Feasibility Study for Evaluation of Geothermal Energy

Regarding:

The First Avenue PK-8 District School
Newark, New Jersey

Prepared for:

New Jersey Schools
Construction Corporation
Two Gateway Center
Newark, New Jersey

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Table of Contents

1.0 EXECUTIVE SUMMARY

A new Pre-K-8 school is being planned for construction on First Avenue in Newark, New Jersey. In this report a ground-coupled heat pump (GCHP) system will be evaluated against a conventional heating and cooling system.

During the course of this study, it was ascertained that the minimal land available for the geothermal ground loop heat exchange (GLHE) system at the site would limit the geothermal system from providing the full capacity of the cooling and heating loads of the school. It was determined that 233 tons of cooling capacity could be provided by installing geothermal wells inside the sidewalk boundary around the outer perimeter of the property and in the Great Courtyard space, providing adequate cooling capacity to heat and cool the Classrooms and associated Corridors.

The use of a geothermal heat pump is being considered for Newark Science Park High School, which is located a few miles south of the First Avenue School project site. PS&S reviewed reports for the Newark Science Park High School prepared by Geothermal System, Inc. (GSI) of Mays Landing, New Jersey and Geothermal Resource Technologies, Inc (GRTI) of Asheville, North Carolina. Consistent results were reported from both pilot tests, indicating a thermal conductivity of 1.47 and 1.43 British Thermal Units/hour-foot-degree F (Btu/hr-ft-F), with an estimated Thermal Diffusivity of 1.13 and 1.11 square feet/day (sq ft/day) for the formation. The temperature of undisturbed soil samples from the test borings was 56^{o} to 57^{o} F.

Overall, subsurface hydrogeologic conditions at the site and project area appear to be favorable for the use of closed loop geothermal heat pump system. The geothermal wells would most likely be installed into the underlying bedrock.

Capital costs for the two systems are presented in Table A2. Capital costs for the conventional were $2,044,428 before rebates, and after rebates ($28/Ton) the cost became $2,037,873, while the geothermal system cost before rebates was $2,311,881 and after rebates ($580/Ton) the cost became $2,176,093.

Total Annual Building HVAC Maintenance Costs for the two systems are shown in Table A3. Maintenance costs for the conventional 2-pipe system totaled $29,566 while the geothermal system produced reduced maintenance costs of $15,264. Subsequent discussions with persons in the business of maintaining HVAC equipment have indicated that there may be little or no maintenance cost savings associated with the use of multiple small heat pump units in place of 2-pipe fan coil units.

Operating costs for the two comparative systems are shown in Table A4. Operating costs for the conventional 2-pipe system totaled $31,934 while the geothermal system had reduced operating costs of $22,701.

Table A5 shows the Lifecycle costs for the two systems. The construction cost differential between the geothermal system with rebates and the conventional 2-pipe system with rebates totaled $138,220. Maintenance and operating cost savings between the conventional 2-pipe system and the geothermal system totaled $14,303 and $9,232 respectively, with a simple payback of 5.9 years. Eliminating the maintenance cost savings, as suggested by persons in the business of maintaining HVAC systems, would increase the simple payback to 14.9 years.

A 20-year lifecycle cash flow analysis was run for the conventional 2-pipe system and the geothermal system as shown in Table A6. Total yearly saving of the geothermal system over the conventional 2-pipe system are tabulated showing a total 20-year savings of $369,564. Eliminating the maintenance cost savings, as suggested by persons in the business of maintaining HVAC systems, would decrease the 20-year savings to $4,214.

The Life Cycle Cost Estimate requires numerous assumptions, particularly regarding the capital costs and operating costs associated with each of the systems being considered. Slight variations in key assumptions can result in appreciable changes in the life cycle cost analysis, decreasing the simple payback to 5.0 years, or less, or increasing it to 14.9 years, or more, with corresponding changes to total 20-year savings.

