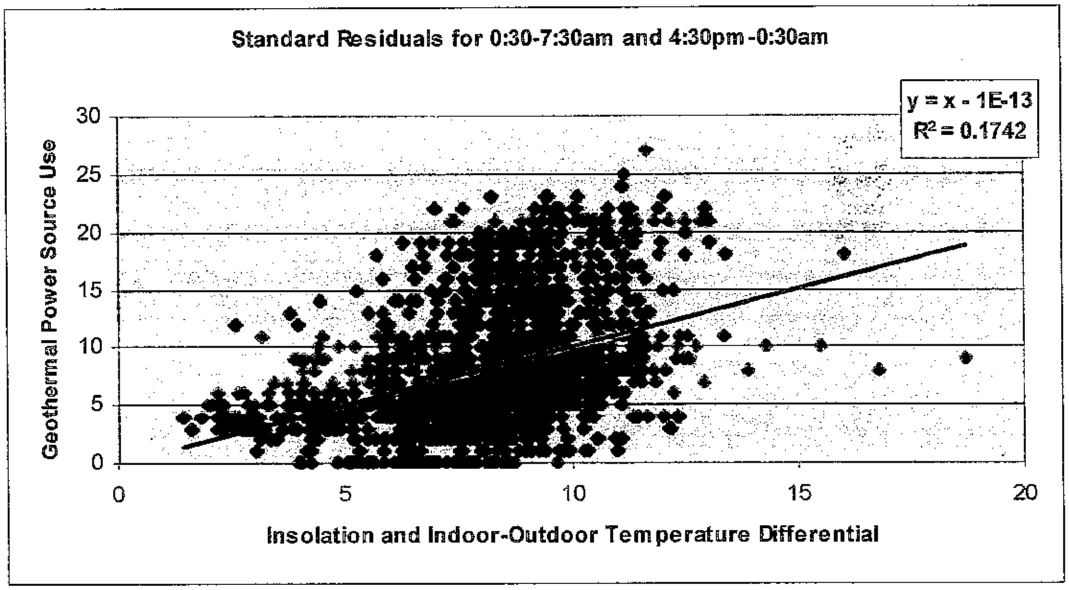
ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	15762.90262	7881.451311	665.566	4.8995E-197
Residual	1239	14671.88643	11.84171625		
Total	1241	30434.78905			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	2.009326449	0.348092665	5.772389519	9.87E
X Variable 1	0.581661667	0.01628502	35.71758971	1.1E-
X Variable 2	-0.00258422	0.00054233	-4.765030662	2.11E

The above graph shows the predicted y for the geothermal power usage for all the data between 7:30am and 4:30pm. The R-square value of 0.52 indicates that 52% of the variation in the power usage of the ground source can be explained by insolation and the indoor-outdoor temperature differential. The Multiple R is the square root of the R-square value.

The shape of this scatter plot indicates that the residual terms are uniformly distributed around the regression line.



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.417429864
R Square	0.174247691
Adjusted R Square	0.17330127
Standard Error	4.697331187
Observations	1748

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	8124.843967	4062.421984	184.1122	2.82779E-73
Residual	1745	38503.2859	22.06492028		
Total	1747	46628.12986			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.253812565	0.43878701	0.578441384	0.563041
X Variable 1	0.364481028	0.019954539	18.26556978	2.41E-
X Variable 2	0.286785179	0.04166827	6.882579506	8.17E-

The above graph shows the standard residuals for all the data between 4:30pm and 7:30 am. The R-square value of 0.17 indicates that only 17% of the variation in the power usage of the ground source can be explained by insolation and the indoor-outdoor temperature differential. The Multiple R is the square root of the R-square value.

So, we can see that the R squared value for the times between 7:30am and 4:30pm is much higher. One of the primary reasons we perform multivariable regressions is because compared to simple regression, multiple independent variables increase the predictive power of our analysis. However, in the case of the times from 4:30pm to 7:30am, one of our independent variables (insolation) essentially has no variation or information to predict y. Thus, the overall predictive power of this regression is greatly reduced, and R squared is lower. The first multivariable regression has a better 'fit' and higher R square, so this one works better.

Discussion

Based on our findings, we can state that solar insolation definitely has an effect on amount of power used by the ground source power unit. The thermal mass of the building also has a significant effect. This can be seen both in the reduction in power use a few hours after the thermal capacity of the building has had time to increase after the sun has come up, and also in the long, gradual increase in power use over the course of the night as the building loses its heat. This is certainly due in large part to the fact that the visitors center is constructed from stone, which has a very long thermal time constant. Thus, the data reveal that although there is not an immediate reaction in power usage, it is nonetheless correlated to the indoor-outdoor temperature differential and the amount of insolation.

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Black Rock Forest Energy Use

1. INTRODUCTION

1.a. The object of study

The study has been conducted in order to examine the relative contributions of solar insolation, thermal mass of the building and the ground source geothermal heating system for heating of the visitors center at Black Rock Forest.

1.b.Background Facts

1.b.a.Heat Transfer

Heat is transferred in three ways as follows;

Conduction: Heat transfers from molecule to molecule without significant movement of the molecules.

Q/t = 1/ R * A * Delta T

Q = heat flow, A = Area,

Convection: Heat transfers by movement of hot material to colder areas, involving molecular movement.

Radiation: Heat transfers by movement of electromagnetic radiation.

Description of Variables

We need to minimize these three types of heat transfer in order to have an energy-efficient building.

1.b.b.Thermal Mass

Heat transfers from warmer to cooler. Thermal mass material conducts and stores energy (heat and cool) and releases that energy back into living space when it is needed.

The basic method of thermal mass in a house can be described as follows;

① Solar heats the ceiling ?
② This warms the air around the ceiling
③ Since mass floor and walls are cooler than the air, they absorb$ and conducts heat.
④ When the sun sets and the inside temperature decreases, it will reach a point where the mass materials are warmer than the inside temperature. Since the heat seeks out cold, the stored energy will now return to the room. The more mass in the home, the more energy is stored.

However, because energy and heat is stored in a solid matter, it is difficult to control the heat transfer unlike a liquid or fluid matter.

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1bd.Ground Source Power Use

In addition to thermal mass, Black Rock Forest is heated and cooled by a ground source geothermal heat pump. Ground source heat pumps heat the building by moving heat from the ground into the building during the winter when air is cooler than ground and they cool the building by moving heat from the building into the ground in the summer.

2. Methods

With the data collected at Black Rock Forest, we calculated or performed;

- The average power use by the ground source geothermal power unit for each hour of the day
- The Delta T for the entire data set
- The mean value of solar insolation, of Delta T, and of the power use of the ground source geothermal unit/divided by Delta T for each hour of the day between 630 am and 1630 pm for March
- The slope and R square values of Delta T versus ground source power use for 630am, 730am, 830am, noon, and 430 pm
- A multivariate fit to the colums with Delta T, ground source power use and solar insolation using all of the data with times between 30am and 430 pm.

3. Results

3.a. Data set <u>1</u>

This shows the average ground power use by each time of a month and the examination of the data as well.

Through the year, the highest peaks of ground power use occur between 6am and 8 am and the lowest peaks occur from 24 pm to 1am.

The highest use and the lowest use of solar power are statistically significantly different for each month.

3.b. Data set <u>2</u> - <u>6</u>

The chart shows the relation of Delta T and the ground power use for the selected times. As a whole, Delta T and power use is positively related, with elevating Delta T and elevating power uses. However, the slope and R square vary for each hour. Both the flattest slope and the

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T stat column shows the ratio between the coefficient and the standard error. If the population coefficient is 0, then this has the t-distribution with degree of freedom 1242-2-1=1239.
The next column, P value is the corresponding p-value. For solar insolation, the t-value is – 4.765, so the probability of a t this large or larger in absolute value is about 9.9E-09. The coefficient is significant at the 5% level because this is less than 0.05. In terms of hypothesis testing, we reject the null hypothesis that the coefficient is 0 at the 5% level and accept the alternative hypothesis. Here, both solar insolation and Delta temperature are significant.
As the regression formula shows, a change in Delta T has a stronger effect to power use than solar radiation. Increase in Delta T by one unit will cause an increase in power use by 0.5871 unit while one unit increase in solar radiation will cause a decrease in power use by 0.00258 unit.

3.f. Data set <u>**11**</u>
Same analysis is adopted as above. R square is 0.173 that is much more lower than the R square of the previous regression. Standard error is 4.696.
The prediction equation is,

Power Use = 0.255 + 0.2796 (solar insolation) + 0.3644 (Delta T)

For both variables, p-value is quite low therefore both are strongly significant.

4.Discussion

There are two heat sources at a visitor center at Black Rock Forest. One is ground source geothermal energy and the other is solar insolation.
The mechanism of ground source geothermal system is as follows;
In summer... the ground is much cooler than the air and the cooler air transfers to warmer place. Eventually the temperature in the air drops.
In winter... the air is cooler than the ground and cooler air transfers to warmer place. Eventually the temperature in the air rises.
Solar insolation is a component of heating system at Black Rock Forest. Basically the components of solar heating systems are solar collector, thermal energy storage, distribution system for heating and active systems such as pumps or fans.(*William Menke*). As shown in the data set 9, solar radiation has a peak around noon and a lowest peak in the early morning. This is easily explained by the movement of the sun. The sun rises to the top around noon and the amount of solar insolation received by the earth comes to an peak as well. Solar insolation is the amount of energy from the sun reaching a given site. The amount of solar insolation

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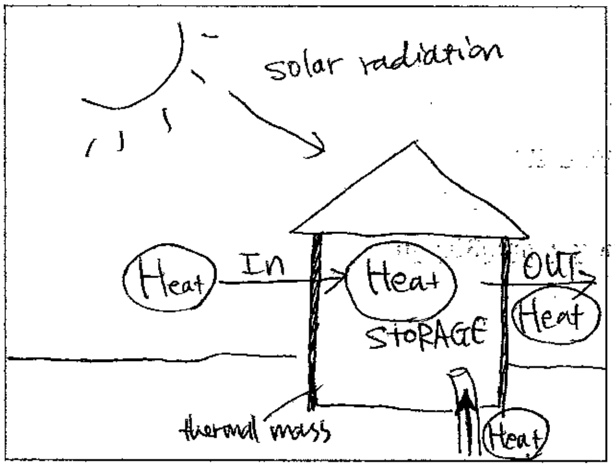
Mayako Hashiba

In summary, Black Rock Forest visitor center has a heat storage mechanism in the picture.



When there is a difference in temperature between the outside and the ground, the ground emits heat or absorbs heat serving as a natural air conditioner to the center. Thermal mass is important for heat storage. It slows heating of the building during the day and keep heat during the night. Rocks and concrete are good sources of thermal mass. (http://www.ldeo.columbia.edu/users/menke/energy3/img38.htm) . Passive solar energy plays a part in heating mechanism. Angle of incidence of solar insolation is important in passive solar design.

AVERAGE Ground_Source_Power_Use by each time of a month

Hour of Day	November	December	January	February	March
100	4.869565217	6.64516129	5.523809524	**3.178571429**	**2.333333333**
200	5.5	7.709677419	5.952380952	4.821428571	2.80952381
300	5.708333333	8.677419355	7.318181818	6.107142857	4
400	6	7.451612903	6.363636364	5.428571429	4.19047619
500	7.833333333	13.74193548	13.36363636	12.67857143	9.619047619
600	**9.875**	18.58064516	16.27272727	18.10714286	15.52380952
700	9.541666667	18.64516129	18.13636364	18	18.19047619
800	9.5	20.38709677	20.5	**20.21428571**	**19.61904762**
900	9.083333333	18.83870968	14.03181818	18.71428571	18.35
1000	8.333333333	16.96774194	16.54545455	15.71428571	12.95
1100	8.333333333	15.19354839	13.59090909	14.14285714	12.57894737
1200	8.541666667	13.77419355	12.04545455	13.42857143	10.63157895
1300	9.125	13.67741935	11.76190476	12.96428571	10.36842105
1400	8.916666667	12.22580645	10.57142857	11.78571429	9.578947368
1500	8.625	11.96774194	8.904761905	10.89285714	8.45
1600	8	11.96774194	9.047619048	10.57142857	8.8
1700	8	11.96774194	10.42857143	10.89285714	8.65
1800	7.333333333	12.80645161	11.14285714	11.42857143	9.05
1900	5.583333333	7.806451613	7.142857143	8.321428571	6.75
2000	5.416666667	6.709677419	5.428571429	6.035714286	5.4
2100	5.041666667	6.483870968	6.19047619	6.214285714	5.35
2200	5.333333333	6.709677419	5.095238095	6.714285714	5.75
2300	5.5	7.516129032	6.238095238	6.428571429	5
2400	**3.375**	4.096774194	[illegible]	4.178571429	4

