American Recovery and Reinvestment Act (ARRA)

FEMP Technical Assistance

U.S. Air Force
Hill Air Force Base (AFB)
Project 121 Energy Security for Hill AFB

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Executive Summary

Hill AFB seeks to become energy secure, that is, to produce as much or more energy than is required to operate the base. To do so, Hill AFB plans to increase its supply of sustainable renewable energy, as well as implement energy conservation measures. In a letter dated May 21, 2009, the Hill AFB Director of Plans and Programs requested the support of DOE FEMP the in specific assessment areas to work toward the accomplishment of Hill's energy security strategy. The scope of the request covered a wide array of potential technologies. To provide substantive results with the funding that was allocated by DOE FEMP, the scope of the Technical Assistance project was narrowed to cover 1) the feasibility study for Ground Source Heat Pump (GSHP) system application and 2) solar photovoltaic (PV) technologies.

A feasibility study for a new proposed office complex at Falcon Hill Quad was performed to evaluate energy and cost savings potential by applying GSHP systems. The current proposed Heating, Ventilating and Air Conditioning (HVAC) system for the building is a conventional VAV system with chiller and boilers. Although the proposed building already has numerous Energy Conservation Measure (ECM) features such as Exterior Insulation Finishing System (EIFS), water side economizer, high performance glazing systems, etc., the building has a good potential to save further energy by applying the GSHP system. The soil thermal conductivity test which was conducted in May 2010 supports the feasibility by presenting relatively good soil thermal conductivity and undisturbed underground soil temperature. The proposed GSHP system has 114 vertical boreholes (each borehole has 390 ft depth) and water-to-air heat pump systems to provide both space cooling and heating. The simulation result shows that there could be 2,393.8MBtu of annual energy savings compare to the baseline building (i.e., proposed design), which corresponds 25.9% energy savings. The corresponding annual energy cost saving is estimated as $20,413. Since a study shows that the capital cost for this GSHP system could be lower than the conventional VAV system with chiller/boiler, the immediate simple payback would be possible. The estimated green house gas emission reductions from this application would be 16.5 ton annually.

As another feasibility study, the ORNL team investigated the state-of-art PV technology to find the optimal PV array for the base, and to find the potential energy generation and cost effectiveness by applying the chosen technology.

The chosen PV array system is a single axis tracking PV array to maximize the electricity generation. When carefully selected, installed and maintained, the new generation of single axis tracking system could generate 15% to 35% more electricity at a similar cost to a fixed array.

Based on the site analysis, several case studies, and PV calculators (i.e., PVWatts), the annual electricity generation and the avoided green house gas emissions were estimated. Currently, there are three potential sites for the PV array installation, and two of them (i.e., 250 acres of West of MAMS and 740 acres of Little Mountain) have been selected for the study. In order to estimate the annual energy generation from the selected array, the PVWatts Solar PV Energy Calculator was utilized. When the one axis tracking system is chosen, the 1MW system would generate 1,824,038 kWh of electricity, annually. This value corresponds to 20.1% of capacity factor. Therefore, if each of the potential sites were fully covered by solar PV arrays,

1) West of MAMS can generate about 45.6 GWh annually.
2) Little Mountain can generate about 135 GWh annually.

The capital cost would be $175 million for West of MAMS, and $518 million for the Little Mountain, and this will result in 38 years of simple payback. The total greenhouse emission avoided for West of MAMS and Little Mountain would be 20,571 tons and 60,891 tons, respectively.

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Description of ARRA Program

On Feb. 13, 2009, Congress passed the American Recovery and Reinvestment Act (ARRA) of 2009 at the urging of President Obama, who signed it into law four days later. A direct response to the economic crisis, the Recovery Act has three immediate goals:

- Create new jobs and save existing ones
- Spur economic activity and invest in long-term growth
- Foster unprecedented levels of accountability and transparency in government spending.[1]

In a competitive grant approach across the services and commands, the national labs were awarded over $7,600,000 from the Department of Energy Federal Energy Management Program (DOE FEMP) to support Department of Defense (DOD) needs. The ARRA funds are dedicated to technical assistance projects aimed at bringing the most advanced energy efficiency, renewable power generation assessments and analyses to DOD installations.

Hill AFB seeks to become energy secure, that is, to produce as much or more energy than is required to operate the base. To do so, Hill AFB plans to increase its supply of sustainable renewable energy, as well as implement energy conservation measures. In a letter dated May 21, 2009, the Hill AFB Director of Plans and Programs requested the support of DOE FEMP in specific assessment areas to work toward the accomplishment of Hill's energy security strategy. The scope of the request covered a wide array of potential technologies. To provide substantive results with the funding that was allocated by DOE FEMP, the scope of the Technical Assistance project was narrowed to cover ground source heat pump and solar photovoltaic technologies.

[1] http://www.recovery.gov/

Background

Site Description

Hill Air Force Base (IATA: HIF, ICAO: KHIF) is a major U.S. Air Force Base located in northern Utah, just south of the city of Ogden, and near the towns of Clearfield, Roy, Sunset, and Layton. It is about 30 miles north of Salt Lake City. In this decade Hill A.F.B. is the sixth-largest employer in the state of Utah, and the third-largest one excluding the State Government and Higher Education employers.

Site Visit

As an effort to provide quality technical assistance for the American Recovery and Reinvestment Act (ARRA) project, the assessment team from ORNL visited the site from January 11 to 12, 2010. Several sites in the base were visited based on the discussions and recommendations from site personnel. The summary of the site visits is shown below.

Areas Visited Site	Mission/Use Type	Area
Falcon Hill Quad	Air Force Office Complex - future	25,000 ft^2 per floor
Falcon Hill North End	Commercial Development - future	TBD
East Side Development	3-Bay Fire Station and other future facilities	TBD
West of MAMS	Potential Solar	200-300 acres
North Perimeter	Potential Solar	TBD
South of MAMS	Existing 250 kW Solar Array	
Little Mountain	Potential Solar	740 acres

Based on site visit, discussions with the site personnel, and other case studies conducted close to the site, the assessment team decided to perform 1) a feasibility study for the application of GSHP system for the new Air Force Office Complex (i.e., Building 1575), and 2) evaluation of potential solar PV array application. Appendix A presents the pictures taken during the site visit.

Energy Use Accounting

Since the chosen study building is a new building, there is no energy use data available at this moment.

Energy Conservation Measures Identified/Estimated

The ORNL assessment team decided to perform 1) a feasibility study for the application of GSHP system for the new Air Force Office Complex (i.e., Building 1575), and 2) evaluation of potential solar PV array application.

Feasibility Study for the GSHP System Application for a New Air Force Office Complex

A building target for the GSHP system application has been identified from the site visit performed on January 11-12, 2010. The selected building for the feasibility study is Building 1575 which is a new office complex that will be constructed at Falcon Hill Quad. One of the reasons for the selection of the new building was that the GSHP system application for a new building could realize relatively faster payback comparing with the retrofit project. There could even be an immediate payback if the initial installation cost for the GSHP system is the same or lower than the conventional chiller/boiler system. For example, one case study which was conducted close to the target site shows that the actual GSHP system installed in a school building was less expensive than the conventional VAV system with chiller/boiler.

In addition, the building site was identified to have enough land area to install a set of vertical boreholes.

Soil Conductivity Test for Two Vertical Boreholes

As an effort to identify the feasibility for the GSHP system for the building, two sets of soil thermal conductivity test were performed at the sites during May, 2010 by Sound Geothermal Corporation. First, two test wells in the Hill AFB were identified for the soil thermal conductivity test. The selected locations are 1) Hill AFB Falcon hill Quad, which is the designated site for the building 1575 construction, and 2) Hill AFB 3-Bay Fire Station. The summary of the test result for each site is presented below.

1) Hill AFB Falcon Hill Quad

A formation thermal conductivity test was performed at the Falcon Hill Quad site at Hill AFB at a GPS location of N 41° 7' 28.92" (latitude), W 112° 0' 52.20" (longitude). The vertical bore was completed on May 2, 2010 by Bertram Drilling, Inc. A test unit was attached to the vertical bore on the afternoon of May 10, 2010. Geothermal Resource Technologies, Inc. (GRTI) analyzed the collected data using the “line source” method.

The following average formation thermal conductivity was found from the data analysis.

⇒ Formation Thermal Conductivity = **1.23 Btu/hr-ft-°F**

Due to the necessity of a thermal diffusivity value in the design calculation process, an estimate of the average thermal diffusivity was made for the encountered formation.

⇒ Formation Thermal Diffusivity ≈ **0.80 ft2/day**

An estimate of the undisturbed formation temperature was determined from the initial temperature data at startup.