GLHE systems are inherently dependent on the ground parameters of the specific site under investigation. Thermal conductivity and ground temperatures are major factors in the accurate design of a geothermal well field. The use of data developed for other sites is adequate for a preliminary assessment; however, for a more accurate assessment, and for detailed design, site-specific information must be obtained, as recommended in our proposal to the New Jersey Schools Construction Corporation (NJSCC) dated September 02, 2003.

In general, this study has determined that a GLHE system is technically feasible for this project. This study has also determined that a GLHE system is economically feasible for the Classroom portion of the project, when compared to a 2-pipe fan coil system for the Classroom portion of the project.

The application of the geothermal system for this building is limited by the capacity of the available well field (in this case, 233 tons). The cooling load for the entire building is estimated to be 550 tons; therefore, evaluation of the overall geothermal system costs (Capital, Maintenance, Operating and Life Cycle) must address the type of system to be used for the balance of the building.

In addition, the NPS and NJSCC have expressed interest in comparing the pros and cons of several different HVAC systems, including their system costs (Capital, Maintenance, Operating and Life Cycle). PS&S has developed order-of-magnitude opinions of these costs for the following systems:

System 1: “Traditional” boilers, air-cooled chillers, 2-pipe fan coils for Classrooms and packaged DX rooftop units with gas-fired heat for other spaces. Dedicated Outdoor Air units for Classroom ventilation (with energy recovery and CHW and HW coils). This system is used as the baseline for comparisons.

System 2: same as System 1, but with higher efficiency modular boilers in place of “traditional” boilers.

System 3: same as System 2, but with thermal (ice) storage and reduced chiller plant size (partial storage system).

System 4: Same as System 1, but with gas-fired absorption chiller-heaters in place of “traditional” boilers and air-cooled chillers.

System 5A: GLHE heat pumps for Classrooms and Corridors (in place of 2-pipe fan coils and central plant chillers and boilers) and packaged DX rooftop units with gas-fired heat for other spaces.

System 5B: GLHE heat pumps for Classrooms and Corridors (in place of 2-pipe fan coils) and roof mounted CHW/HW air handling units for other spaces (with modular boilers and air cooled chillers with thermal ice storage to provide HW and CHW to the units).

A summary of our systems comparisons is presented in Table A.7; a detailed discussion of the various systems is found in Section 9 of this report.

From the results in Table A.7, there is no single clear choice for the best system for the project (although it is clear that System 4 is the least desirable choice, and System 2 is not particularly attractive, either). If budget constraints alone dictate the choice of a system, then System 1 is the best choice (albeit by a slim margin). If Maintenance Costs are the primary concerns, then Systems 2, 3, 5A and 5B are virtually identical choices (although Systems 5A and 5B may be more difficult to maintain in practice). Operating Costs are subject to wide variations with slight changes in basic assumptions such as utility rates and inflation, and should not be used as the sole factor in selecting a system. System 3 has the most attractive Simple Payback (5.4 years). Life Cycle (20 Year Ownership) Costs are subject to wide variations with slight changes in basic assumptions in much the same way as Operating Costs; still, System 3 has the lowest Life Cycle Cost ($11,672,269), with Systems 5B and 5A virtually even ($11,708,782 and $11,728,228 respectively).

A case can be made for selecting either System 1, 3, 5A or 5B, depending upon the NPS and NJSCC’s dominant criteria; however, it is our opinion that System 3 offers a number of advantages over the other systems and that these advantages are not as likely to be affected by potential deviations from the assumptions of this report as are those offered by Systems 5A and 5B.

2.0 BACKGROUND INFORMATION

A new Pre-K-8 school is being planned for construction on First Avenue, in the block bordered by Second Avenue, Sixth Street and Seventh Street in Newark, New Jersey. The use of a geothermal heat-pump system is being evaluated for incorporation in the new school. The use of a geothermal heat-pump system is being evaluated as a supplement to the traditional heating and cooling systems currently under consideration.

The project site is located in the western portion of Newark, near its border with East Orange, New Jersey. The project area is densely populated with residential housing (multi-family buildings, single family homes and apartment buildings) and small commercial districts surrounding the proposed school area for several blocks in all directions.