Difference in power use between peak and least use

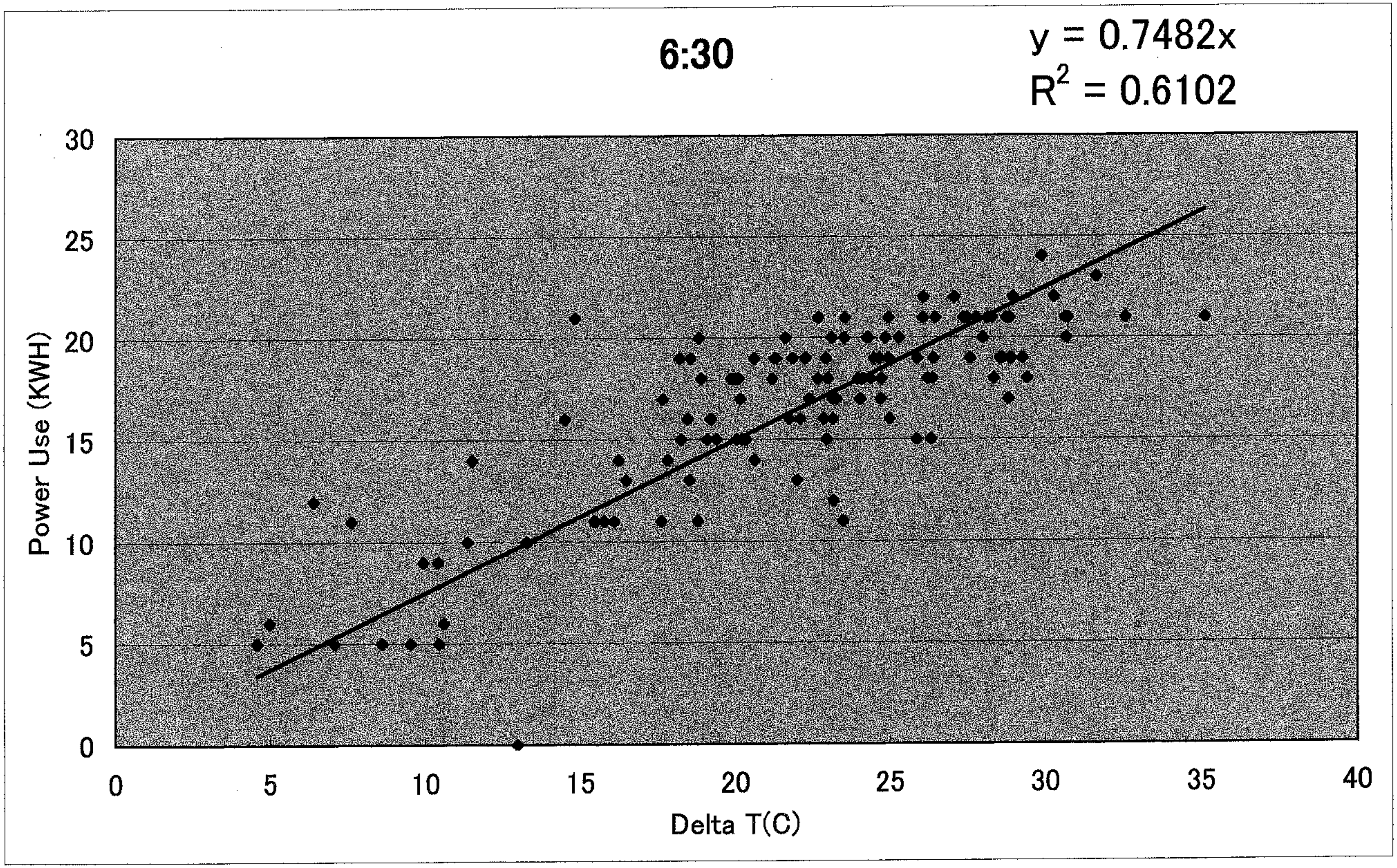
6.5	**16.29032258**	**17.4047619**	**17.03571429**	**17.28571429**

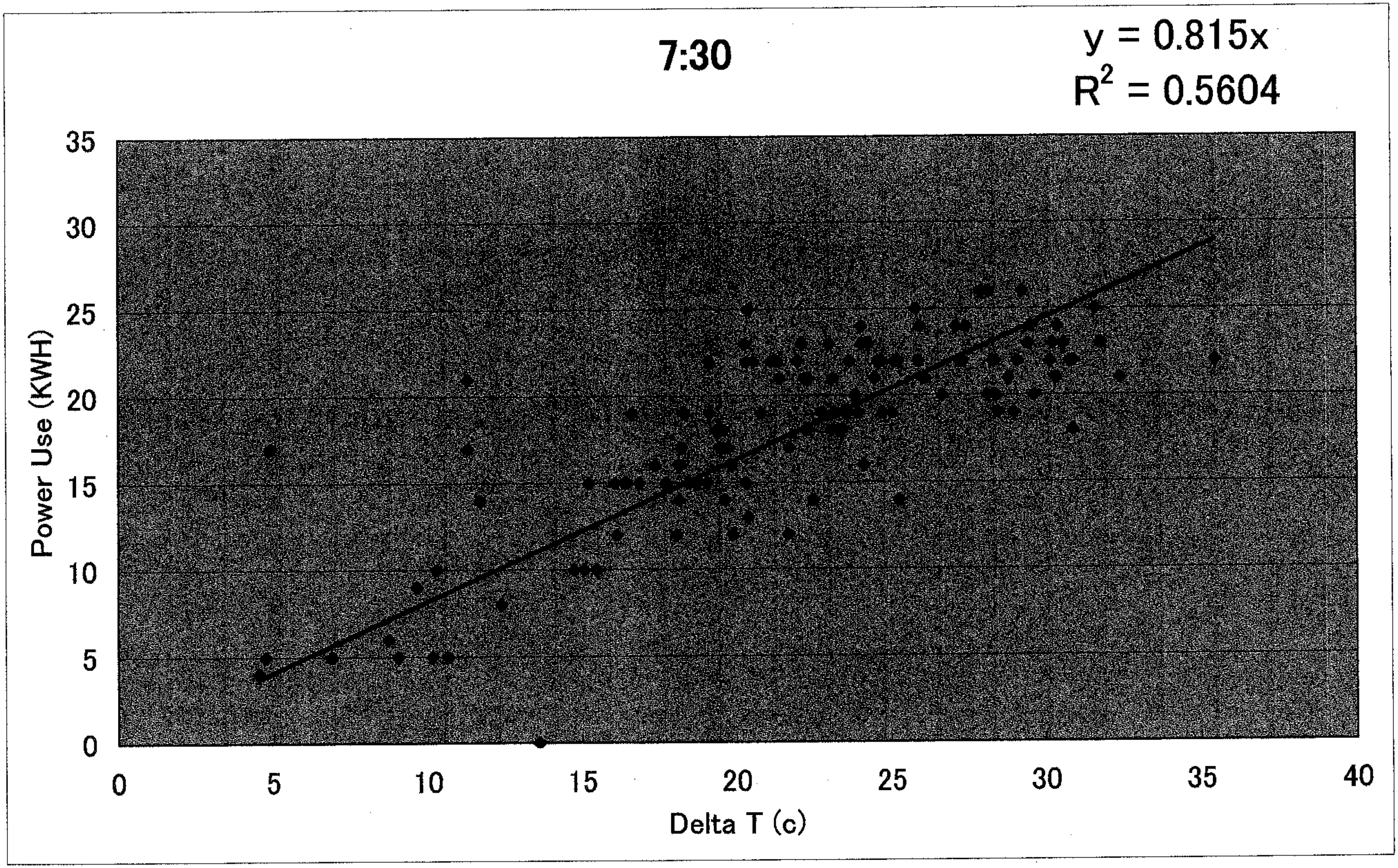
	Highest	Lowest
Nov	9.875	**3.375**
Dec	20.38709677	4.096774194
Jan	20.5	[illegible]
Feb	**20.21428571**	3.178571429
Mar	**2.333333333**	**19.61904762**

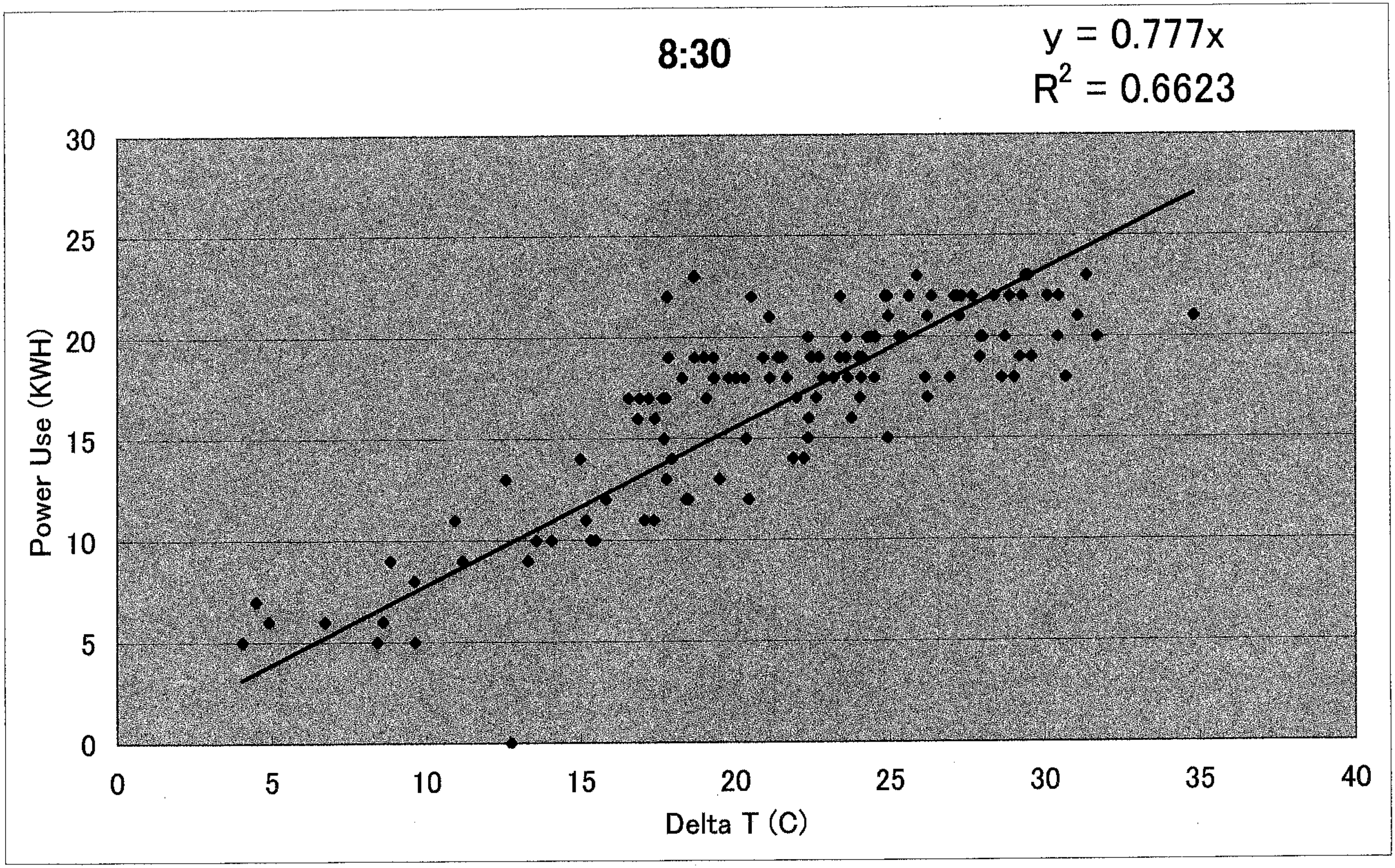
	Nov	Dec	Jan	Feb	**Mar**
Highest	**9.875**	20.38709677	20.5	**20.21428571**	**19.61904762**
time	600	800	800	800	800
SD for Highest	4.376940563	2.906056	2.132515	3.604084	3.308719
# of samples	24	31	22	28	21
Lowest	**3.375**	4.096774194	[illegible]	**3.178571429**	2.333333333
time	2400	2000	2400	100	100