⇒ Undisturbed Formation Temperature ≈ **54.3-55.4°F**

2) Hill AFB 3-Bay Fires Station

A formation thermal conductivity test was performed at the 3-Bay Fire Station site at Hill AFB at a GPS location of N 41° 7' 43.32" (latitude), W 111° 57' 56.16" (longitude). The vertical bore was completed on May 4, 2010 by Bertram Drilling, Inc. GRTI’s test unit was attached to the vertical bore

on the afternoon of May 10, 2010. Geothermal Resource Technologies, Inc. analyzed the collected data using the "line source" method.

The following average formation thermal conductivity was found from the data analysis.

⇒ Formation Thermal Conductivity = **1.17 Btu/hr-ft-°F**

Due to the necessity of a thermal diffusivity value in the design calculation process, an estimate of the average thermal diffusivity was made for the encountered formation.

⇒ Formation Thermal Diffusivity ≈ **0.77 ft2/day**

An estimate of the undisturbed formation temperature was determined from the initial temperature data at startup.

⇒ Undisturbed Formation Temperature ≈ **52.1-53.2°F**

The full report for the test results can be found at Appendix B.

<u>Building Description</u>

The selected building is one of three buildings in the new office building complex that will be constructed at Falcon Hill Quad. The site for the building is shown in Figure 1, and the bird eye view of the buildings is shown in Figure 2. The selected building is indicated in the circle in Figure. The building is a general office building with several communication rooms and server rooms. Due to the high power demands from the equipments in these communication rooms and server rooms, the equipment electricity uses are expected to be higher than the typical office buildings.

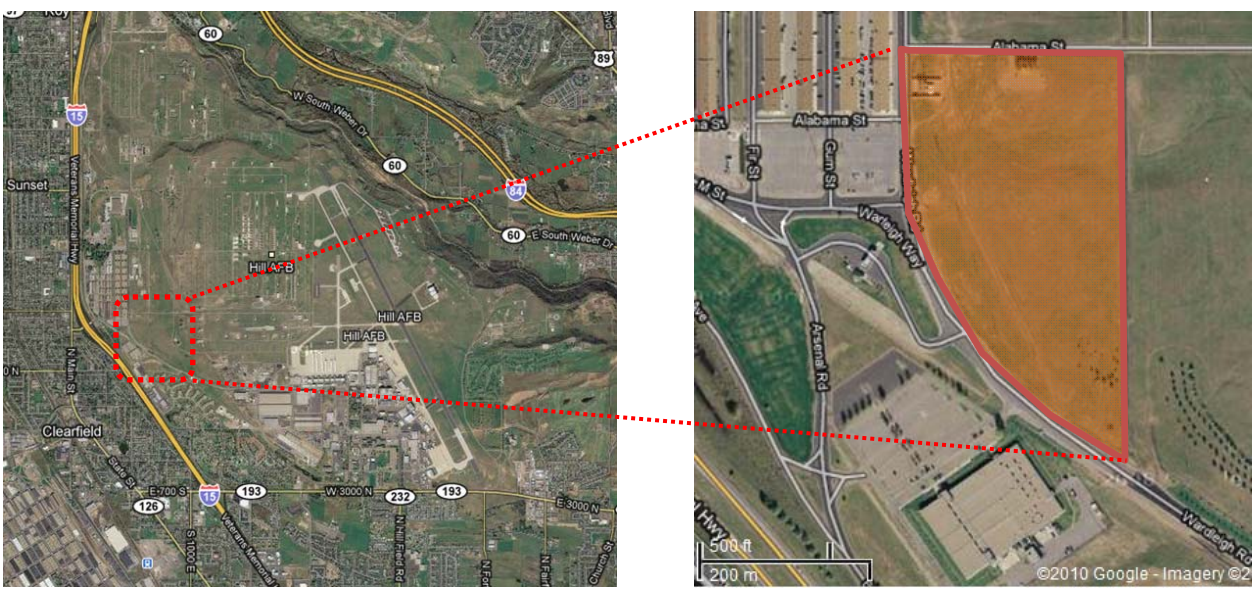


Figure 1: Site for Building 1575

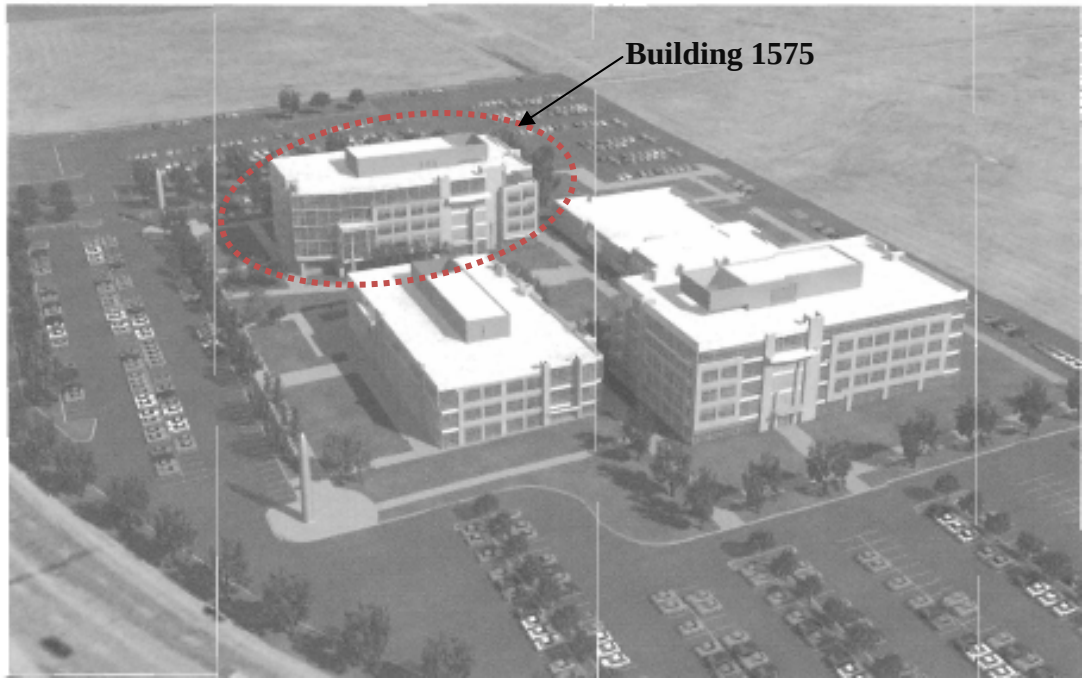


Figure 2: Bird Eye View of Building 1575 with Two Other Buildings

As shown, the building is 5-story building with basement floor, and the total conditioned floor area is about 151,200 sqft. The exterior wall is composed of Exterior Insulation Finishing System (EIFS) and spandrel/metal panel, and the weighted wall U-value is about 0.0436 Btu/h-ft^2-F. The glazing properties in this building vary. The U-values of the windows are about 0.355 to 0.390 Btu/h-ft^2-F, and the SHGC is 0.275 to 0.321.

Major portion of the building is equipped with central A/C system. The type of the AHU is the standard VAV with reheat system, and one electric screw chiller (about 150 ton) and cooling tower provide chilled water for the AHU. There are two natural gas HW boilers to provide HHW for the building. In addition, there is one natural gas service water heater (373 gallon) installed to provide SWH for the building.

Building Simulation Modeling

Before the feasibility study was performed for this building, a separate building energy study had been done by a local A/E design firm. The energy study report shows that they used the same energy simulation program (i.e., eQuest (DOE-2.2 based)) that this feasibility study intended to utilize. Therefore, their building simulation model was obtained with their agreement, and used as the baseline building model. Figure 3 shows the rendering of the building simulation model obtained from the firm.

The final proposed model obtained is already tuned to save the energy compared to typical office building design. Therefore, the energy savings potential from the application of the GSHP system would not be as big as the typical existing building's case, which can be equipped with an energy inefficient HVAC system.
The initial building simulation result is shown at Figure 4. As shown, the miscellaneous equipment electricity uses are highest among all end uses as expected due to the communication rooms and server rooms. The annual electricity and natural gas consumptions were simulated as 1,923.5 MWh/yr, and 2,668.3 MMBtu/yr, respectively.