The use of geothermal energy in the mid-Atlantic states is limited to the dissipation or extraction of thermal energy (heat) from the ground or groundwater. The use of groundwater in both direct and non-contact cooling has been used for several decades by business and industries. There are a number of facilities in the Newark area which primarily use either direct or non-contact cooling for industrial purposes. Over the past decade or so, the use of a heat-pump to extract or dissipate heat from the ground and groundwater to provide supplemental heat energy has gained some popularity due to the operational benefits. In this report a ground-coupled heat pump (GCHP) system will be evaluated against a conventional heating and cooling system. While groundwater heat pumps utilizing production and injection wells are generally less costly to install, they are not usually recommended in consolidated rocky formations that are typical in the Newark area, plus they may have environmental permitting and water quality concerns over and above those of a closed-loop system.

Geothermal ground-coupled heat-pump systems utilize a closed loop well system that can be installed in either “dry” boreholes or water saturated boreholes (groundwater systems or aquifers) advanced into either consolidated or unconsolidated formations. In the mid-Atlantic states, groundwater is an excellent source for heating or cooling because the temperature of groundwater is relatively constant at a depth of approximately 20 to 25 feet to approximately 500 feet. The temperature of groundwater typically rises at a rate of 1 degree per 100 feet (natural geothermal gradient) in depth. In addition, the movement of groundwater through either consolidated or unconsolidated material aids in transferring heat energy away from the borehole.

The basic concept of a GCHP system consists of a heat extraction/cooling unit with a circulating pump connected to a liquid circulating piping loop capable of absorbing or releasing thermal energy to maintain a comfortable temperature range within a building. The basic components of a GCHP system consists of the closed loop (either horizontal or vertical loop installed in the ground or groundwater), the pump to circulate the liquid in the cooling loop and the water-to-water or water-to-air heat extraction pump system. Heat-pump operation permits the ground or groundwater source to be used as either a sink or a source, depending on whether heating or cooling is required.

If the liquid in the loop is cooler than the ground or groundwater around it, heat will flow from the ground to the liquid in the loop. The liquid in the loop then flows to the heat-pump, where the heat is extracted. In the cooling mode, the system is reversed and heat is removed from the building and transferred to the liquid in the loop, where the heat is then conducted into the ground or groundwater. The loop itself does not have to be in contact with groundwater to function, but if it is partially immersed in groundwater the transfer of heat is facilitated. Brine, water with a non-toxic antifreeze additive or a non-toxic fluid with a low freezing point, can be circulated through the closed loop in such a system.

3.0 INTRODUCTION

PS&S has evaluated the potential of geothermal ground coupled heat pump (GCHP) technology for the 1st Avenue PK-8 School in compliance with our proposed scope of work and has prepared the following report detailing the results of our findings. During the investigation of GCHP technology for the 1st Avenue School, it was ascertained that the minimal land available for the geothermal ground loop heat exchange (GLHE) system at the site would limit the geothermal energy system from providing the full capacity of the cooling and heating loads of the school. Therefore, to determine which school spaces could be served by the GCHP system, PS&S reverse engineered the maximum GLHE capacity and matched it with a logical space to be served by the GCHP system. Since maximum cooling load sets the design basis of a GCHP system for this geographic location, it was determined (details are discussed in Section 6) that 233 tons of cooling capacity could be provided by installing geothermal wells inside the sidewalk boundary around the outer perimeter of the property and in the Great Courtyard space. These well fields provided adequate cooling capacity to heat and cool the Classrooms and associated Corridors.