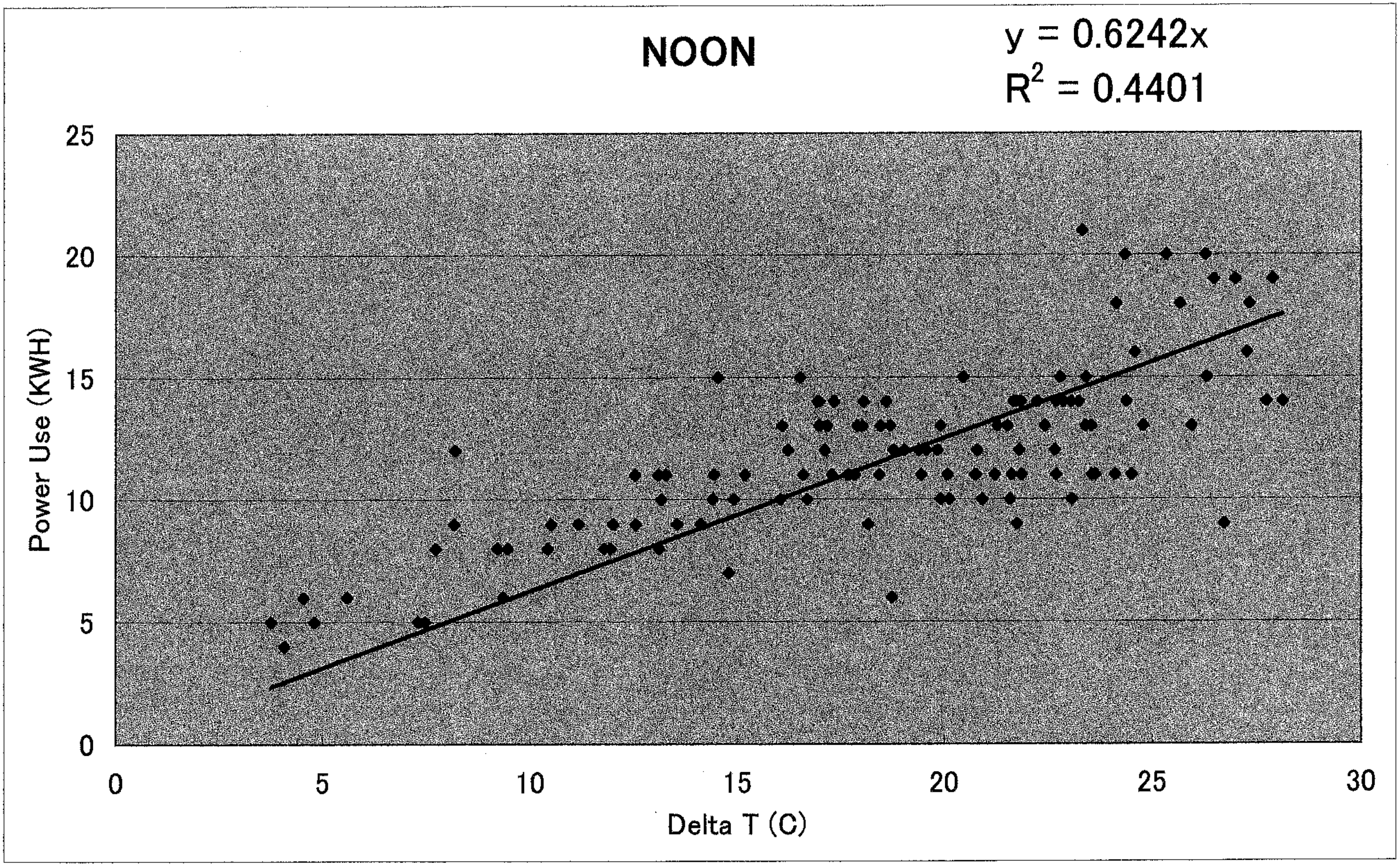
SD for Lowest	2.392242899	2.773143	2.119074371	4.09203	3.087609647
# of samples	24	31	21	28	21
Ttest for High	0.303135701	1.006803829	1.740061714	0.893277567	1.140033984
Ttest for Low	-0.55462886	-1.05505858	-1.79230634	-0.78676046	-1.22167389
Ptest for High	0.76451138	0.322081099	0.096484476	0.379601813	0.267741554
Ptest for Low	#NUM!				

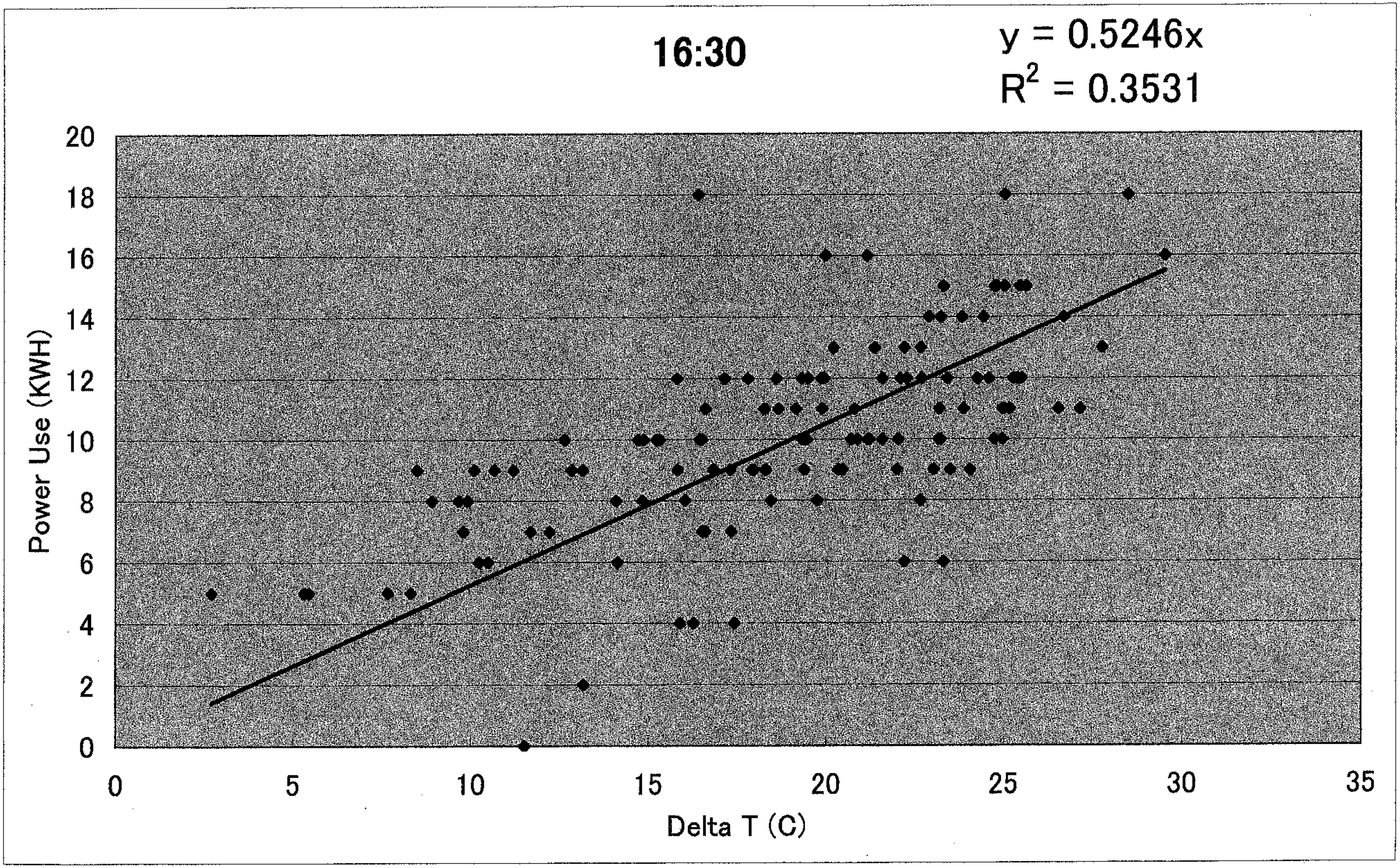
1 Cf

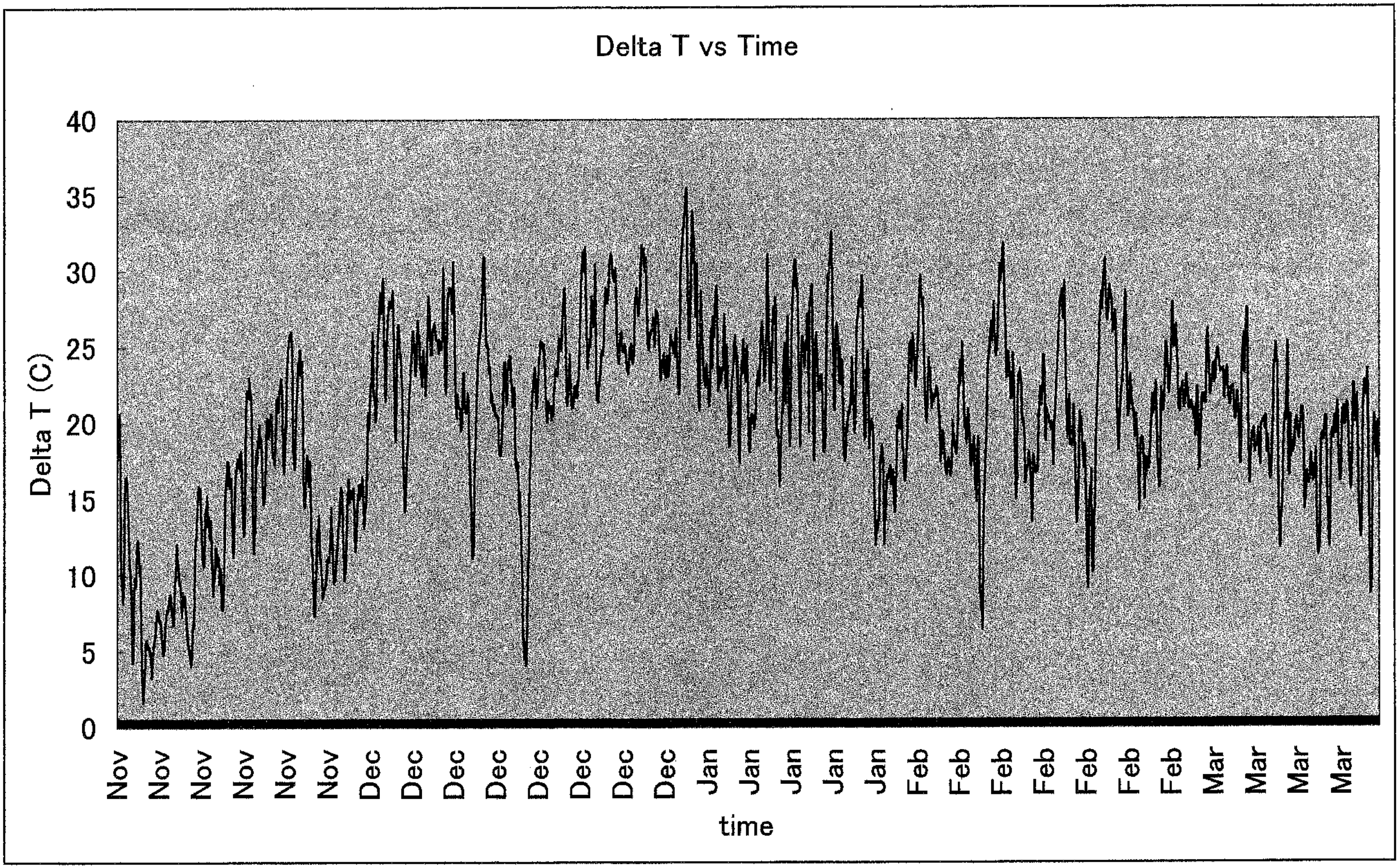

6:30
y = 0.7482x
R2 = 0.6102
Power Use (KWH)
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
Delta T(C)


7:30
y = 0.815x
R2 = 0.5604
Power Use (KWH)
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
Delta T (c)

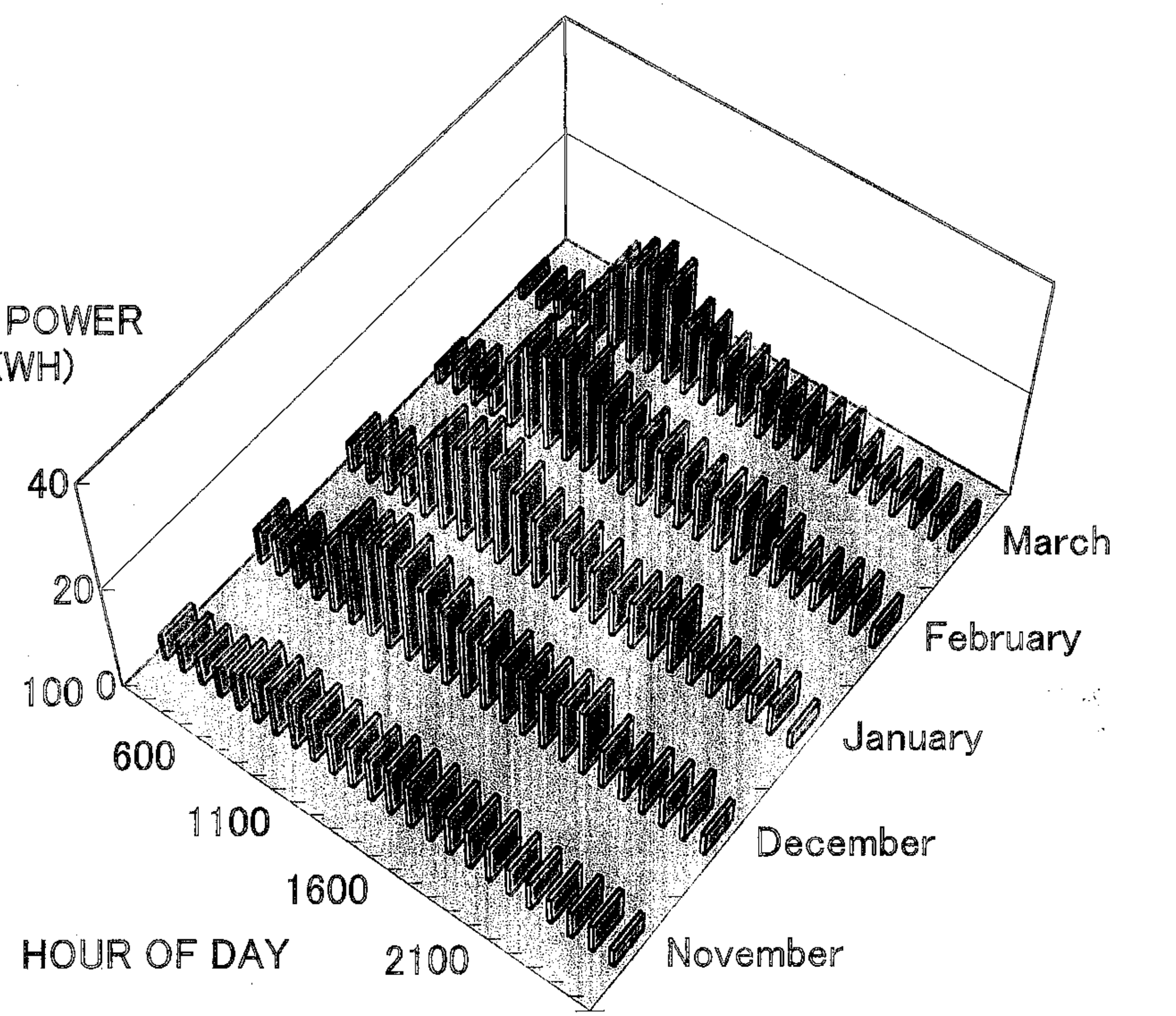

8:30
y = 0.777x
R2 = 0.6623
Power Use (KWH)
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
Delta T (C)