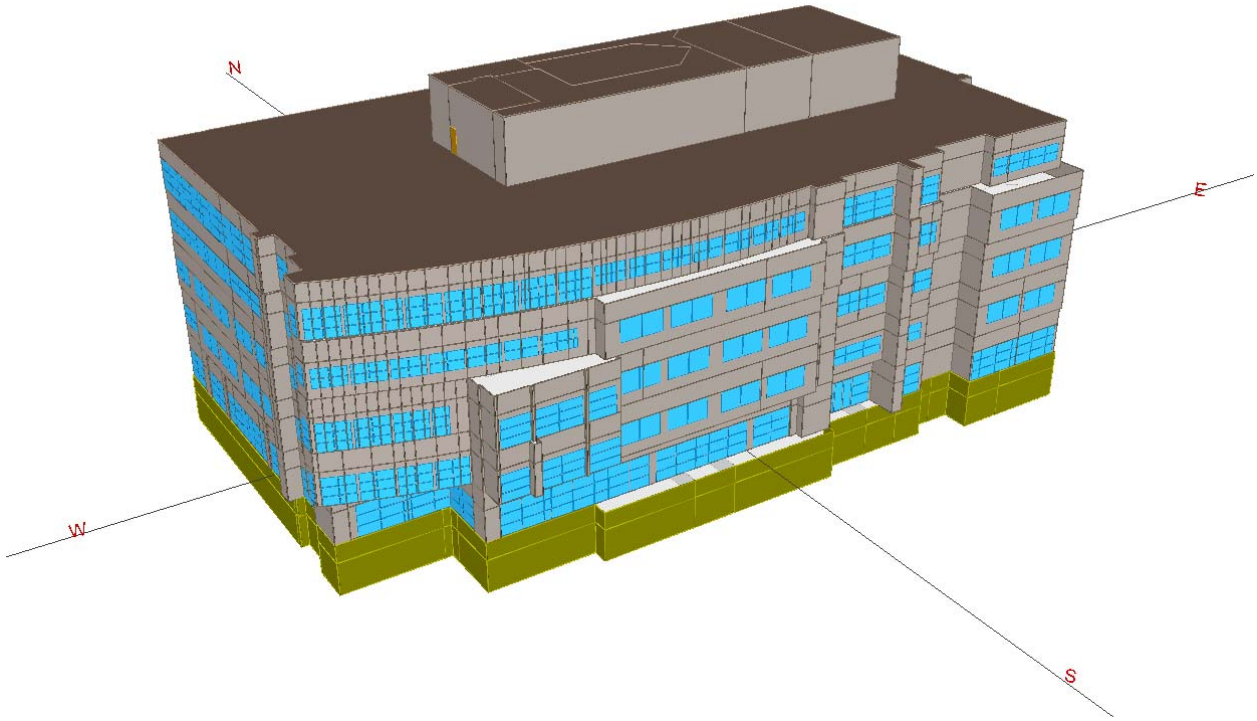


Figure 3: eQuest 3-D Rendering of the Building 1575 Simulation Model

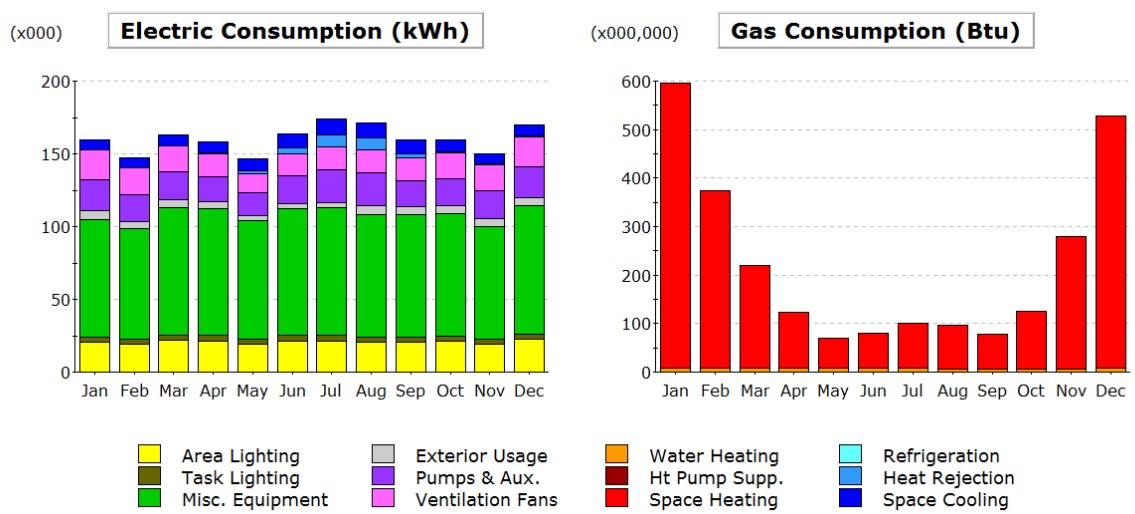


Figure 4: Baseline Simulation Result

Application of GSHP System

Based on the site visit and the building drawings, the type of vertical borehole heat exchanger was selected for the building. The required size of borehole was determined based on the simulated monthly building cooling and heating load, the peak cooling and heating load, and the borehole test results. The

commercially available borehole design software, Ground Loop Design (GLD) geothermal design studio was used for the borehole sizing. Appendix C shows the detailed inputs and outputs of the software.

The result shows that there would be 114 boreholes with 390ft depth of each borehole required to meet the building load. The 390ft of the depth was determined by the borehole test results.

Next step is to modify the original simulation model to replace the current HVAC system with the proposed GSHP system. In this study, the water-to-air heat pump system type with vertical boreholes was chosen. All the input assumptions made from the GLD sizing procedure have been entered into the eQuest simulation program, and the results are shown at Figure 5.

As shown, the total annual electricity and natural gas use are estimated as 1,967 MWh/yr and 92 MMBtu/yr, respectively. The total combined annual energy use is 6,803.4MMBtu, which is 26.3% savings compared to the baseline energy use.

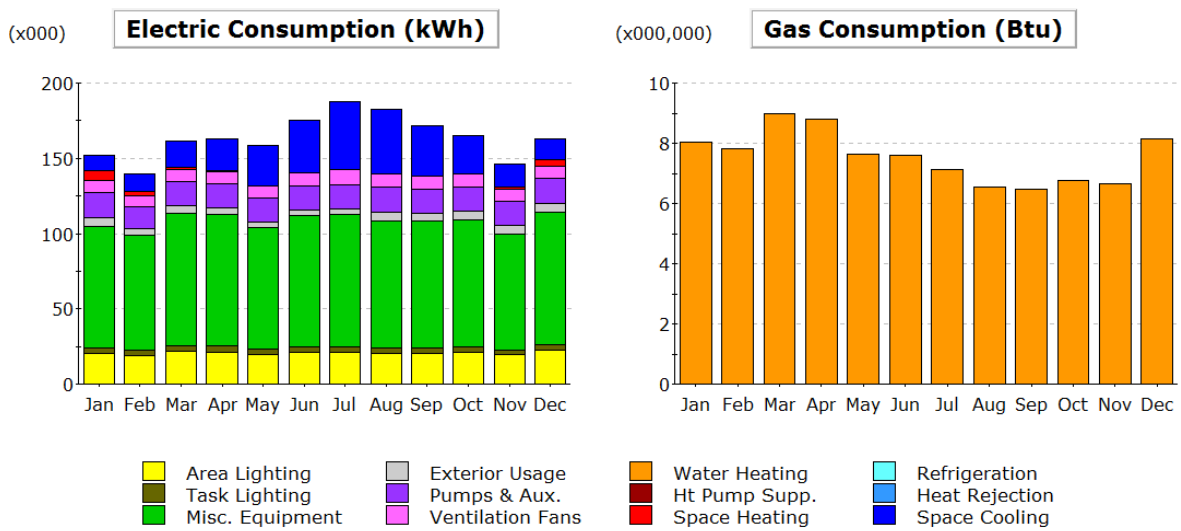


Figure 5: Simulation Result with the GSHP System

Cost Analysis

The initial investment cost in this project has been estimated using available resources. Since this building is a new building, the initial investment costs both for the conventional HVAC systems and the proposed GSHP systems should be estimated to calculate simple payback. Some literatures shows that the initial HVAC installation cost for the commercial GSHP systems can be lower than the standard VAV systems with chiller(s)/and boiler(s) (Bloomquist 2000). According to this study, the capital cost ($/sqft) for VAV with chiller/boiler system and GSHP system are about $15 and $10, respectively. Therefore, the immediate simple payback would be possible in this new building project. The real simple payback would be differing based on the actual price quotation from installers, drilling, etc.

One more source for the capital cost estimation is from a case study building close to the site (i.e., Salt Lake City metropolitan area). The case study building is the Murray high school which is equipped with ground source heat pump system with 316 vertical boreholes. In this study, the actual conventional mechanical system bid was $19.00/ ft^2, whereas the ground source heat pump system (i.e., including heat pump and loop field) bid was $14.95/ ft^2. Therefore, there was $4.05/ ft^2 of cost savings by choosing the

GSHP system instead of the conventional mechanical system. When this cost is applied to this study, the capital cost savings for the building 1575 is about $612,360 (i.e., 21.3% savings).

The annual energy cost was calculated based on the 2009 average electricity and natural gas rates, which are about $0.1/kWh and $10/MMBtu. The total annual energy cost saving using this rate was calculated as $21,413, which corresponds 9.8% cost savings compared to the baseline.