This geothermal energy concept became the basis of design supported by preliminary ground parameter engineering for GLHE capacity and space load analysis to match a GCHP system with appropriate occupancy and load. This led the feasibility study investigation into ground geohydrology, GLHE Well and Borehole specifics and spacing, GCHP zone selection and design, and GCHP/GLHE lifecycle cost estimates. Detailed discussions of the findings and future recommendations as part of the limited feasibility study can be found in sections 4 to 8 of this report. Section 4 provides an overall review of pertinent local, regional, state and federal initiatives, information, agencies opportunities and restrictions of geothermal energy appropriate for the site location. An overview of the local geology and hydrogeology for the school site is covered in Section 5 which outlines the ground parameters, well spacing requirements, and the dynamic interaction of the GLHE systems with groundwater thermal and hydrostatic phenomena. Preliminary heating and cooling loads are calculated and presented in Section 6 for the school spaces and the capacity requirements of the GLHE well field to match the classroom space for system design. Section 7 provides the essence of the GCHP system design and the details of the GLHE well field design for the school. The cost of the GCHP/GLHE system in reference to a traditional heating and cooling system and the operating benefits provided by the geothermal energy system are developed and presented in Section 8. The cost of six (6) potential HVAC schemes for the school are developed and presented in Section 9.

In an effort to summarize the final results and recommendations of the feasibility study for school officials, management and architects, an executive summary has been provided in Section 1 of this report. This will allow for quick review of the benefits of the geothermal energy system for the 1st Avenue PK-8 District School and the future recommendations required for development of the detailed engineering requirements for the geothermal energy system.

4.0 REVIEW OF AVAILABLE INFORMATION

PS&S requested information from the New Jersey Department of Environmental Protection, Bureau of Water Allocation (NJDEP-BWA) regarding the installation and use of geothermal closed loop wells in the project area. Discussions with NJDEP-BWA indicated that while NJDEP does not specifically "track" geothermal closed loop wells, there are a number of traditional production and injection wells in the area that are used for cooling purposes. NJDEP-BWA suggested that an individual "well search" be considered for the project area if looking for a specific well type.

PS&S also reviewed a report for the Newark Science Park High School prepared by Geothermal System, Inc. (GSI) of Mays Landing, New Jersey and Geothermal Resource Technologies, Inc (GRTI) of Asheville, North Carolina. The use of a geothermal heat pump is being considered for Newark Science Park High School, which is located a few miles south of the First Avenue School project site. GSI performed a geothermal test-boring program at the Newark Science Park High School site in May 2003. The GSI geothermal test-boring program included the construction and installation of two geothermal closed-loop wells to a depth of 450 feet. These wells were used to assess thermal conductivity of the subsurface. Groundwater was encountered in both the near surface fill material at a depth of 18 feet and at depths of 60 to 80 feet in the bedrock. A closed loop system was installed in both geothermal test borings to facilitate a geothermal pilot test conducted several days later.

Each of the pilot tests was reported to have been performed in accordance with standards set forth by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE). Each of the geothermal pilot tests were conducted for a period of approximately 46 hours until the conditions of the test became steady state. The pilot test was performed by injecting and circulating heated water through the closed loop while measuring the temperature of the water entering and exiting the loop. The data collected during the geothermal pilot tests were analyzed using the "line source" method, wherein the average temperature of the water entering and exiting the loop is plotted versus the natural log of time. The data is regressed using the Least Squares Method of linear regression to determine the coefficients needed for the equation.

Consistent results were reported from both pilot tests. The results for test borings one and two indicated a thermal conductivity of 1.47 and 1.43 British Thermal Units/hour-foot-degree F (Btu/hr-ft-F), with an estimated Thermal Diffusivity of 1.13 and 1.11 square feet/day (sq ft/day) for the formation. The temperature of undisturbed soil samples from the test borings was 56^{o} to 57^{o} F.

5.0 OVERVIEW OF LOCAL GEOLOGY AND HYDROGEOLOGY

The project site is located in the central portion of the New Jersey Piedmont Physiographic Province. The Piedmont Province is located between the Highland Province to the north and the Costal Plain Province to the south. The Piedmont Province of northern New Jersey is typically characterized by low rolling hills and small valleys, which may include streams. The Piedmont Province is also referred to as the Triassic Lowlands. A significant feature of the Piedmont Province is the Newark Basin, which is oriented northeast to southwest, and extends from southern New York to Pennsylvania. The Newark Basin was formed as a result of continental rifting and faulting with infilling of sediment by fluvial process of the Newark Supergroup during the Mesozoic Era. The Newark Basin is asymmetrical in cross section with the western basin being deeper than the eastern portion. The Newark Supergroup includes rock units of both sedimentary and igneous origin. The igneous rock units include basalt flows of the Preekness, Hook Mountain and Orange Mountain along the western margin of the basin and the diabase intrusion of the Pallislades along the eastern margin of the basin. The sedimentary rock units include the Passaic, Stockton, Lockatong formations.