NOON
y = 0.6242x
R2 = 0.4401
Power Use (KWH)
Delta T (C)
0
5
10
15
20
25
30


16:30
y = 0.5246x
R2 = 0.3531
Power Use (KWH)
Delta T (C)
0
2
4
6
8
10
12
14
16
18
20
0
5
10
15
20
25
30
35


Delta T vs Time
Delta T (C)
0
5
10
15
20
25
30
35
40
Nov
Nov
Nov
Nov
Nov
Nov
Dec
Dec
Dec
Dec
Dec
Dec
Dec
Dec
Jan
Jan
Jan
Jan
Jan
Feb
Feb
Feb
Feb
Feb
Feb
Feb
Mar
Mar
Mar
Mar
time

AVERAGE GROUND SOURCE POWER USE BY EACH TIME OF MONTH



Average Values for 630 am - 1630 pm in March

	Power Use KWH	Solar Radiation W/m2	Delta T C	Delta T/Energy Use C/KWH	
630	18.19047619	**9.322761905**	**21.8147**	1.22617854	**630**
730	**19.61904762**	55.45061905	21.4837	**1.109720702**	**730**
830	18.35	187.9541	20.5232	1.138935221	**830**
930	12.95	294.1395	19.6028	1.622623258	**930**
1030	12.57894737	402.3252632	18.9505	1.544735897	**1030**
1130	10.63157895	**460.0568421**	18.0946	1.724796799	**1130**
1230	10.36842105	450.9521053	17.3507	1.747553042	**1230**
1330	9.578947368	393.2747368	**16.8616**	1.874381444	**1330**
1430	**8.45**	293.4325	16.8708	2.255770527	**1430**
1530	8.8	170.08065	17.2227	2.354649497	**1530**
1630	8.65	73.2173	17.684	2.47015017	**1630**

730-1630

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.71966925
R Square	0.51792383
Adjusted R Square	0.51714566
Standard Error	3.44117948
Observations	1242

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	15762.90262	7881.451311	665.566641	4.8995E-197
Residual	1239	14671.88643	11.84171625		
Total	1241	30434.78905			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.00932645	0.348092665	5.772389519	9.8681E-09	1.326410372	2.692242527
X Variable 1	-0.00258422	0.00054233	-4.765030662	2.1114E-06	-0.00364821	-0.001520234
X Variable 2	0.58166167	0.01628502	35.71758971	1.132E-192	0.54971241	0.613610925

1730-0630

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.416311354
R Square	0.173315144
Adjusted R Square	0.172367111
Standard Error	4.696392988
Observations	1747

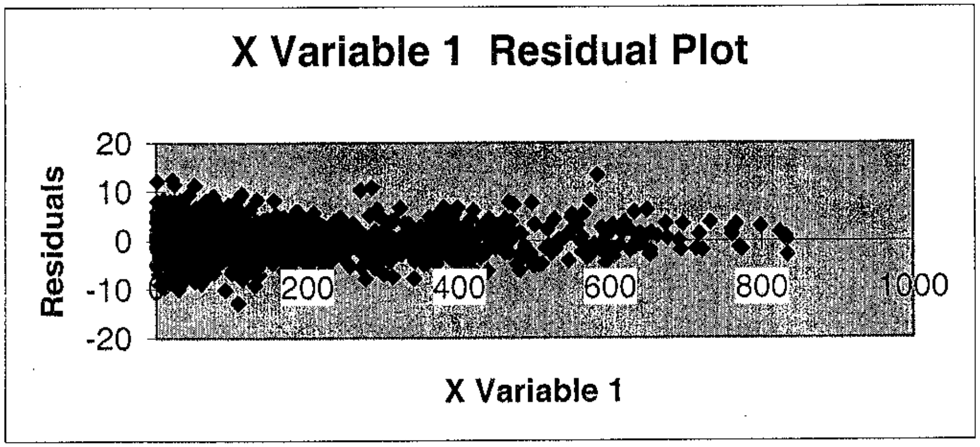
ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	8064.396497	4032.198249	182.8155	8.32653E-73
Residual	1744	38465.85078	22.0561071		
Total	1746	46530.24728			

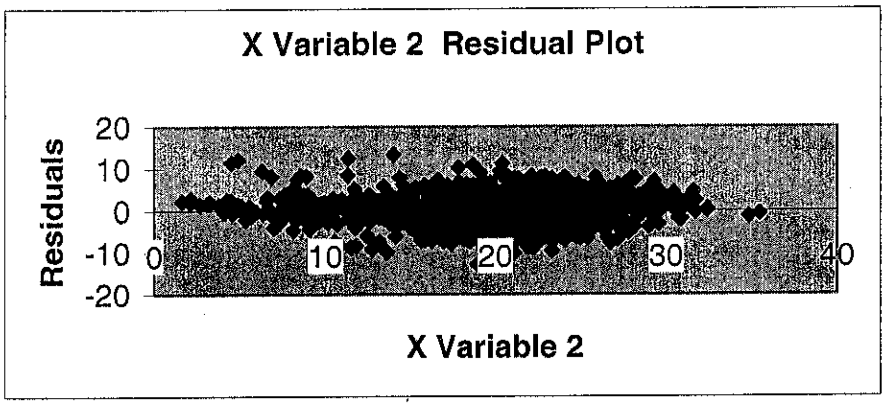
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.255108011	0.438700497	0.58150837	0.560973028	-0.60532638	1.115542407
X Variable 1	0.279642139	0.042019199	6.655104003	3.77943E-11	0.19722882	0.362055458
X Variable 2	0.364413519	0.019950621	18.26577325	2.42365E-68	0.325283861	0.403543177

730-1630

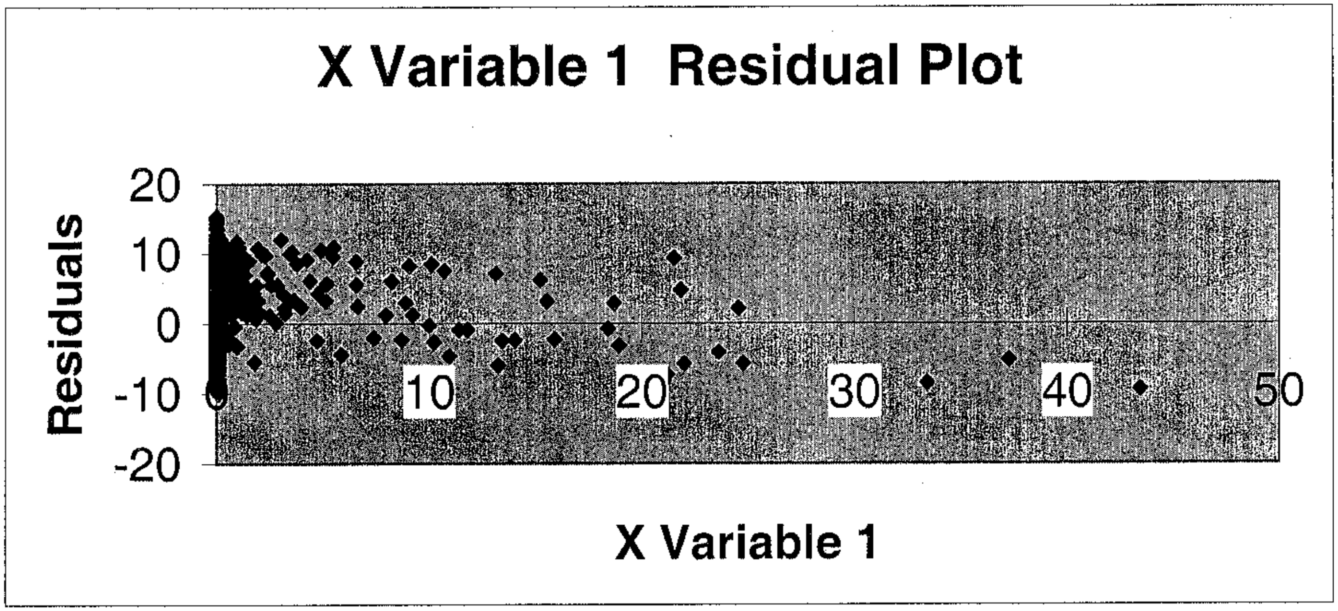
12-I



12-II



12


X Variable 1 Residual Plot
Residuals
20
10
0
-10
-20
0
10
20
30
40
50
X Variable 1

A-

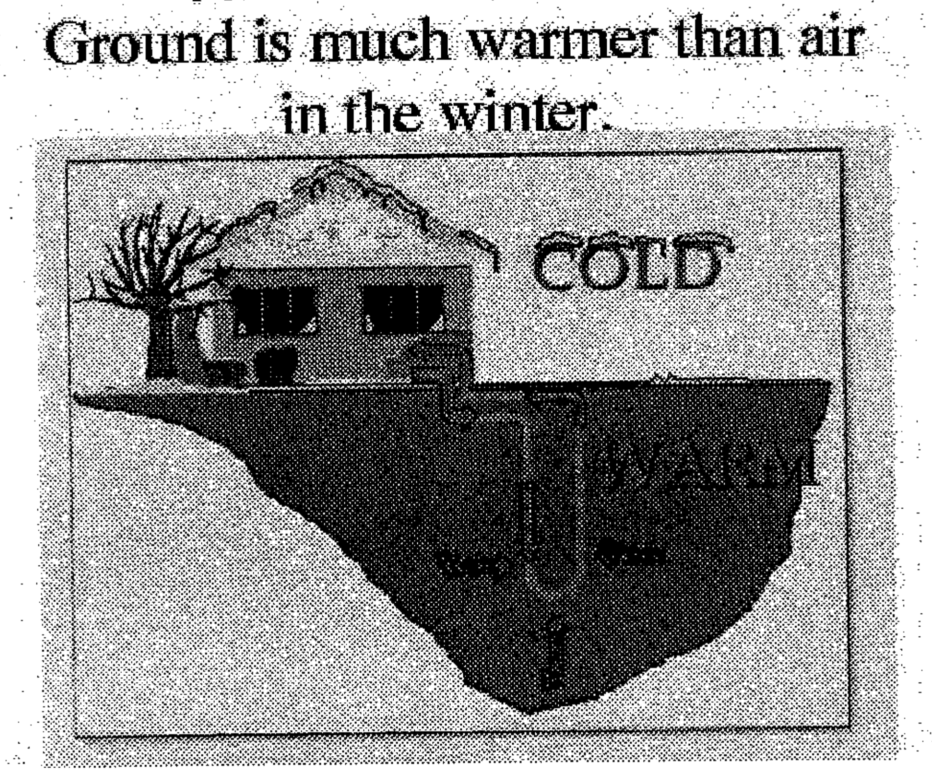
Ground Source Energy System at Black Rock Forest Visitor Center
Ravi Corea – Environmental Data Analysis – December 05, 2001

Introduction:

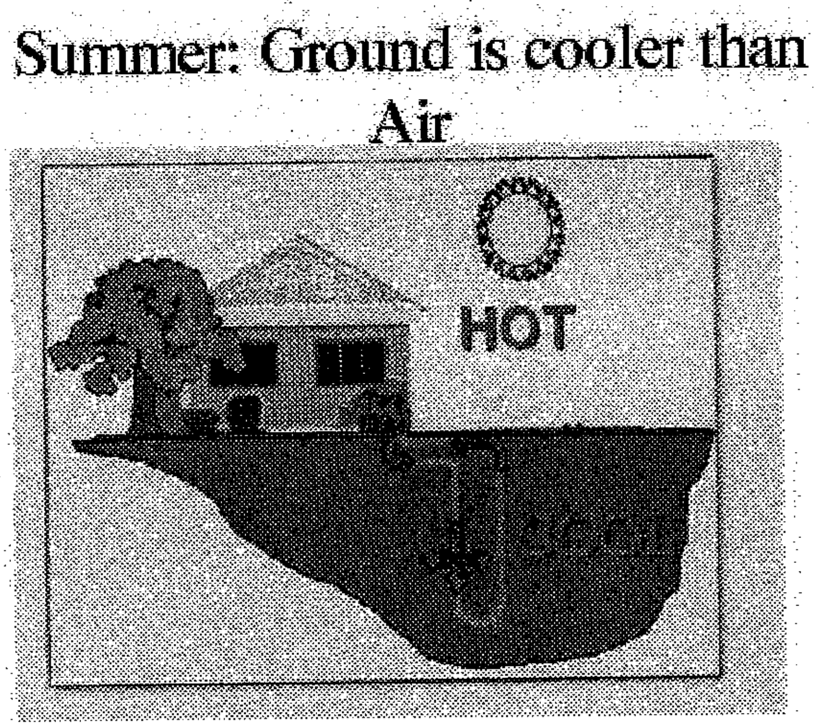
Heat is transferred in three ways. Conduction is the transfer of heat from molecule to molecule without significant movement of the molecules. This is a major method of heat transfer in solids especially of metals. Convection is the transfer of heat by movement of hot material to colder areas. This involves molecular movement and is the major method of heat transfer in liquids. Radiation is the transfer of heat by the movement of electromagnetic radiation. This is only way heat is transferred in a vacuum. The energy efficient building design tends to minimize all three methods of heat transfer.