Potential Green House Gas Reductions

Carbon emission reductions due to the potential energy savings are also calculated. The EPA's eGrid database was used for the calculation of the emission reductions. According to the eGrid 2007, the electricity emission factor for carbon dioxide in Utah was 902.24 lbs/MWh. A separate source, EPA's AP42, *Compilation of Air Pollutant Emission Factors* was used for the emission rate from the on-site natural gas boiler. According to this source, the CO_2 emission rate from natural gas boilers is 120,000 lb/10^6scf, which is 117.65 lbs/MMBtu. Therefore, the total greenhouse emission reduction would be 21.6 tons annually by applying the GSHP system.

Job Created

If the recommended GSHP system will be implemented on the base, there will be 24.6[2] job-years created.

Conclusion

A feasibility study for a new proposed office complex at Falcon Hill Quad was performed to evaluate energy and cost savings potential by applying GSHP systems. The current proposed HVAC system for the building is a conventional VAV system with chiller and boilers. Although the proposed building already has numerous ECM features such as EIFS, water side economizer, high performance glazing systems, etc., the building has a good potential to save further energy by applying the GSHP system as described in this report. The soil thermal conductivity test which was conducted in May, 2010 supports the feasibility by presenting favorable soil thermal conductivity and undisturbed underground soil temperature. The proposed GSHP system has 114 vertical boreholes (each borehole is 390 ft depth) and water-to-air heat pump systems to provide both space cooling and heating. The simulation result shows that there could be 2,428 MBtu of annual energy savings compare to the baseline building, which corresponds 26.3% energy savings. The corresponding annual energy cost saving is estimated as $21,413. Since the capital cost for this GSHP system could be lower than the conventional VAV system with chiller/boiler, the immediate simply payback would be possible. The estimated green house gas emission reductions from this application would be 21.6 tons annually. Therefore, the immediate simple payback and the $21K of annual cost savings suggest that this GSHP project is highly feasible for the given building.

Table 1 shown next page summarizes the energy and cost savings, and emission reductions.

[2] Number of job-years created = Total capital cost ($)/$92,000

Table 1: Summary - Energy, Cost, and Emissions

	Annual Elec. Use (MWh/yr)	*Annual N.G. Use (MMBtu/yr)*	*Annual Total Energy Use (MMBtu/yr)*		*Annual Elec. Cost ($/yr)*	*Annual N.G. Cost ($/yr)*	*Total Cost ($/yr)*		*Conceptual Implementation Costs ($)*		*Simple Payback*
Baseline (VAV with Chiller)	1,923.5	2,668.3	9,231.3		192,350.0	26,683.0	219,033.0		2,872,800.0		
GSHP System (Vertical GHX)	1,967.0	92.0	6,803.4		196,700.0	920.0	197,620.0		2,260,440.0		
Savings	**-43.5**	**2,576.3**	**2,427.9**	**(26.3%)**	**-4,350.0**	**25,763.0**	**21,413.0**	**(9.8%)**	**612,360.0**	**21.3%**	**Immediate**

	Annual Elec. Use (MWh/yr)	*Annual N.G. Use (MMBtu/yr)*	*Annual CO2 Emission from Power Plant (lbs/yr)*	*Annual CO2 Emission from Site (lbs/yr)*	*Total Annual CO2 Emission (lbs/yr)*	*Total Annual CO2 Emission (tons/yr)*
Baseline (VAV with Chiller)	1,923.5	2,668.3	1,735,458.6	313,917.6	2,049,376.3	1,024.7
GSHP System (Vertical GHX)	1,967.0	92.0	1,774,706.1	231,411.8	2,006,117.8	1,003.1
Savings	-43.5	2,576.3	-39,247.4	82,505.9	43,258.4	21.6

Evaluation of Onsite Solar Photovoltaic Array Application

In addition to the GSHP feasibility study, onsite solar PV installation has been identified as renewable energy application opportunity to be evaluated. The Hill AFB has an existing 250 kW solar array, which is the biggest solar array existing in Utah area. Currently, the base is intending to extend the capacity of the solar array by installing other solar array on the potential sites available (i.e., West of MAMS, North Perimeter, and Little Mountain). Therefore, the ORNL team investigated the state-of-art PV technologies to find the optimal PV array for the base, and to find the potential energy generation capacity, and cost effectiveness by applying the chosen technology.

Based on a literature review and existing case studies for large scale solar array projects, the type of single axis tracking PV arrays is chosen for the site to maximize the electricity generation. Although there have been several issues in tracking PV arrays due to the higher initial cost, and frequent maintenance needs, the current improvements in this technology makes the system more reliable, cost effective, and better performing (NREL 2007). According to the source, when carefully selected, installed and maintained, the new generation of single axis tracking system could generate 15% to 35% more electricity at a similar cost to a fixed array.

In addition, there is an existing solar photovoltaic power plant using this technology at Nellis AFB in NV. This power plant was constructed in December 2007, and has 14.2 megawatts capacity with 140 acres of covered area (i.e., 70,000 panels). This system is expected to save $1 million annually. Given the available area (i.e., 200 to 300, and 740 acres) in the Hill AFB and the solar pathfinder analysis results, the one axis tracking PV systems would be ideal for the sites.

Site Analysis

The site analysis was performed using the solar pathfinder and visual inspection. Figure 6 shows the picture taken at West of MAMS Area, and the site has no particular obstacles to block the direct sunlight, which makes the site good candidate for the solar array installation. Visual surveys of the other two sites also show that the sites have good potential for solar PV arrays.

Figure 6: Solar Pathfinder – West of MAMS Area

Selected System

Based on the research, the one axis tracking system was selected for this study. The specific PV panels are not chosen for this preliminary level of study, but the case study shows that multiple panels were installed with the tracking system at one site. Figure 7 shows one of the prototype trackers, and Figure 8 shows the installed arrays at Nellis Air Force Base. Detailed installation manual and other information can be found a technical report (NREL 2007).

Total land area required for the 1MW system was estimated based on two references. One from NREL shows that a 1,258.4 kW system using the tracker needs 7.6 acres, while an existing power plant in Nevada shows that a 14.2 MW system using the same tracker needs 140 acres of covered area. Therefore, the 1MW system from both cases needs about 6 to 10 acres of total land area. In this study, 10 Acres/MW system will be used for the estimation. Given the total land area available in the Hill AFB,

1) West of MAMS can be installed with 20 to 30 MW array (250[3] acres available)
2) Little Mountain can be installed with 74 MW array (740 acres available)

Figure 7: Prototype Tracker Installed in San Jose, California

[3] Average of 200 to 300 acres are used in this study

Figure 8: 14.2 MW PV Array at Nellis Air Force Base

Annual Energy Generation

In order to estimate the potential annual energy generation from the selected array, the PVWatts Solar PV Energy Calculator[4] was utilized (See Figure 9). The calculation results are shown at Table 2. When the one axis tracking system is chosen, the 1MW system would generate 1,824,038 kWh of electricity, annually. This value corresponds to 20.1% of capacity factor. Therefore, if each of potential site would be fully covered by solar PV arrays,

1) West of MAMS can generate about 45.6 GWh annually.
2) Little Mountain can generate about 135 GWh annually.

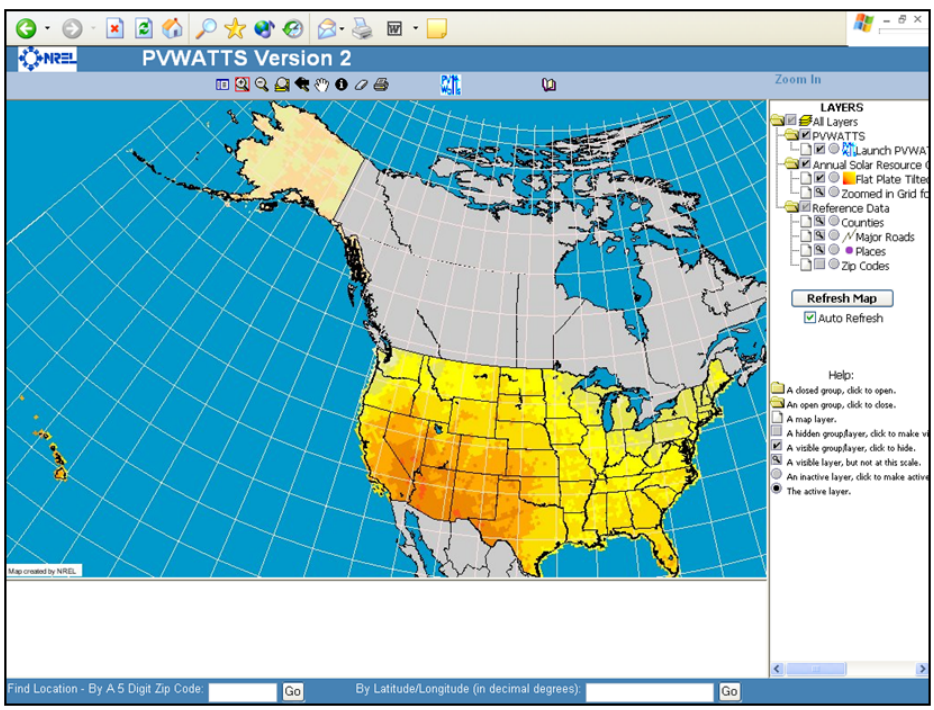


Figure 9: Screenshot of PVWatts

[4] http://www.nrel.gov/rredc/pvwatts/

Table 2: Input and Output of PVWatts

Station Identification	
City:	Salt_Lake_City
State:	Utah
Latitude:	40.77° N
Longitude:	111.97° W
Elevation:	1288 m
PV System Specifications	
DC Rating:	1000.0 kW
DC to AC Derate Factor:	0.770
AC Rating:	770.0 kW
Array Type:	1-Axis Tracking
Array Tilt:	40.8°
Array Azimuth:	180.0°
Energy Specifications	
Cost of Electricity:	10.0 ¢/kWh