The bedrock of the northern portion of the Newark Basin was extensively glaciated during the Pleistocene era. The bedrock surface was eroded and scoured, and a layer of glacially derived material was deposited on top of the bedrock surface. In many low-lying areas, the glacially derived material has reworked and re-deposited by fluvial processes.

5.1 Description of Local Geology

In the vicinity of the project site, the Piedmont Province is underlain by the Passaic Formation of Triassic age and consists primarily of siltstone and shale with intervening layers of fine grain sandstone. The strata of the Passaic Formation in this portion of the Newark Basin generally dips to the northwest at low angles (5 to 25 degrees). Several miles west of the project site is the first Watchung Mountain (Orange and Hook Mountain), which is composed of basalt lava flows, and the great Border Fault system, which denotes the western margin of the Newark Basin from the Highlands Province of PreCambrian age.

This portion of the Newark Basin was glaciated, as the glacial advance terminated just south of the Newark area. The area was impacted by fluvial processes from the melt off of retreating continental glaciation. The Passaic Formation is generally encountered at depths of 5 to 25 feet below ground surface and is typically covered with man made fill material and residual and weathered soils from the decomposition of the underlying bedrock. The soils tend to be silty with various amounts of clay and sand. In areas immediately adjacent to streams and rivers, a near surface layer of fluvium or reworked colluvium may be encountered in the floodplains.

5.2 Description of Local Hydrogeology

Based on the USGS topographic quadrangle for Orange and Elizabeth, the project site is located on a slight topographic rise with the Passaic River to the east and tributary streams to the north (Second Brook) and east (Branch Brook) of the project site. The surface water drainage patterns have been reworked by man, but tend to follow the structural orientation of the bedrock in a north to south direction. The Passaic River is a major groundwater discharge boundary and forms a groundwater divide.

The Passaic Formation is preferentially fractured and exhibits anisotropic properties, dependent of the location within the geologic media and degree of fracturing. Groundwater occurrence and movement is dependent on the extent of fracturing and the amount of interconnection between the fractures within the formation and to areas of recharge. The primary porosity and permeability of the rock media is extremely low due to the fine grain and cemented nature of the sedimentary rock units. However, secondary permeability and porosity exists in the Passaic Formation which is dependent on the length, width and interconnection of fractures, jointing plans and separated sedimentary bedding planes. The transmission of groundwater along these geologic features depends on the continuity and spatial relationship of these zones, which tend to significantly decrease with depth below 500 feet. The occurrence of groundwater at intermediate depths is discontinuous with intervening unsaturated zones, which are dependent upon the dip of the fractures and interconnection of fractures to areas of recharge. Fractured zones tend to be interlayered between less fractured zones, resulting in an aquifer exhibiting a strongly defined directional permeability.

Groundwater can occur in the Passaic Formation as a “perched condition” within the decomposed and weathered bedrock above more competent bedrock; within the upper portion of the bedrock at intermediate depths; and as a regional zone of saturation at depth in the bedrock. Given the project site’s location to surface water and soil types, it is possible that all three of these aquifer conditions can exist. The direction of groundwater flow is dependent on the structural orientation of the zones of secondary permeability and porosity and the proximity to areas of surface water recharge and discharge.

Overall, subsurface hydrogeologic conditions at the site and project area appear to be favorable for the use of closed loop geothermal heat pump system. The geothermal wells would most likely be installed into the underlying bedrock.