The Black Rock Center For Science Education

The Black Rock Center For Science Education combines modern day technology with environmental ideology. Careful planning has allowed for the construction of a building that addresses the needs of researchers and educators, and at the same time not compromising the environmental ethic that is the foundation of Black Rock Forest's development. The center utilizes self-composting toilets, solar radiation, and geothermal heating and cooling systems. Much of the material that has been used in the construction of the center was harvested from the forest. The labs and lecture areas are connected to a network of computers and have access to the Internet. This network ensures that data gathered in the forest can be accessed at any of the established computer terminals. Students can observe and monitor environmental changes in both the forest and the center. The center provides opportunities to learn, teach, and conduct research using the most modern equipment in a building that conveys an environmental conscience (See below).



The concept behind the Geothermal Power unit is that during winter the ground is much warmer than the upper environment and this can be an energy efficient source of heat (see above figure). And during the summer the ground is much cooler than the outside temperature and similarly can be a source of cool air (see below).



2. There is a considerable difference in power use between time of day and peak or least power use. See table below for all of the months.

	November		December		January		February		March	
	600	9.875	800	20.387097	800	20.5	800	20.2142857	800	[illegible]
	2400	3.375	2400	4.0967742	2400	3.0952381	100	3.17857143	100	[illegible]
Difference		6.5		16.290323		17.404762		17.0357143		17.285714

A T-test for statistical significance of the difference in peak power use and lowest power use was done (see table below).

	November		December		January		February		March
T of High	**0.3031357**	T of High	**1.0068038**	T of High	**1.7400619**	T of High	**0.89327769**	T of High	**1.1400341**
T of Low	**-0.5546289**	T of Low	**-1.0550585**	T of Low	**-1.7923063**	T of Low	**-0.78676047**	T of Low	**-1.221673**

needs the p-value

3. When for March the mean value of solar radiation, of delta T, and the power use of ground source geothermal unit/divided by delta T is calculated for each hour of the day between 630 A.M. and 1630 P.M., the following was observed. Whenever their was a great difference between the inside temperature and the outside temperature, the ratio of power use to delta T is small. Some of these differences for the same time period each day have delta T's greater than observed for the highest and lowest use time period for the entire month.

The reason there are time lags between different variables in the data set in terms of thermal mass in passive solar buildings and thermal time constants of these buildings is because of the ability of these buildings to absorb heat much faster ~~and~~ than their ability to cool very slowly during the winter.

4. The Delta T vs. Ground Source power use graphs that were fitted with a line the following was observed. The three early morning hours of 630 AM, 730 AM and 830 AM had had very similar slopes (see graphs). The R^2 values were high for the 630 AM & 730 AM graphs telling that there was a correlation between Ground Source Power use and Delta T. From 830 AM to 430 PM the slopes diverge considerably and the R^2 values are very small showing a decreasing correlation between delta T and Ground Source Power Use. This reflects the fact that by this time the sun is up and the building is also absorbing heat from solar radiation.

5. I could not perform this exercise because I do not have the data analysis function and capabilities.

6. In summation it can said that the Visitor Center at Black Rock Forest Research Station is behaving in the manner that is expected from a building that was solely constructed to conserve the use of energy. Though the initial costs are high to install such environmentally friendly green technology to conserve energy, it is claimed that the breakeven time for the incurred cost in saved money from efficient energy utilization is ten years. This is a long time at present to be attractive to a mass consumer market considering the present attitude is that the cost incurred to change over to such a radical technology should pay back within 3 years from saved costs.

Ravi Corea - EDA - Black Rock Forest Lab - December 05, 2001

Averaged Hourly Ground Source Power Use for Each Month

Hour of Day	November	December	January	February	March
100	4.869565217	[redacted]	[redacted]	[redacted]	[redacted]
200	5.5	[redacted]	[redacted]	[redacted]	[redacted]
300	5.708333333	[redacted]	[redacted]	[redacted]	[redacted]
400	6	[redacted]	[redacted]	[redacted]	[redacted]
500	7.833333333	[redacted]	[redacted]	[redacted]	[redacted]
600	9.875	[redacted]	[redacted]	[redacted]	[redacted]
700	9.541666667	[redacted]	[redacted]	[redacted]	[redacted]
800	9.5	[redacted]	[redacted]	[redacted]	[redacted]
900	9.083333333	[redacted]	[redacted]	[redacted]	[redacted]
1000	8.333333333	[redacted]	[redacted]	[redacted]	[redacted]
1100	8.333333333	[redacted]	[redacted]	[redacted]	[redacted]
1200	8.541666667	[redacted]	[redacted]	[redacted]	[redacted]
1300	9.125	[redacted]	[redacted]	[redacted]	[redacted]
1400	8.916666667	[redacted]	[redacted]	[redacted]	[redacted]
1500	8.625	[redacted]	[redacted]	[redacted]	[redacted]
1600	8	[redacted]	[redacted]	[redacted]	[redacted]
1700	8	[redacted]	[redacted]	[redacted]	[redacted]
1800	7.333333333	[redacted]	[redacted]	[redacted]	[redacted]
1900	5.583333333	[redacted]	[redacted]	[redacted]	[redacted]
2000	5.416666667	[redacted]	[redacted]	[redacted]	[redacted]
2100	5.041666667	[redacted]	[redacted]	[redacted]	[redacted]
2200	5.333333333	[redacted]	[redacted]	[redacted]	[redacted]
2300	5.5	[redacted]	[redacted]	[redacted]	[redacted]
2400	3.375	[redacted]	[redacted]	[redacted]	[redacted]

Ravi Corea - EDA - Black Rock Forest Lab - December 05, 2001

Difference in Least & Peak Power Use

	November		**December**		**January**		**February**		**March**
600	**9.875**	800	[redacted]	800	[redacted]	800	[redacted]	800	[redacted]
2400	**3.375**	2400		2400		100		100	
Difference	6.5		16.29032258		17.40476		17.0357143		17.2857143
STDEV 600	**4.376940563**	STDEV 800	**2.906055968**	STDEV 800	**2.132515**	STDEV 800	**3.60408352**	STDEV 800	**3.30871864**
STDEV 2400	**2.392242899**	STDEV 2400	**2.773143087**	STDEV 2400	**2.119074**	STDEV 100	**4.09202994**	STDEV 100	**3.08760965**
N	24	N	31	N	22	N	28	N	21
				N (2400)	21				
T of High	**0.303135701**	T of High	**1.00680384**	T of High	**1.740062**	T of High	**0.89327769**	T of High	**1.14003411**
T of Low	**-0.554628857**	T of Low	**-1.055058544**	T of Low	**-1.79231**	T of Low	**-0.78676047**	T of Low	**-1.22167389**
P of High	**0.76451138**	P of High	**0.322081094**	P of High	**0.044931**	P of High	**0.37960175**	P of High	**0.2677415**
P of Low	**#NUM!**	P of Low	**#NUM!**	P of Low		P of Low		P of Low	

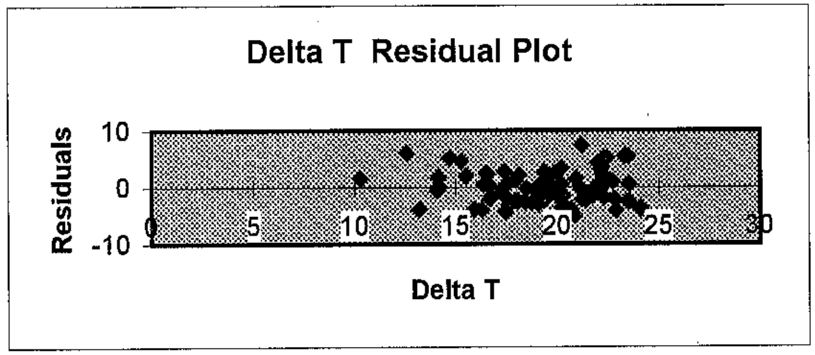
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.422959
R Square	0.178894
Adjusted	0.157567
Standard	2.894906
Observati	80

ANOVA

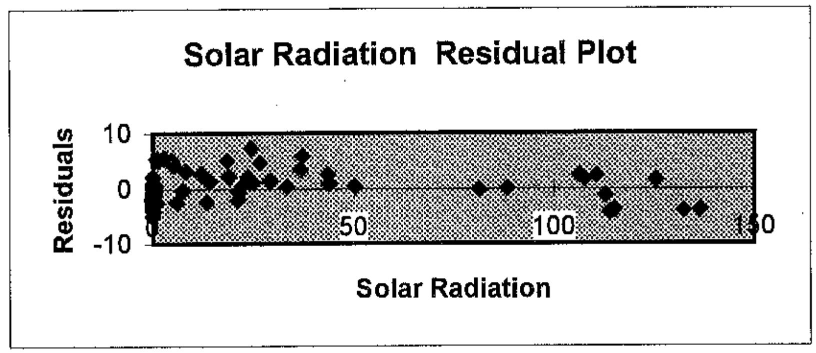
	df	SS	MS	F	Significance F
Regressio	2	140.5906	70.2953	8.387981	0.000506255
Residual	77	645.2969	8.380479		
Total	79	785.8875			

	Coefficient	andard Err	t Stat	P-value	Lower 95%	pper 95%	ower 95.0	Upper 95.0%
Intercept	-3.83162	2.829423	-1.3542	0.179632	-9.465723259	1.802493	-9.46572	1.802492502
Delta T	0.566134	0.139342	4.062898	0.000116	0.28866755	0.843601	0.288668	0.843600667
Solar Radi	0.019626	0.010354	1.895529	0.061775	-0.000991132	0.040242	-0.00099	0.040242355

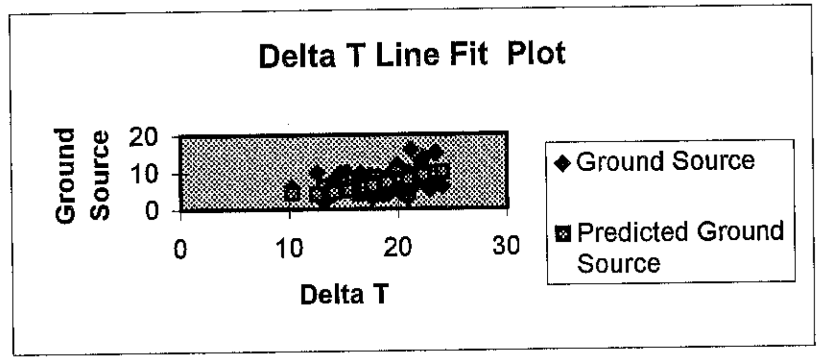


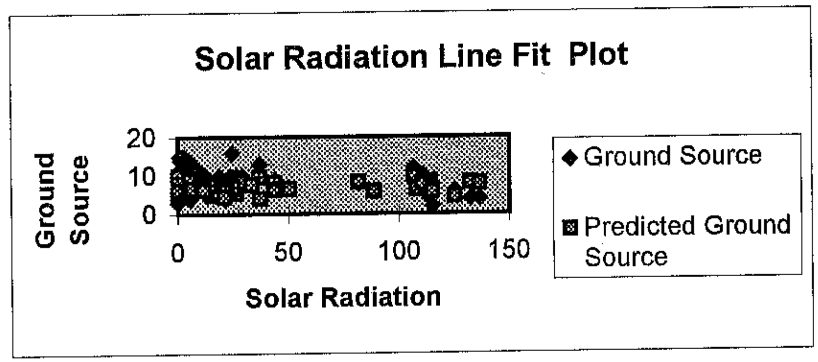
RESIDUAL OUTPUT

bservatio	d Ground	Residuals	dard Residuals
1	8.63209	7.36791	2.577971
2	8.572108	1.427892	0.499608
3	8.00707	0.99293	0.347418
4	8.840335	3.159665	1.105541
5	9.426336	5.573664	1.950179
6	9.471217	3.528783	1.234692
7	8.265798	-4.2658	-1.49257
8	8.210518	-0.21052	-0.07366
9	9.499973	2.500027	0.874739
10	8.196088	-1.19609	-0.4185
11	6.263724	1.736276	0.607509
12	7.681888	2.318112	0.811088