Results			
Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	3.85	93612	9361.20
2	5.36	116150	11615.00
3	6.39	149702	14970.20
4	7.25	160853	16085.30
5	8.50	191174	19117.40
6	9.06	189944	18994.40
7	9.62	202860	20286.00
8	9.60	204961	20496.10
9	8.42	180027	18002.70
10	6.88	155091	15509.10
11	4.71	105918	10591.80
12	3.07	73745	7374.50
Year	6.90	1824038	182403.80

Cost Analysis

Capital Cost

The initial installation cost for the system is usually hard to obtain from the manufacturer. However, one report shows the actual installation cost for Nellis AFB. The installed cost in 2007 for the same type of system was $7/W. Therefore, the installation cost for each site would be

1) West of MAMS installation cost would be $175 million when the available land area fully covered with the array.
2) Little Mountain installation cost would be $518 million when the available land area fully covered with the array.

Simple Payback

For both cases, the simple payback would be 38 years. However, there are several rebate programs and price discounts available for several states. Therefore, the additional cost savings in initial investment costs, and the expected electricity rate increase in future will shorten the simple payback.

Potential Green House Gas Reductions

Carbon emission reductions due to the energy savings are also calculated. The EPA's eGrid database was used for the calculation of emission reductions. According to the eGrid 2007, the emission rate for carbon dioxide in NECC Northwest was 902.24 lbs/MWh. Therefore, the total greenhouse emission avoided for West of MAMS and Little Mountain would be 20,571 tons and 60,891 tons, respectively.

Job Created

If the recommended PV arrays will be implemented on the base, there will be 1,902 and 5,630[5] job-years created for West of MAMS and Little Mountain sites, respectively.

Conclusion

The ORNL team investigated the state-of-art PV technologies to find the optimal PV array for the base, and to find the potential energy generation, cost effectiveness by applying the chosen technology.

The chosen PV array system is a single axis tracking PV arrays to maximize the electricity generation. When carefully selected, installed and maintained, the new generation of single axis tracking system could generate 15% to 35% more electricity at a similar cost to a fixed array.

Based on the site analysis, several case studies, and PV calculators (i.e., PVWatts), the annual electricity generation and the avoided green house gas emission were estimated. Currently, there are three potential sites for the PV array installation, and two of them (i.e., 250 acres of West of MAMS and 740 acres of Little Mountain) have been selected for the study. In order to estimate the annual energy generation from the selected array, the PVWatts Solar PV Energy Calculator was utilized. When the one axis tracking system is chosen, the 1MW system would generate 1,824,038 kWh of electricity, annually. This value corresponds to 20.1% of capacity factor. Therefore, if each of potential site would be fully covered by solar PV arrays,

3) West of MAMS can generate about 45.6 GWh annually.
4) Little Mountain can generate about 135 GWh annually.

The capital cost would be $175 million for West of MAMS, and $518 million for the Little Mountain, and this will result in 38 years of simple payback. The total greenhouse emission avoided for West of MAMS and Little Mountain would be 20,571 tons and 60,891 tons, respectively.

Summary of energy and cost savings is shown in Table 3.

[5] Number of job created = Total capital cost ($)/$92,000

Table 3: Summary - Energy, Cost and Emission Avoided

Solar PV Array	*Annual Elec Generation (MWh/yr)*	*Annual Elec Cost Savings ($)*	*Conceptual Implementati on Costs ($)*	*Simple Payback*	*Green House Gas Emission Avoided (Tons/yr)*
West of MAMS	45,601	4,560,095	175,000,000	38.4	20,572
Little Mountain	134,979	13,497,881	518,000,000	38.4	60,892

Action Plan for Implementation of ECM's

Two opportunities have been identified for the given site, which are 1) GSHP system application for the building 1575, and 2) Installation of single axis solar PV tracking system.

Both projects are feasible at the sites, and there are numerous GSHP designer and installers close to the base. For actual installation, the assessment team recommends contacting the GSHP designers and installers to perform engineering designs, and the cost estimates.

APPENDIX A

Appendix A provides the site visit report and the pictures taken.

FEMP Site Visit Summary Report

American Recovery and Reinvestment Act (ARRA)
FEMP Technical Assistance
Hill Air Force Base Energy Security

Agency Name: U. S. Air Force
Site Name: Hill Air Force Base – Ogden Air Logistics Center
City (location), State: Ogden, Utah
Dates of Site Visit: January 11-12, 2010
Date of FEMP Debrief: January 12, 2010

ASSESMENT TEAM

The following ARRA team members participated in the Site visit:

John Rast
Piljae Im

SITE SUPPORT

The following site personnel participated in the ARRA Inbrief Meeting, site visits, discussions, and ARRA Debrief Meeting:

Mary Enges, Esq, Energy Project Manager
Lt Col Rudy Tessnow, IMA to the Director
Steven Phibbs, Financial Manager
David Bruce Evans, Biofuels/Nuclear
Tom Holland, Wind/ESPC/Solar
David Lund, Project Manager Solar/Cogen/ESPC
Dale Scott P.E., Base Civil Engineering / Resource Efficiency Manager
Mark Holt, EUL Program Manager

ACTIVITIES

Areas Visited

Site	Mission/Use Type	Area
Falcon Hill Quad	Air Force Office Complex - future	25,000 ft^2 per floor

Falcon Hill North End	Commercial Development - future	TBD
East Side Development	3-Bay Fire Station and other future facilities	TBD
West of MAMS	Potential Solar	200-300 acres
North Perimeter	Potential Solar	TBD
South of MAMS	Existing 250 kW Solar Array	
Little Mountain	Potential Solar	740 acres

Energy Conservation Opportunities Identified

The team identified recommendations for reducing energy consumption, operating costs, and for increasing renewable energy opportunities. The initial list is as follows:

1. Evaluate potential application of Ground Source Heat Pumps for new office complex
2. Determine best locations for two thermal conductivity tests (test well locations)
3. Evaluate sites for potential solar PV arrays
    - Hill AFB West Perimeter
    - Little Mountain
    - Wendover

ADDITIONAL INFORMATION

Statement of Work

Ground Source Heat Pump Analysis

ORNL will perform ground thermal conductivity tests at two locations selected by Hill AFB. The test wells will be installed by a subcontractor to ORNL.

ORNL will develop energy simulation models for two buildings at the Falcon Hill Air Force Office complex based on the building plans provided by Hill AFB. Using the results of the thermal conductivity tests and the simulation model, ORNL will determine the best application of GSHP technology for the buildings, estimate costs and simple payback. Results will be presented in a report to Hill AFB.

Hill AFB will provide the following additional information:

1. Locations for the two test wells (latitude and longitude)
2. Hill AFB requirements/permits for drilling test wells

Solar PV Evaluation

ORNL will evaluate solar PV potential for the three sites listed above. Based on the land area available at each site, ORNL will determine the potential solar PV production. ORNL will evaluate the alternative solar PV technologies and recommend the technology most suited to the sites. ORNL will estimate costs for solar PV installations and simple payback. Results will be presented in a report to Hill AFB.