6.0 ENERGY LOAD ANALYSIS

A heating and cooling load analysis was performed to determine the maximum seasonal capacity sizing required for the GLHE system. Geothermal heat exchanger systems must be sized for the maximum peak loads because there is no traditional boiler, chiller or cooling tower in the loop to augment the cooling and heating supplied by the geothermal system. In the Newark area, cooling load capacity takes precedence over the heating load capacity. GLHE systems in this area are usually sized to meet the maximum summer time demands for cooling of the space served. Preliminary calculations show the capacity requirements for cooling and heating and the dominant affect that the cooling load has over heating. The geothermal GLHE system will be sized to handle the maximum cooling load. Another design alternative would have been a hybrid geothermal system where the GLHE system would be sized for the maximum heating load and a cooling tower would be installed into the system to meet maximum cooling requirements during the summer season. Although the hybrid system would have reduced the number of boreholes and the borehole field capital costs, the system would also have additional capital cost for the cooling tower and reduced operational savings when compared to the maximum capacity cooling GLHE system proposed in this report.

7.0 GEOTHERMAL SYSTEM DESIGN

The geothermal energy system designed for the school consists of two major sub-systems namely, the ground loop heat exchange (GLHE) system and the ground coupled heat pump (GCHP) system. The equipment included in the GLHE system are the geothermal borehole wells (the downhole heat exchangers (DHE)), the DHE piping, supply and return headers, the circulating pumps, and the associated piping specialties, expansion tank and controls. The GCHP system is comprised of the water-to-air heat pumps, duct work, air distributors, duct work specialties and associated controls for the classrooms spaces. The design requirements for both of these systems will be discussed separately below.

7.1 Ground Loop Heat Exchange System

GLHE systems are inherently dependent on the ground parameters of the specific site under investigation. Thermal conductivity and ground temperatures are major factors in the accurate design of a vertical geothermal well field. ASHRAE testing methods and their accuracy for formation thermal conductivity, thermal diffusivity and undisturbed soil temperature are essential data requirements for proper sizing of the GLHE system. For purposes of this feasibility study and to avoid costs associated with a geothermal borehole test, PS&S has utilized the ground parameter data provided by the Geothermal Resource Technologies, Inc., Formation Thermal Conductivity Test and Data Analysis report prepared for the Newark Science Park High School and completed on May 28, 2003. (Refer to Section 4.) The ground parameter data presented in Table A4 and utilized in GLHE capacity sizing was taken from the above referenced report. A grid system for the layout of the geothermal wells was determined based on 115 perimeter loop wells spaced on 15 foot centers and a rectangular 7 x 5 grid of wells in the Great Courtyard spaced on 20 foot centers. For this arrangement, with a ground loop heat exchanger bore hole length of 284 feet per ton of cooling capacity (calculated per ASHRAE publication "Ground-Source Heat Pumps: Design of Geothermal Systems for Commercial and Institutional Buildings"), the perimeter and Great Courtyard wells provided 233 tons of cooling capacity. The vertical geothermal well physical parameters include 6" bore holes with 1.25" vertical HDPE U-tubes connecting to 2" branch piping and 4" manifolds. The ground loop piping design contains five piping loops with a total flow of 712 gpm. Each loop will service approximately 30 wells. The GLHE main pumps will be located in a mechanical room on the lower level next to parking. The supply and return headers feeding the branch circuit manifold piping are 6" diameter pipe sized for total GLHE flow.

7.2 Ground Loop Heat Pump System

The heat pump system will include individual heat pumps for each classroom and classroom corridor spaces to provide heating and cooling. Thermal conditioning for these spaces will be designed in coordination with the dedicated outside supply and return ventilation system. Individual vertical heat pumps will be located in closets in the Classrooms with supply and return ductwork serving exiting each Classroom. Individual horizontal heat pumps will be located above the corridor ceilings with supply and return ductwork serving the Corridors. Ground loop heat exchange system water will be supplied to each heat pump from the GLHE main pumps located in a mechanical room on the lower level next to parking.