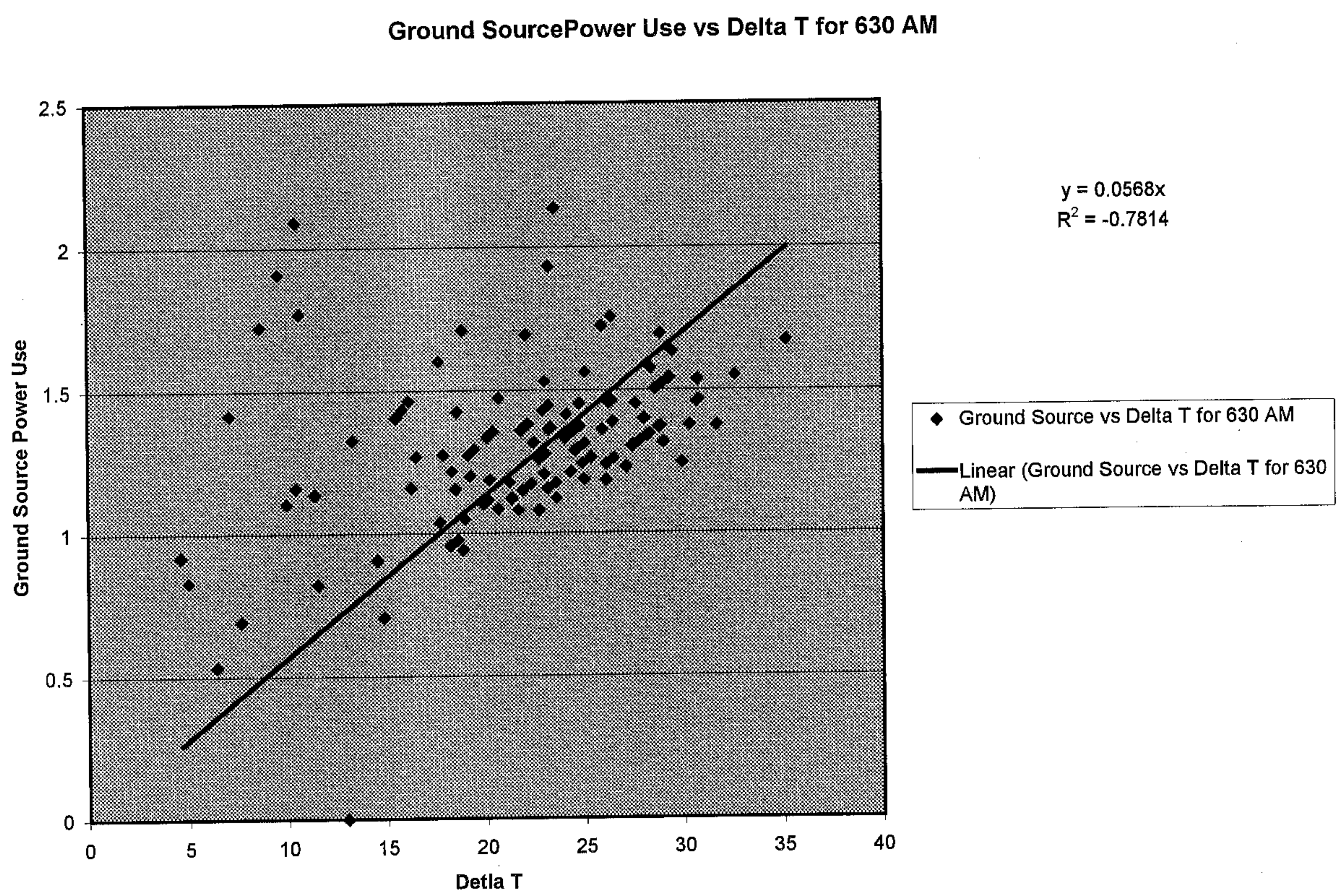


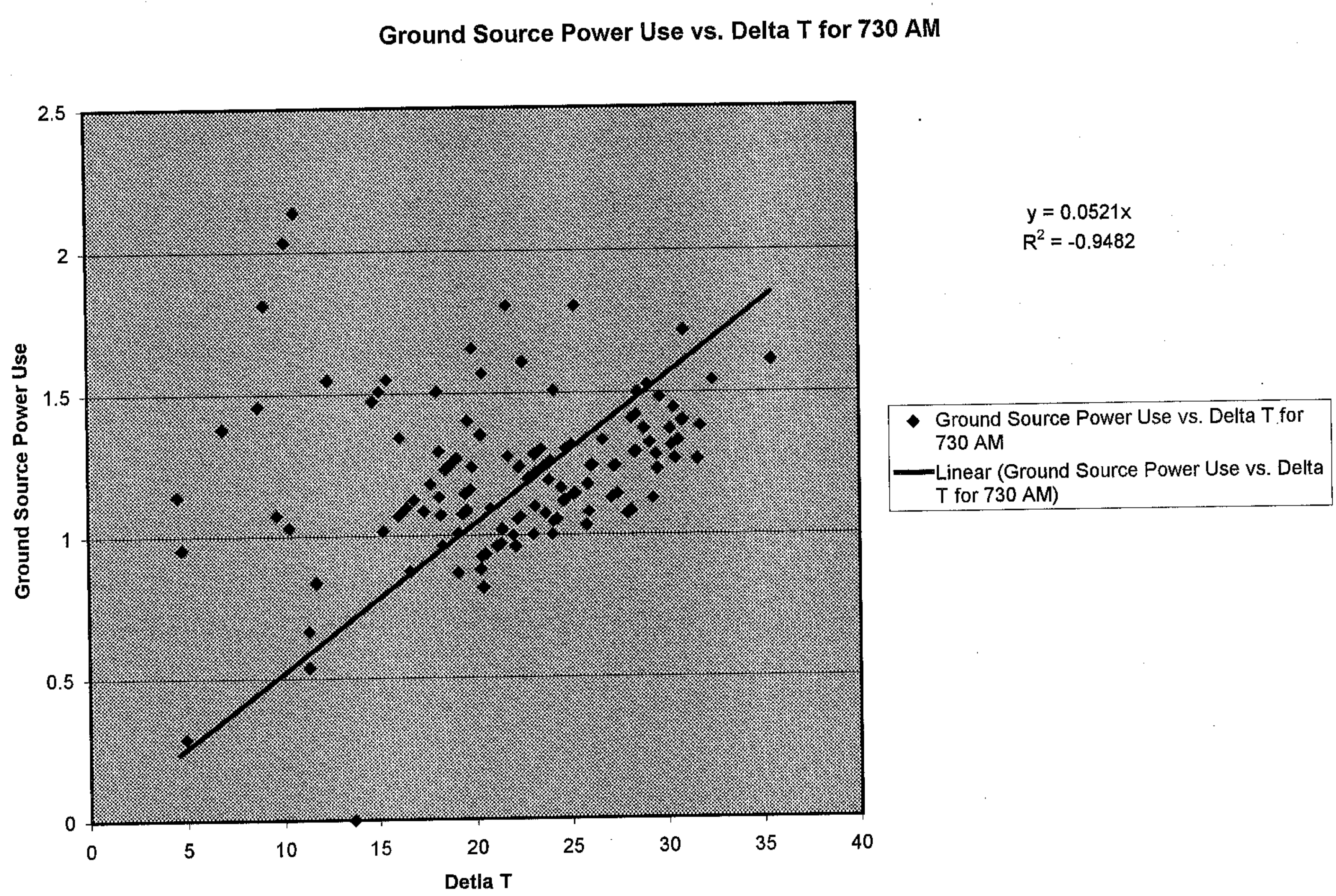
13	7.357266	2.642734	0.924671
14	7.973024	-3.97302	-1.39013
15	5.909293	0.090707	0.031738
16	5.315849	4.684151	1.638946
17	6.554202	0.445798	0.155981
18	7.840623	-3.84062	-1.3438
19	5.88894	-3.88894	-1.36071
20	4.430348	1.569652	0.549208
21	8.708745	4.291255	1.501475
22	8.286978	-0.28698	-0.10041
23	7.74224	3.25776	1.139863
24	8.894315	5.105685	1.786437
25	9.49407	5.50593	1.92648
26	8.874079	5.125921	1.793518
27	7.354986	-2.35499	-0.82399
28	7.621756	0.378244	0.132345
29	7.89555	2.10445	0.73633
30	6.794828	2.205172	0.771572
31	4.826561	5.173439	1.810144
32	6.801333	1.198667	0.419404
33	7.649224	1.350776	0.472625
34	6.351008	2.648992	0.926861
35	6.50277	0.49723	0.173977
36	6.25107	2.74893	0.961828
37	6.496408	-2.49641	-0.87347
38	6.01554	-2.01554	-0.70522
39	4.532185	-0.53219	-0.18621
40	3.992707	6.007293	2.101903
41	8.746186	2.253814	0.788591
42	8.263274	-1.26327	-0.44201
43	8.288203	-2.2882	-0.80062
44	9.020761	0.979239	0.342628
45	9.478783	0.521217	0.182369
46	8.753546	0.246454	0.086232
47	9.141049	-4.14105	-1.44892
48	7.091189	-1.09119	-0.3818
49	7.481429	-1.48143	-0.51834