Hill AFB will provide the following additional information:

1. Acreage available for solar development at each site
2. Potential financial incentives for the Wendover site
3. Proximity of grid tie-in point for the Wendover site

Schedule

Site Visit: January 11-12, 2010

Ground Thermal Conductivity Tests: complete by April 30, 2010

Draft GSHP and Solar PV Reports: issue by May 28, 2010

Hill AFB Review & Comments: by June 30, 2010

Issue Final Reports: by July 30, 2010

Customer Survey: by August 16, 2010

All Activities Complete: by August 30, 2010

Photos

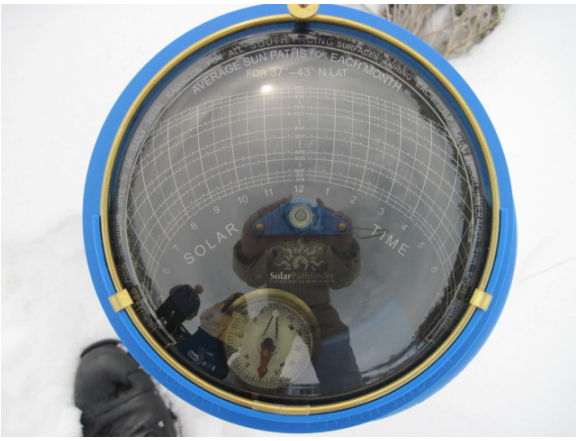
Little Mtn. East of Water Plant – Looking South

Little Mtn. East of Water Plant – Looking West

Little Mtn. East of Water Plant – Looking North

West of MAMS Area – Looking South

West of MAMS Area – Looking North



Solar Pathfinder – West of MAMS Area

Quad – Future Air Force Office Complex

East Development SE of 680 – Looking South

Quad – Future Air Force Office Complex

North Falcon Hill Development Area

East Development SE of 680 – Toward Future Fire Station

North Falcon Hill Development Area

APPENDIX B

Appendix B provides the formation thermal conductivity test and data analysis conducted May 2010 on the base. There are two test results in this report. The first test was conducted at Falcon Hill Quad, and the second test was conducted at 3-Bay Fire Station.

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WEB SITE:
www.GRTI.com

FORMATION THERMAL CONDUCTIVITY TEST AND DATA ANALYSIS

Analysis for: **Sound Geothermal Corporation**
3962 East Alpine Valley Circle
Sandy, UT 84092
Phone: 801-942-6100
Fax: 801-942-6127

Test location: **Falcon Hill Quad**
Hill AFB, UT

Report Date: May 24, 2010

Test Performed by: **Sound Geothermal Corporation**

Executive Summary

A formation thermal conductivity test was performed at the Falcon Hill Quad site at Hill AFB at a GPS location of N 41° 7' 28.92" (latitude), W 112° 0' 52.20" (longitude). The vertical bore was completed on May 2, 2010 by Bertram Drilling, Inc. GRTI's test unit was attached to the vertical bore on the afternoon of May 10, 2010. Geothermal Resource Technologies, Inc. analyzed the collected data using the "line source" method.

This report provides a general overview of the test and procedures that were used to perform the thermal conductivity test along with a plot of the data in real time and in a form used to calculate the formation thermal conductivity. The following average formation thermal conductivity was found from the data analysis.

⇒ Formation Thermal Conductivity = 1.23 Btu/hr-ft-°F

Due to the necessity of a thermal diffusivity value in the design calculation process, an estimate of the average thermal diffusivity was made for the encountered formation.

⇒ Formation Thermal Diffusivity ≈ 0.80 ft^2/day

An estimate of the undisturbed formation temperature was determined from the initial temperature data at startup.

⇒ Undisturbed Formation Temperature ≈ 54.3-55.4°F

A copy of the original collected data is available either in a hard copy or an electronic format upon request.

Test Procedures

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) has published a set of recommended procedures for performing formation thermal conductivity tests for geothermal applications. GRTI is committed to adhering to ASHRAE recommendations. Some of these recommended procedures are listed below:

(1) Required Test Duration – A minimum test duration of 36 hours is recommended, with a preference toward 48 hours.

(2) Power Quality – The standard deviation of the power should be less than or equal to 1.5% of the average power, with maximum power variation of less than or equal to 10% of the average power. The heat flux rate should be 51 Btu/hr (15 W) to 85 Btu/hr (25 W) per foot of borehole depth to best simulate the expected peak loads on the u-bend.

(3) Undisturbed Formation Temperature Measurement – The undisturbed formation temperature should be determined by recording the minimum loop temperature as the water returns from the u-bend at test startup.

(4) Installation Procedures for Test Loops – The bore diameter is to be no larger than 6 inches, with 4.5 inches being the target diameter. To ensure against bridging and voids, the bore annulus is to be uniformly grouted from the bottom to the top using a tremie pipe.

(5) Time Between Loop Installation and Testing – A minimum delay of five days between loop installation and test startup is recommended if the formation is expected to have a low thermal conductivity or if low conductivity grouts (< 0.75 Btu/hr·ft·ºF) are used. A minimum delay of three days is recommended for all other conditions.

GRTI's testing procedures deviate slightly from those above with regard to item (5). While item (5) bases the delay between installation and testing on the expected formation conductivity, GRTI bases its delay on the type of drilling used in the installation. When air drilling is required, a five-day delay is recommended to allow the bore to return to its undisturbed temperature. For mud rotary drilling, a minimum waiting period of two days is sufficient.

For a complete list of recommended procedures, refer to the ASHRAE 2007 HVAC Applications handbook, pages 32.12-32.13.

Data Analysis

Geothermal Resource Technologies, Inc. uses the "line source" method of data analysis. The line source equation used is not valid for early test times. Also, the line source method assumes an infinitely thin line source of heat in a continuous medium. If a u-bend grouted in a borehole is used to inject heat into the ground at a constant rate in order to determine the average formation thermal conductivity, the test must be run long enough to allow the finite dimensions of the u-bend pipes and the grout to become insignificant. Experience has shown that the amount of time required to allow early test time error and finite borehole dimension effects to become insignificant is approximately ten hours.

In order to analyze real data from a formation thermal conductivity test, the average temperature of the water entering and exiting the u-bend heat exchanger is plotted versus the natural log of time. Using the Method of Least Squares, the linear equation coefficients are then calculated that produce a line that fits the data. This procedure is normally repeated for various time intervals to ensure that variations in the power or other effects are not producing erroneous results.

Through the analysis process, the collected raw data is converted to spreadsheet format (Microsoft Excel®) for final analysis. A copy of this data can be obtained either in a hard copy or electronic copy format at any time. If desired, please contact Geothermal Resource Technologies, Inc. and provide a ship-to address or e-mail address at one of the following:

Contact: Galen Streich
Phone: (605) 692-9069
Fax: (605) 692-2604
E-mail: gstreich@grti.com

Formation Thermal Conductivity Test Report

Date	May 10-12, 2010
Location	Hill AFB, UT
Undisturbed Formation Temperature	Approx. 54.3-55.4°F

Borehole Data – As Provided by Sound Geothermal Corporation

Borehole Diameter ..... 5 1/8 inches

Drill Log .....

Brown silt and clay, trace sand	0'-50'
Brown clay, trace silt and sand	50'-80'
Brown and gray-brown clay, trace sand	80'-210'
Clay with intermittent lenses of fine sand	210'-260'
Clay, trace sand	260'-270'
Clay, some sand lenses	270'-290'
Fine sand, trace clay	290'-300'
Silty clay with black sand	300'-380'
Silty clay with black sand, trace fine gravel	380'-400'

U-bend Size	1 1/4 inch HDPE
U-Bend Length	400 ft
Grout Type	GeoPro Thermal Grout Select 1.07
Grout Solids	6:1 sand to bentonite ratio
Grouted Portion	Entire bore

Test Data for Analysis Time Period

Test Duration	42.4 hrs.
Average Voltage	241.7 V
Average Power	10,435 W
Total Heat Input Rate	35,616 Btu/hr
Calculated Circulator Flow Rate	9.6 gpm
Standard Deviation of Power	0.12%
Maximum Variation in Power	0.70%