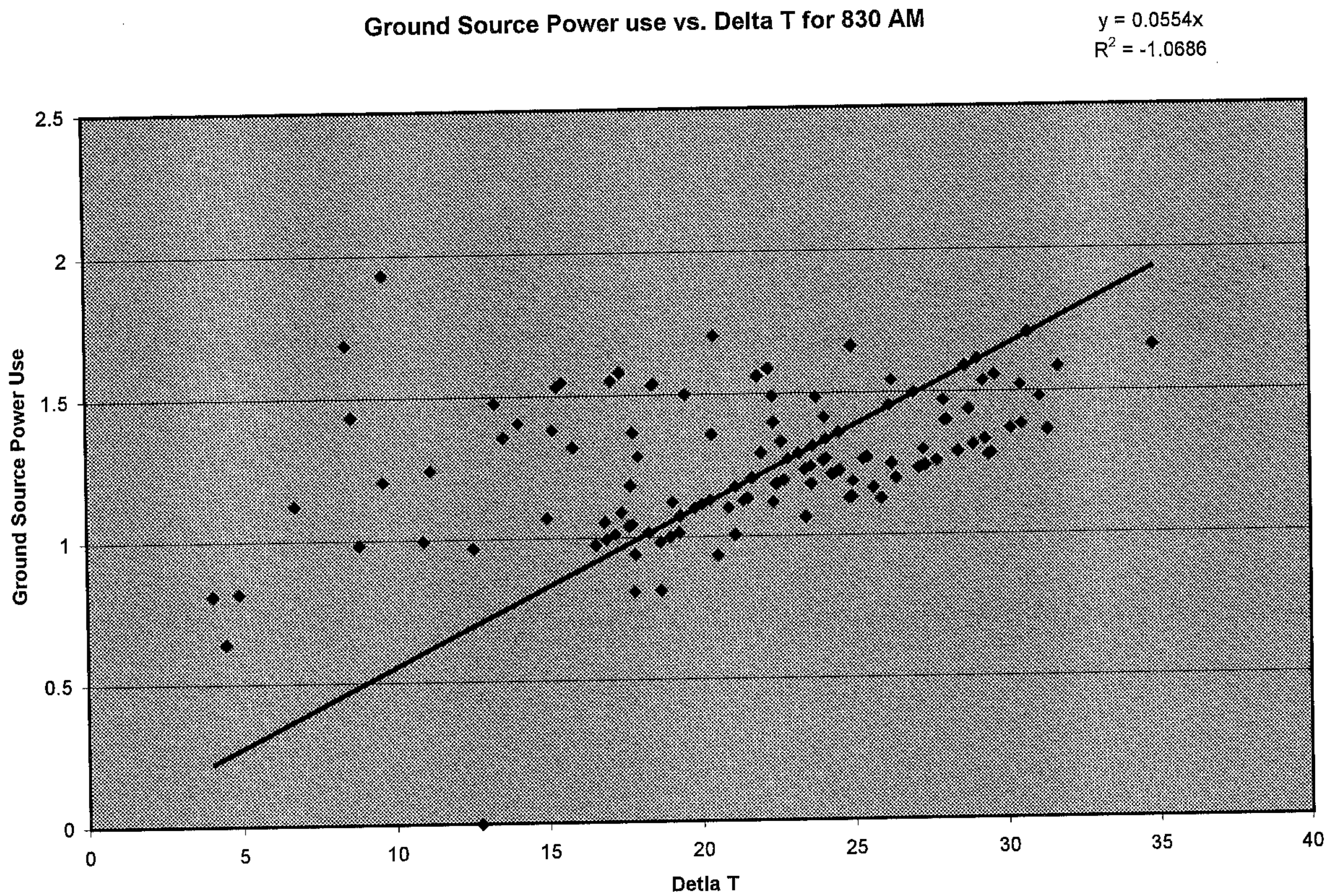


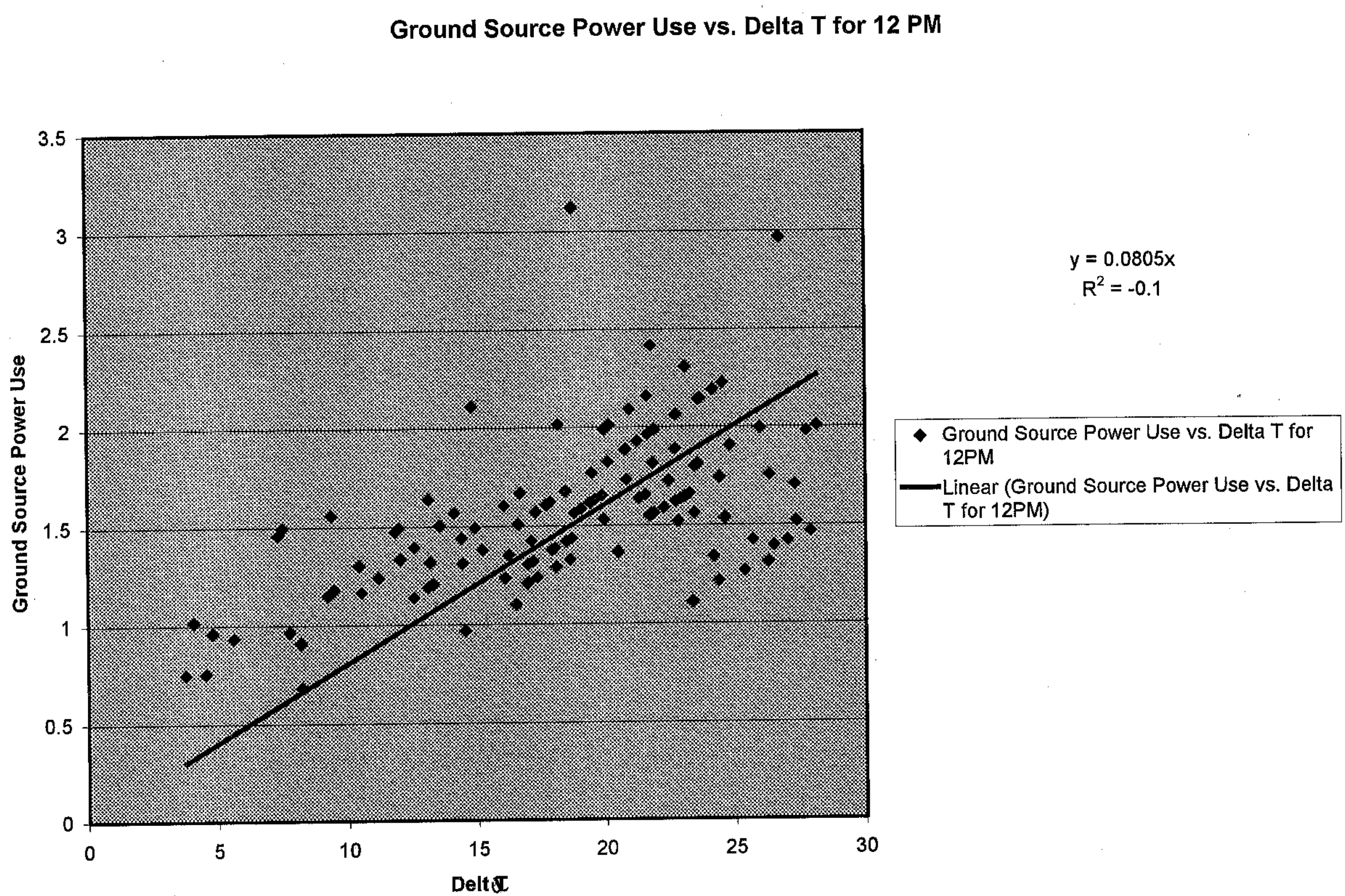
50	7.286722	-0.28672	-0.10032
51	4.934299	2.065701	0.722772
52	7.60156	0.39844	0.139411
53	7.510747	-0.51075	-0.17871
54	6.335762	-2.33576	-0.81726
55	6.756131	-2.75613	-0.96435
56	6.976291	-0.97629	-0.3416
57	7.223559	0.776441	0.27167
58	6.384741	-2.38474	-0.8344
59	6.599544	-2.59954	-0.90956
60	5.442727	0.557273	0.194985
61	8.606917	0.393083	0.137536
62	8.173258	-2.17326	-0.76041
63	8.454627	-1.45463	-0.50896
64	9.07511	-2.07511	-0.72606
65	9.470838	-2.47084	-0.86453
66	8.786948	-1.78695	-0.62524
67	9.797497	-3.7975	-1.32871
68	7.106681	-2.10668	-0.73711
69	7.52277	-0.52277	-0.18291
70	7.863017	-3.86302	-1.35164
71	5.636431	-1.63643	-0.57257
72	7.759414	-3.75941	-1.31539
73	7.60486	-3.60486	-1.26131
74	5.748506	-0.74851	-0.2619
75	6.932996	-2.933	-1.02623
76	7.089112	-2.08911	-0.73096
77	7.642791	-1.64279	-0.5748
78	6.889325	-1.88933	-0.66106
79	7.980989	-4.98099	-1.74281
80	6.118368	-3.11837	-1.09109

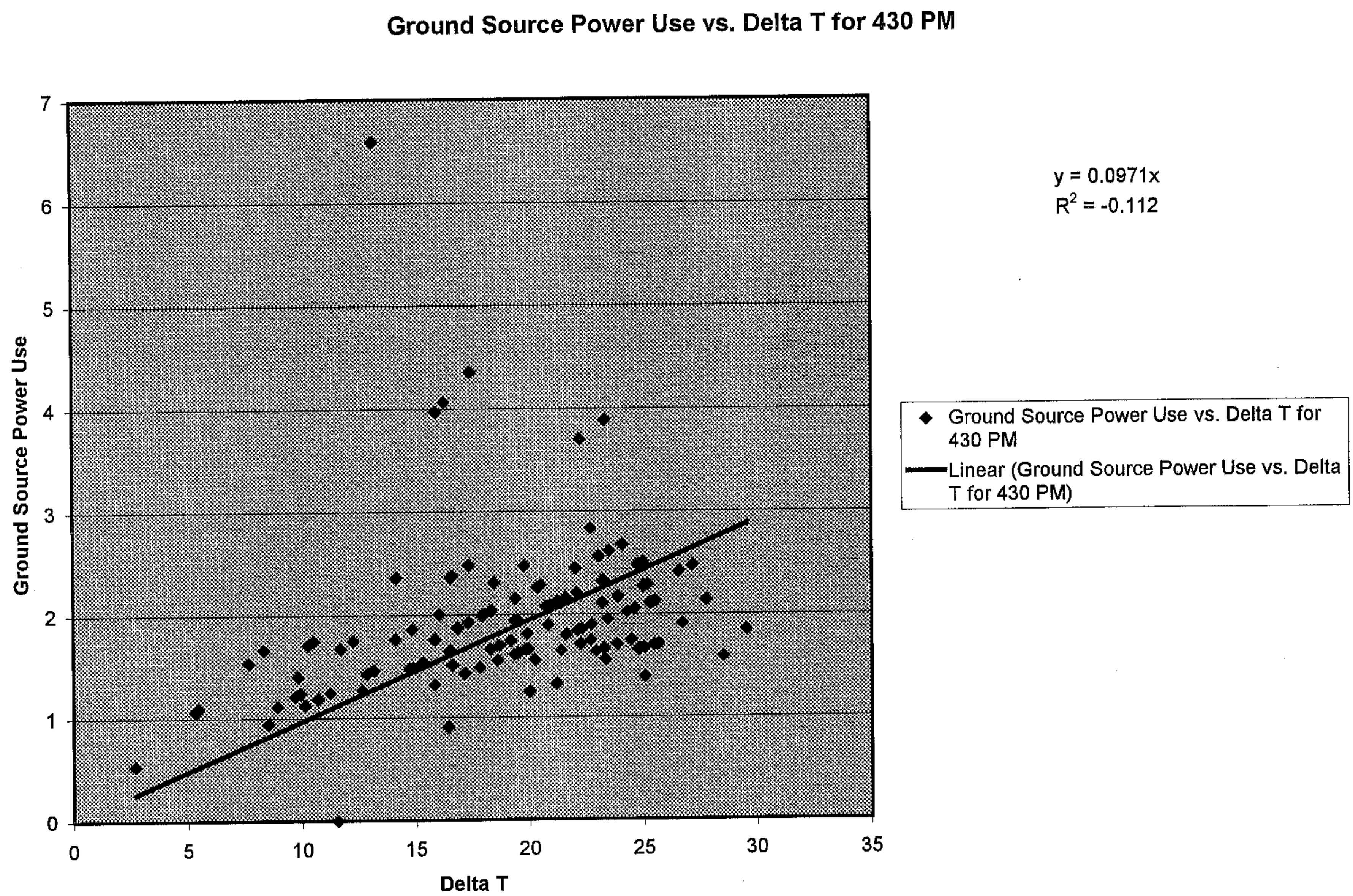

Ground SourcePower Use vs Delta T for 630 AM
y = 0.0568x
R2 = -0.7814
Ground Source Power Use
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
35
40
Detla T
Ground Source vs Delta T for 630 AM
Linear (Ground Source vs Delta T for 630 AM)



Ground Source Power Use vs. Delta T for 730 AM
Ground Source Power Use
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
35
40
Detla T
y = 0.0521x
R2 = -0.9482
Ground Source Power Use vs. Delta T for 730 AM
Linear (Ground Source Power Use vs. Delta T for 730 AM)


Ground Source Power use vs. Delta T for 830 AM
y = 0.0554x
R² = -1.0686
Ground Source Power Use
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
35
40
Detla T


Ground Source Power Use vs. Delta T for 12 PM
Ground Source Power Use
3.5
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
Delta T
y = 0.0805x
R^2 = -0.1
Ground Source Power Use vs. Delta T for 12PM
Linear (Ground Source Power Use vs. Delta T for 12PM)



Ground Source Power Use vs. Delta T for 430 PM
y = 0.0971x
R^2 = -0.112
Ground Source Power Use
Delta T
0
1
2
3
4
5
6
7
0
5
10
15
20
25
30
35
Ground Source Power Use vs. Delta T for 430 PM
Linear (Ground Source Power Use vs. Delta T for 430 PM)

A

The Relationship between the difference in Temperature between the outside and inside, solar radiation and the geothermal system at Black Rock Visitor Center

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December 3, 2001

The Black Rock visitor center at Black Rock Forest uses a geothermal heating and cooling system to regulate the temperature inside of the center. Geothermal systems use the earth's stored energy in the ground to transfer heat. The heat is transferred into the building in the winter and out of the building in the summer. The geothermal system works from a temperature gauge inside the building. Data was collected during the months of November, December, January, February and March of solar radiation, ground source geothermal power, the temperature inside the building and the temperature outside the building, everyday of the month on the hour. Careful study of the data indicated that there is a distinct relationship between the amount of solar radiation, the difference in temperature between the outside and the inside and the ground source geothermal power unit. The larger the temperature difference the larger the ground source geothermal power unit, and the larger the solar radiation the smaller the ground source geothermal power unit. This study interprets the data and presents graphs and diagrams to explain these relationships and the nuances that exist.

Introduction-

The Black Rock Forest is a 3750 acre preserve dedicated to scientific research, education and conservation of the natural ecosystem that once covered much of the New York State Region. It is located in the Hudson Highlands, 50 miles north of NYC on the western Bank of the Hudson River. It was established as a research and demonstrative forest in the early 1900's by Dr. Ernest Stillman and acquired by the non-for-profit Black Rock Forest Preserve in 1989 who set the area aside as a natural area for perpetuity. The Preserve's visitor center is useful for both scientists and students without compromising the environmental ethics of the institution. The building utilized self-composting toilets, solar radiation and most importantly geothermal heating and cooling systems.

Geothermal systems use the earth's stored energy in the ground to heat the building in the winter and cool the building in the summer. As one gets deeper and deeper into the surface of the Earth the temperatures come closer and closer to the average year round surface temperature. This is around 50 degrees Fahrenheit at 30 feet depth. The temperature stays about the same to 500ft and then there is a rise of about 3/4 of a degree of Fahrenheit for every 100ft depth. This additional rise in temperature is due to the heat of the core of the Earth heating up the crust of the Earth.

In the winter months the temperature in the air is much cooler then the temperature in the ground, this is because the surface of the Earth has a higher heat capacity then the air. In order to utilize this energy source a well is put in the ground, at an appropriate depth whose water is the same temperature as the ground around it. The water is then pumped up to heat transfer equipment, which concentrated the heat in the water from about 50 degrees Fahrenheit to 120 degrees Fahrenheit. This is then distributed around the building.

Geothermal systems are considered to be environmentally friendly because they recycle a renewable energy source, rather then creating heat by the combustion of fossil fuels. The pumping of the water up and the transfer of the geothermal energy does however use electricity, but the creation of this electricity is much less harmful then the heating of a house using tradition means would be. The Geothermal system produces zero local pollution and is a step towards a cleaner, more efficient source of energy for heating.

The Black Rock visitor center does not just rely on the Geothermal System to provide all the heat in the winter. There are overhangs over the windows on the South side of the building that let the sun in during the winter, but block it out during the summer. Because the angle of incidence of the sun is low in the winter, as it never rises very high in the sky, there is less average solar radiation in a given area per day. The overhangs on the window bring light in at a certain angle, maximizing the warmth from the energy of the sun. This is called passive solar heating.

Another factor that is important is the thermal mass in the building. The mass in the building absorbs the heat from the sun and then slowly radiates it out according to its heat capacity. Rocks and concrete blocks are good sources of thermal mass. The thermal mass slows the rate of heat loss at night and decreases the rate of heat gain in the day, as the mass in the building absorbs the heat and then radiates it into the air.

Methods:

Data was taken from inside the Black Rock visitor center and at the Open Lowland Site. Only two measurements from the open lowland site are solar radiation and the outside temperature. Inside the building the temperature was taken and the ground source geothermal power unit was measured. There are some gaps in the data, (before from 11/1-11/7, 1/14-1/24, and after 3/21) most likely because the center was closed, or the researcher was on holiday. The data set is very large however, with 24 measurements almost every day of the five months.

The Data was analyzed using regression analysis, t-tests, graphing and correlation.

Results:

In order to find the hour of the highest power use and the lowest power use the data was sorted by month and then hour. The ground source geothermal power unit was then averaged for each hour of every month. The hour with the highest ground source geothermal power unit occurred at 8AM for November, December, January, February and March. The hour with the lowest ground source geothermal power unit occurred at Midnight for November, December and January and at 1AM from February and March. This can be seen in figure 1 below.

	Highest power use	Least power use	Hour of peak	Hour of least
November	9.875	3.375	800	2400
December	20.38709677	4.096774194	800	2400
January	20.5	3.1	800	2400
February	20.21428571	3.178571429	800	100
March	19.61904762	2.333333333	800	100

Table 1: This shows the peak hour of ground source geothermal power unit and the hour of the least ground source geothermal power unit.

A t-test was performed on order to make sure that the differences in these averages were significantly different. The results are summarized in the table 2 below.

Month	P-value
November	1.84E-10
December	5.08E-31
January	1.25E-27
February	8.77E-23
March	2.37E-20

Table 2: This shows the P-value between the average peak hour of ground source geothermal power unit and the average of the least hour of ground source geothermal power unit. All the p-values are below 0.05

The mean value of solar radiation, the difference in temperature between the inside and the outside (delta temperature), and the mean value of the ground source geothermal power unit divided by the delta temperature for each hour of the day between 630AM and 1630PM. The when the peak values occurred were then compared to the time of the peak values found previously, in table 1. The results are in the table below.

Hour of the day	ground source geothermal power unit	delta temp	solar radiation	gspgu/delta T
700	18.2	21.8	9.32	0.83
800	19.6	21.5	55	0.91
900	18.35	20.5	188	0.90
1000	12.95	19.6	294.1	0.66
1100	12.6	19	402.3	0.66
1200	10.63	18.1	460.1	0.59
1300	10.4	17.4	450.9	0.60
1400	9.6	16.9	393.3	0.57
1500	8.45	16.9	293.4	0.50
1600	8.8	17.2	170.1	0.51
1700	8.65	17.7	73.2	0.49

Table 3: This shows the average ground source geothermal power unit, solar radiation, and delta temperature for the hours of 700 to 1700 in March.

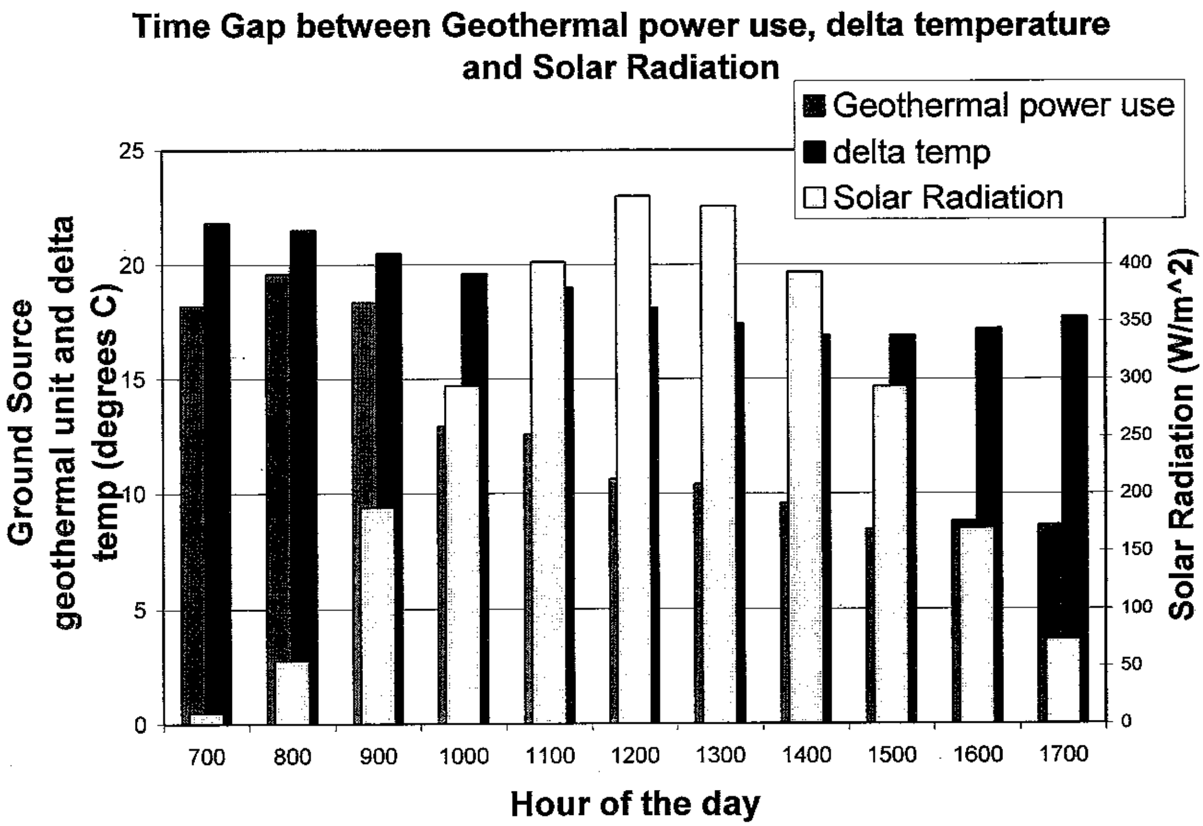

Figure 1: This shows the time lag that occurs between the delta temperature, solar radiation and the ground source geothermal power unit. The difference between the fall in ground source geothermal power unit and the fall in delta temperature is due to the thermal mass in the Black Rock Visitor Center.

The data was then sorted by time of day and the Delta Temperature was graphed against the ground source geothermal power unit for the following times of day: 630, 730, 830, 1200 and 1630. A line was fit, specifying the y-intercept at zero, and the R squared values compared. The R squared values are shown below in table 4.

Time of Day	R-Squared Value	Slope
630	0.6635	1.33
730	0.4512	1.22
830	0.7506	1.3
1230	0.24	1.57
1630	-0.1328	1.867

Table 4: This table shows the R-squared value and slope for the trendline assigned to certain hours correlating the relationship between Delta Temperature and ground source geothermal power unit.

Finally a multivariate fit was made between delta temp, solar radiation and ground source geothermal power unit. The aim was to find out how Delta Temperature and solar radiation could be used to find the ground source geothermal power unit. It was done for two sets of data, one for the hours between 730AM and 430 PM and one for the hours between 430 PM and 730 AM. The results of the multivariate analysis are shown below.

Regression Statistics	
Multiple R	0.72
R Square	0.52
Adjusted R Square	0.52
Standard Error	3.44
Observations	1242

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	15762.9	7881.451	665.57	4.8995E-197
Residual	1239	14671.9	11.842		
Total	1241	30434.8			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	2.0093	0.34809	5.7724	9.86806E-09
X Variable 1	0.5817	0.01629	35.7176	1.1321E-192
X Variable 2	-0.0026	0.00054	-4.7650	2.1114E-06

Lower 95%	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
1.3264	2.6922	1.3264	2.6922
0.5497	0.6136	0.5497	0.6136
-0.0036	-0.0015	-0.0036	-0.0015

Table 5: This shows a summary of the multivariate analysis of a regression between delta Temperature (X variable 1) and solar radiation (X variable 2) to find ground source geothermal power unit for the hours between 730AM and 1630PM. The equation that is derived to find ground source geothermal power unit is **y=2.0093+0.5817(delta temp)-0.0026(solar radiation).**

Regression Statistics	
Multiple R	0.416
R Square	0.173
Adjusted R Square	0.172
Standard Error	4.696
Observations	1747

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	8064.40	4032.20	182.82	8.32653E-73
Residual	1744	38465.85	22.06		
Total	1746	46530.25			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	0.255	0.439	0.582	0.5610	-0.605	1.116	-0.605	1.116
X Variable 1	0.364	0.020	18.266	2.42365E-68	0.325	0.404	0.325	0.404
X Variable 2	0.280	0.042	6.655	3.77943E-11	0.197	0.362	0.197	0.362

Table 6: This shows a summary of the multivariate analysis of a regression between delta Temperature (X variable 1) and solar radiation (X variable 2) to find ground source geothermal power unit for the hours between 1630PM and 730AM. The equation that is derived to find ground source geothermal power unit is **y=0.255+0.364 (delta temp)+0.280(solar radiation).**

Discussion:

The peak power use for all the months is at the 800AM. The peak power uses ranges from 9.875 to 20.5. The 9.875 peak power use occurred in November when there was not such a demand for heat in the building. The reason that the peak is at 800AM is due to the fact that the solar radiation is low and the delta temperature is high. The passive solar heating in the building is low due to low solar radiation and the low angle of incidence in the sun's rays. They lowest ground source geothermal power unit is between midnight and 1AM for each month. This is because the solar radiation that heated the surface of the earth all day also heated the mass of the building itself and the things inside the building. These objects have thermal mass and they dissipate the heat throughout the day and into the evening. Now that the temperature has dropped outside, the thermal mass is still being released. Also the temperature difference between the ground and the air is smallest once the sun has gone down, so the ground source geothermal power unit is low.

The difference between the peak ground source geothermal power unit and the least ground source geothermal power unit is much more in December, January, February and March then it is in November. This is due to the effect of the seasons, and that the sun rises higher in the sky in November then during the winter months, so that the need for extra heat into the building is less.

It is also probable that in morning the building must be heated to a higher degree because people are about to enter it. In the nighttime hours the building is unoccupied so that the amount of heat is not necessary. There is most likely a mechanism that promotes the heat transfer equipment to condense the amount of heat coming from the water to a higher degree in the morning than at night, as this will save the electricity that is used in the heat transfer equipment.

The t-test of the average hour of peak ground source geothermal power unit and least ground source geothermal power unit for all the months showed that there was no overlap in the data, and that the two numbers are significantly different. The P-values are so small that there is no similarity in the distribution of the peak amount of ground source geothermal power unit and the least amount of ground source geothermal power unit.

The peak hours of ground source geothermal power unit in the month of March were at 800AM, the same as derived from the previous analysis. There appears to be a time lag between the delta temperature, solar radiation and the ground source geothermal power unit, as can be seen in Figure 1. To begin with the delta temperature is at the highest point, but the ground source geothermal power unit has not yet peaked. It peaks an hour later, which must be due to the thermal mass that has been heating the building throughout the night. The ground source geothermal power unit is high, but when it peaks it is at 800AM. The ground source geothermal power unit then decreases even though the delta temperature stays about the same. This is because of passive heating of the building, as the solar radiation increases the ground source geothermal power unit decreases. As the evening approaches the solar radiation decreases, the delta temperature increases slightly, but ground source geothermal power unit does not increase. This is because even though the solar radiation is decreasing there is still heat production in the building through the thermal mass. The relationship between solar radiation, delta temperature and ground source geothermal power unit is one that has a slight time lag due to the objects in the building dissipating the heat that they absorbed during the day.

The R-squared value for the trendline that correlated delta temperature and ground source geothermal power unit can be seen in table 4. The R-squared value quantifies the accuracy of the trendline that has been assigned to the data. The R-squared value is highest for 830AM, the same time as the peak ground source geothermal power unit. The R-squared value then decreases dramatically at noon to 0.24, and to a very bad correlation at 430PM of -0.1328. There is a higher correlation between delta temperature and ground source geothermal power unit in the morning as there is no heat in the building from passive solar heating. In the middle of the day the solar heating is taking effect, so the correlation between delta temperature and ground source geothermal power unit is not very high. In the afternoon the correlation is still low because passive solar heating of the building is taking place through the dissipation of heath from thermal mass. The slope of the line, which represent how much the delta temperature is affecting the ground source geothermal power unit stays constant in the morning hours, but as the afternoon progresses it appears that the delta temperature has a higher effect on ground source geothermal power unit. Since the R-squared value is so low, this information is not that reliable. The slope and the R-squared value is different for each hour in the day because the solar radiation is different at each hour of the day, and this effects the relationship between delta temperature and ground source geothermal power unit.

The multivariate fit of the regression analysis of delta temperature, ground source geothermal power unit and solar radiation show how the solar radiation and delta temperature determine the ground source geothermal power unit. Two multivariate fits were made one with hours during the day and another with hours during the night. The results are in tables 5 and 6. Table 5 shows the daytime hours and table 6 shows the nighttime hours.

In the daytime the equation to find the ground source geothermal power unit was **y=2.0093+0.5817(delta temp)-0.0026(solar radiation).** This shows that in the daytime the bigger the delta temperature the larger the ground source geothermal power unit and the bigger the solar radiation the smaller the ground source geothermal power unit. This agrees with the statements previously made about solar radiation and ground source geothermal power unit. The R-squared of the equation was 0.52, which is quite high. All the P-values were below 0.05, showing that there is a significant difference between all the sets of data. This equation makes sense and in Figure 1 it is apparent that the larger the amount of solar radiation is the smaller the amount of ground source geothermal power unit, because passive solar heating is taking place.

At nighttime the equation to find the ground source geothermal power unit from delta temperature and solar radiation was **y=0.255+0.364 (delta temp)+0.280(solar radiation).** This equation makes sense again, as at nighttime there is no solar radiation, so that it will not have a negative effect on the ground source geothermal power unit. Since the data spanned a time that did include some daylight hours, just before sunset and after sunrise, the solar radiation does come into play a tiny bit, but the delta temperature has a higher coefficient, and therefor has a greater effect on the ground source geothermal power unit. The radiation should not have a positive effect on the ground source geothermal power unit though, even if it is small. The R-squared value for this equation is much smaller, 0.17, which does not show a strong correlation. The P-values are all very small, showing that the data are all different, except for the placement of the y-intercept, this had a high P-value.

The correlation that was gained between the delta temperature, solar radiation and ground source geothermal power unit is more reliable from the daytime data because the R-squared value was closer to one.

The Black Rock Visitor Center is wise to use a geothermal heating system, as not only is it using a renewable energy source but also it is heating the building very well. The change of temperature inside the building is very small compared to the change of temperature outside the building. The use of passive solar heating in the visitor center is also important, as this lab has shown it reduces the amount of heat required from the geothermal system during the winter months.