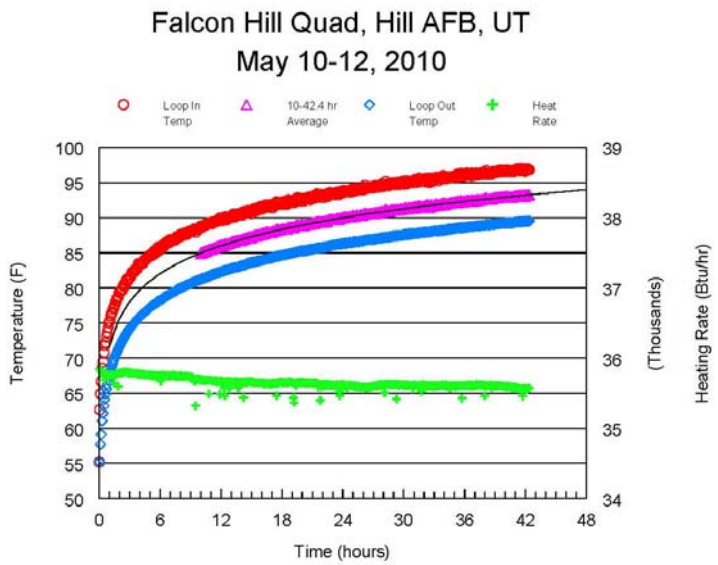

Figure 1: Temperature versus Time Data

Line Source Data Analysis

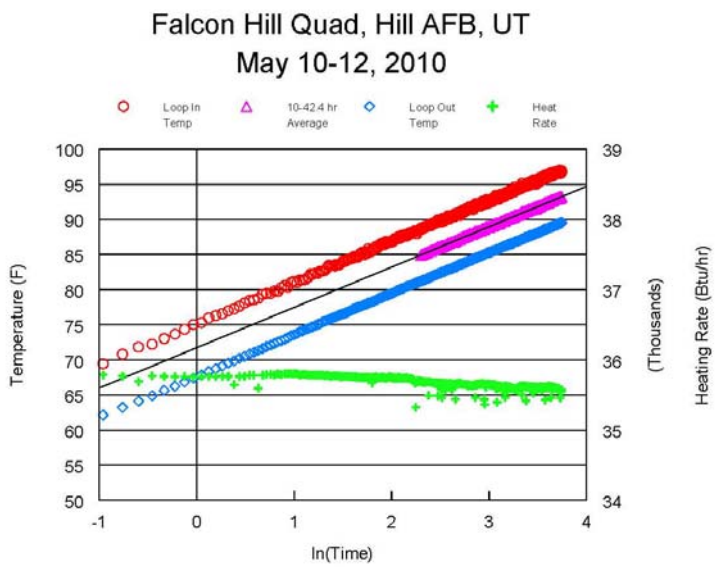

Figure 2: Temperature versus Natural Log of Time

Time Period	Slope	Average Heat Input (Btu/hr-ft)	(W/ft)	Thermal Conductivity (Btu/hr-ft-°F)
10 – 42.4 hrs	5.74	89.0	26.1	1.23

The temperature versus time data was analyzed using the line source analysis for the time period shown above. An average linear curve fit was applied to the data between 10 and 42.4 hours. The slope of the curve was found to be 5.74. The resulting thermal conductivity was found to be 1.23 Btu/hr-ft-°F.

Estimated Thermal Diffusivity

The reported drilling log for this test borehole indicated that the formation consisted of clay, silt, sand and gravel. A weighted average of heat capacity values based on the indicated formation was used to develop an average heat capacity for the formation. A diffusivity value was then found using the calculated formation thermal conductivity and the estimated heat capacity. The thermal diffusivity for this formation was estimated to be 0.80 ft^2/day.

Est. Average Heat Capacity (Btu/ft^3-°F)	Thermal Conductivity (Btu/hr-ft-°F)	Est. Thermal Diffusivity (ft^2/day)
36.8	1.23	0.80

Frequently Asked Questions (FAQ's) Regarding FTC Testing

Q: Thermally-enhanced grout is specified for the final loop field design. The test bore was grouted with a low conductivity, 20% solids, bentonite grout. How do I adjust the thermal conductivity value to account for this?

A: While the conductivity of the grout is important for the loop field design, it is not important for determining formation thermal conductivity. We use the "line source" method to analyze data, which assumes an infinitely thin line rejecting heat at a constant rate into an infinite medium. The initial ten hours, which is influenced by the bore dimensions and grout conductivity, is ignored in the analysis. However, once the heat has penetrated into the formation, the temperature rise of the formation approaches steady-state. It is the slope of the temperature rise that is used in the analysis. Hence, no adjustment to the reported formation thermal conductivity is required.

Q: The software I use to design the loop field requires that I input a value for "soil conductivity". Is this the same as formation thermal conductivity?

A: Absolutely. Formation, soil, and ground are all used interchangeably to describe the conditions in which the u-bends will be installed. The use of the word "formation" simply implies that the installation conditions may be soil, rock, or some combination of the two.

Q: I've just received your report. I have a formation conductivity of 1.54 Btu/hr·ft·°F. How do I translate that into a loop length requirement, in terms of bore depth (in feet) per ton?

A: The formation thermal conductivity test provides values for three key parameters required for the ground loop design. These are the "Undisturbed Formation Temperature, Formation Thermal Conductivity, and Formation Thermal Diffusivity." These parameters, along with many others, are inputs to commercially available loop design software (e.g. GchpCalc, available at GeoKiss.com/software). The software uses all of the inputs to determine the required loop length in bore depth per ton.

Q: Is the "Undisturbed Formation Temperature" listed in the report the temperature that I enter into my loop design software where it calls for the "Deep-Earth Temperature"?

A: Generally, yes. The "Undisturbed Formation Temperature" is the constant temperature of the formation. We attempt to determine this value by measuring the temperature of the water entering the test unit at the beginning of the test. However, the value we measure and report may be inaccurate if the test is initiated too quickly after the installation of the test bore, or if the testing operator failed to activate the data acquisition unit prior to energizing the heating elements. If you suspect the temperature we are reporting to be too high or too low, we recommend that you investigate further through other sources.

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FORMATION THERMAL CONDUCTIVITY TEST AND DATA ANALYSIS

Analysis for: **Sound Geothermal Corporation**
3962 East Alpine Valley Circle
Sandy, UT 84092
Phone: 801-942-6100
Fax: 801-942-6127

Test location: **3-Bay Fire Station**
Hill AFB, UT

Report Date: May 25, 2010

Test Performed by: **Sound Geothermal Corporation**

Executive Summary

A formation thermal conductivity test was performed at the 3-Bay Fire Station site at Hill AFB at a GPS location of N 41° 7' 43.32" (latitude), W 111° 57' 56.16" (longitude). The vertical bore was completed on May 4, 2010 by Bertram Drilling, Inc. GRTI's test unit was attached to the vertical bore on the afternoon of May 10, 2010. Geothermal Resource Technologies, Inc. analyzed the collected data using the "line source" method.

This report provides a general overview of the test and procedures that were used to perform the thermal conductivity test along with a plot of the data in real time and in a form used to calculate the formation thermal conductivity. The following average formation thermal conductivity was found from the data analysis.

⇒ Formation Thermal Conductivity = 1.17 Btu/hr-ft-°F

Due to the necessity of a thermal diffusivity value in the design calculation process, an estimate of the average thermal diffusivity was made for the encountered formation.

⇒ Formation Thermal Diffusivity ≈ 0.77 ft^2/day

An estimate of the undisturbed formation temperature was determined from the initial temperature data at startup.

⇒ Undisturbed Formation Temperature ≈ 52.1-53.2°F

A copy of the original collected data is available either in a hard copy or an electronic format upon request.

Test Procedures

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(1) Required Test Duration – A minimum test duration of 36 hours is recommended, with a preference toward 48 hours.

(2) Power Quality – The standard deviation of the power should be less than or equal to 1.5% of the average power, with maximum power variation of less than or equal to 10% of the average power. The heat flux rate should be 51 Btu/hr (15 W) to 85 Btu/hr (25 W) per foot of borehole depth to best simulate the expected peak loads on the u-bend.

(3) Undisturbed Formation Temperature Measurement – The undisturbed formation temperature should be determined by recording the minimum loop temperature as the water returns from the u-bend at test startup.

(4) Installation Procedures for Test Loops – The bore diameter is to be no larger than 6 inches, with 4.5 inches being the target diameter. To ensure against bridging and voids, the bore annulus is to be uniformly grouted from the bottom to the top using a tremie pipe.

(5) Time Between Loop Installation and Testing – A minimum delay of five days between loop installation and test startup is recommended if the formation is expected to have a low thermal conductivity or if low conductivity grouts (< 0.75 Btu/hr·ft·ºF) are used. A minimum delay of three days is recommended for all other conditions.

GRTI's testing procedures deviate slightly from those above with regard to item (5). While item (5) bases the delay between installation and testing on the expected formation conductivity, GRTI bases its delay on the type of drilling used in the installation. When air drilling is required, a five-day delay is recommended to allow the bore to return to its undisturbed temperature. For mud rotary drilling, a minimum waiting period of two days is sufficient.

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In order to analyze real data from a formation thermal conductivity test, the average temperature of the water entering and exiting the u-bend heat exchanger is plotted versus the natural log of time. Using the Method of Least Squares, the linear equation coefficients are then calculated that produce a line that fits the data. This procedure is normally repeated for various time intervals to ensure that variations in the power or other effects are not producing erroneous results.

Through the analysis process, the collected raw data is converted to spreadsheet format (Microsoft Excel®) for final analysis. A copy of this data can be obtained either in a hard copy or electronic copy format at any time. If desired, please contact Geothermal Resource Technologies, Inc. and provide a ship-to address or e-mail address at one of the following:

Contact: Galen Streich
Phone: (605) 692-9069
Fax: (605) 692-2604
E-mail: gstreich@grti.com

Formation Thermal Conductivity Test Report

Date ..... May 10-12, 2010
Location ..... Hill AFB, UT
Undisturbed Formation Temperature ..... Approx. 52.1-53.2°F

Borehole Data – As Provided by Sound Geothermal Corporation

Borehole Diameter ..... 5 1/8 inches

Drill Log .....

Brown clay and silt	0'-8'
Brown clay and silt, trace gravel	8'-10'
S-M gravel, trace clay and silt	10'-20'
50% clay, 50% gravel	20'-30'
Brown clay, 10% gravel	30'-40'
Silty clay	40'-215'
Clay with S-L gravel	215'-220'
50% clay trace sand, 50% S-L gravel	220'-360'
70% clay trace sand, S-L gravel	360'-401'

U-bend Size ..... 1 1/4 inch HDPE
U-Bend Length ..... 401 ft
Grout Type ..... GeoPro Thermal Grout Select 1.07
Grout Solids ..... 6:1 sand to bentonite ratio
Grouted Portion ..... Entire bore

Test Data for Analysis Time Period

Test Duration ..... 43.0 hrs.
Average Voltage ..... 241.8 V
Average Power ..... 8,312 W
Total Heat Input Rate ..... 28,367 Btu/hr
Calculated Circulator Flow Rate ..... 6.0 gpm
Standard Deviation of Power 0.06%
Maximum Variation in Power 0.16%

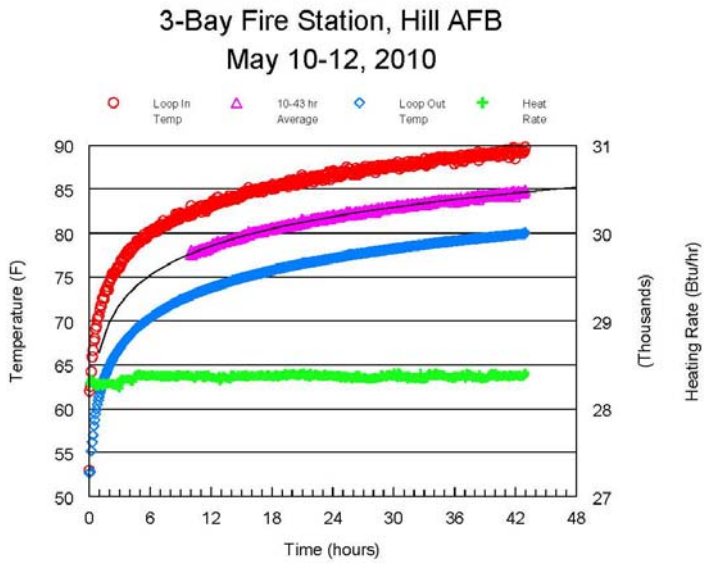

Figure 1: Temperature versus Time Data

Line Source Data Analysis

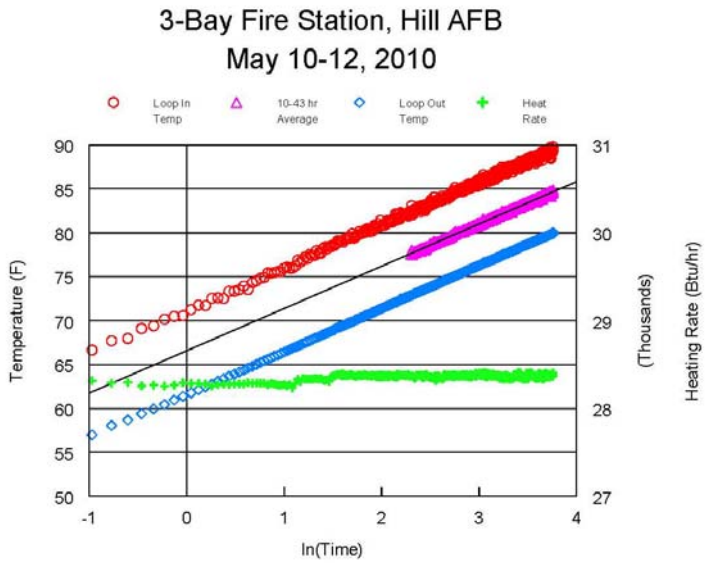

Figure 2: Temperature versus Natural Log of Time

Time Period	Slope	Average Heat Input (Btu/hr-ft)	(W/ft)	Thermal Conductivity (Btu/hr-ft-°F)
10 – 43.0 hrs	4.81	70.7	20.7	1.17

The temperature versus time data was analyzed using the line source analysis for the time period shown above. An average linear curve fit was applied to the data between 10 and 43.0 hours. The slope of the curve was found to be 4.81. The resulting thermal conductivity was found to be 1.17 Btu/hr-ft-°F.

Estimated Thermal Diffusivity

The reported drilling log for this test borehole indicated that the formation consisted of clay, silt, sand and gravel. A weighted average of heat capacity values based on the indicated formation was used to develop an average heat capacity for the formation. A diffusivity value was then found using the calculated formation thermal conductivity and the estimated heat capacity. The thermal diffusivity for this formation was estimated to be 0.77 ft^2/day.

Est. Average Heat Capacity (Btu/ft^3-°F)	Thermal Conductivity (Btu/hr-ft-°F)	Est. Thermal Diffusivity (ft^2/day)
36.3	1.17	0.77

Frequently Asked Questions (FAQ's) Regarding FTC Testing

Q: Thermally-enhanced grout is specified for the final loop field design. The test bore was grouted with a low conductivity, 20% solids, bentonite grout. How do I adjust the thermal conductivity value to account for this?

A: While the conductivity of the grout is important for the loop field design, it is not important for determining formation thermal conductivity. We use the "line source" method to analyze data, which assumes an infinitely thin line rejecting heat at a constant rate into an infinite medium. The initial ten hours, which is influenced by the bore dimensions and grout conductivity, is ignored in the analysis. However, once the heat has penetrated into the formation, the temperature rise of the formation approaches steady-state. It is the slope of the temperature rise that is used in the analysis. Hence, no adjustment to the reported formation thermal conductivity is required.

Q: The software I use to design the loop field requires that I input a value for "soil conductivity". Is this the same as formation thermal conductivity?

A: Absolutely. Formation, soil, and ground are all used interchangeably to describe the conditions in which the u-bends will be installed. The use of the word "formation" simply implies that the installation conditions may be soil, rock, or some combination of the two.

Q: I've just received your report. I have a formation conductivity of 1.54 Btu/hr·ft·°F. How do I translate that into a loop length requirement, in terms of bore depth (in feet) per ton?

A: The formation thermal conductivity test provides values for three key parameters required for the ground loop design. These are the "Undisturbed Formation Temperature, Formation Thermal Conductivity, and Formation Thermal Diffusivity." These parameters, along with many others, are inputs to commercially available loop design software (e.g. GchpCalc, available at GeoKiss.com/software). The software uses all of the inputs to determine the required loop length in bore depth per ton.

Q: Is the "Undisturbed Formation Temperature" listed in the report the temperature that I enter into my loop design software where it calls for the "Deep-Earth Temperature"?

A: Generally, yes. The "Undisturbed Formation Temperature" is the constant temperature of the formation. We attempt to determine this value by measuring the temperature of the water entering the test unit at the beginning of the test. However, the value we measure and report may be inaccurate if the test is initiated too quickly after the installation of the test bore, or if the testing operator failed to activate the data acquisition unit prior to energizing the heating elements. If you suspect the temperature we are reporting to be too high or too low, we recommend that you investigate further through other sources.

APPENDIX C

Appendix C provides the inputs and outputs from the GLD GHX Design software.

Calculation Results

	COOLING	HEATING
Total Length (ft):	**44534.5**	**35320.7**
Borehole Number:	**114**	**114**
Borehole Length (ft):	**390.7**	**309.8**
Ground Temperature Change (°F):	**+3.4**	**+4.3**
Unit Inlet (°F):	**85.0**	**35.0**
Unit Outlet (°F):	**94.9**	**29.4**
Total Unit Capacity (kBtu/Hr):	**3350.7**	**2839.5**
Peak Load (kBtu/Hr):	**2175.8**	**2839.5**
Peak Demand (kW):	**148.4**	**249.1**
Heat Pump EER/COP:	**14.7**	**3.3**
System EER/COP:	**14.7**	**3.3**
System Flow Rate (gpm):	**544.0**	**709.9**

Input Parameters

Fluid		Soil	
Flow Rate:	3.0 gpm/ton	Ground Temperature:	54.0 °F
Fluid:	100% Water	Thermal Conductivity:	1.23 Btu/(h*ft*°F)
Specific Heat (Cp):	1.00 Btu/(°F*lbm)	Thermal Diffusivity:	0.80 ft^2/day
Density (rho):	62.4 lb/ft^3		

Piping	
Pipe Type:	1 in. (25 mm) - SDR11
Flow Type:	Turbulent
Pipe Resistance:	0.104 h*ft*°F/Btu
U-Tube Configuration:	Single
Radial Pipe Placement:	Average
Borehole Diameter:	6.00 in
Grout Thermal Conductivity:	0.85 Btu/(h*ft*°F)
Borehole Thermal Resistance:	0.273 h*ft*°F/Btu