8.0 GEOTHERMAL LIFECYCLE COST ESTIMATE

Capital costs for the conventional 2-pipe system were taken from the Hanscomb, Faithful & Gould Pre-Schematic Construction Cost Estimate and are presented in Table A2. Capital costs for the geothermal system were similar except for the heat pump equipment and the geothermal wells that were developed from discussion with well drillers and square foot costs from similar heat pump projects. Piping and Pumping costs for the geothermal system were escalated for the additional pumping power and piping associated with the ground loop heat exchange well system. Capital costs for the conventional 2-pipe system were $2,044,428 before rebates, and after rebates ($28/Ton) the cost became $2,037,873, while the geothermal system costs before rebates was $2,311,881 and after rebates ($580/Ton) the cost became $2,176,093.

Total Annual Building HVAC Maintenance Costs for the two systems followed the 2003 ASHRAE method described in the Applications Handbook Chapter 36.5 Table 5 and are shown in Table A3. The conventional 2-pipe system included a water tube boiler, a centrifugal electric chiller and a 2-pipe fan coil distribution system. (Note: a centrifugal chiller was used because Table 5 did not address air-cooled screw chillers.) The geothermal system included heat pump equipment for heating and cooling and a 2-pipe fan coil distribution system. (Note: a 2-pipe fan coil system was used because Table 5 did not address heat pump equipment for the distribution system.) Heating system, cooling system and distribution system adjustment factors selected from Table 5 are tabulated along with the calculated annual maintenance costs for the two systems in Table A3. Maintenance costs for the conventional 2-pipe system totaled $29,566 while the geothermal system produced reduced maintenance costs of $15,264. Again we note that conversations with HVAC maintenance professionals have indicated that there would be little maintenance cost savings, if any, for the change from a 2-pipe fan coil system to a heat pump system.

Operating costs for the two comparative systems are shown in Table A4. Electric and fuel consumption in MMBTU/yr and kWh are tabulated along with gas and electric rates for the conventional 2-pipe system. Electric consumption for the geothermal GLHE/GCHP system is also tabulated in Table A4. Heating and cooling distribution pumping and fan energy consumption is also considered in the operating cost for both systems. Operating costs for the conventional 2-pipe system totaled $31,934 while the geothermal system had reduced operating costs of $22,701.

Table A5 shows the Lifecycle costs between the two systems. The construction cost differential between the geothermal system with rebates and the conventional 2-pipe system with rebates totaled $138,220. Maintenance and operating cost savings between the conventional 2-pipe system and the geothermal system totaled $14,303 and $9,232 respectively, with a simple payback of 5.9 years.

A 20-year lifecycle cash flow analysis was run for the conventional 2-pipe system and the geothermal system as shown in Table A6. Operating and maintenance costs and debt service are calculated and tabularized for both systems. Initial construction costs included geothermal rebates and an energy escalation rate of 3% was used along with an inflation rate of 2.5%. A 7% interest rate was used in the debt service calculation. Total yearly saving of the geothermal system over the conventional 2-pipe system are tabulated showing a total 20-year savings of $369,564.

The Life Cycle Cost Estimate described above requires numerous assumptions, particularly regarding the capital costs and operating and maintenance costs associated with each of the systems being considered. Slight variations in key assumptions can result in appreciable changes in the life cycle cost analysis. Two of the most difficult costs to accurately predict at this time are the capital cost of maintenance and the future costs of energy. A discussion of the potential impacts of variations in these two parameters follows.

Discussions with HVAC equipment maintenance contractors have indicated that there is little or no difference in the maintenance costs for a 2-pipe fan coil system and a series of individual heat pumps, contrary to the indications of ASHRAE. For the above life cycle cost analysis, we have used a maintenance cost savings of $14,303 for the geothermal system. If this cost savings is reduced by half, to $7,152, with no other changes, the simple payback becomes 8.4 years, with a total savings over 20 years of $186,910. If this cost savings is eliminated entirely, with no other changes, the simple payback increases to 14.9 years, with a total savings over 20 years of only $4,214.

The natural gas costs are estimated to be in the range of $7.00 to $8.00 per MMBTU in the near term. To be conservative, we have conducted the above life cycle cost analysis using an operating cost of $7.00 per MMBTU. At $8.00 per MMBTU, with no other changes, the simple payback improves to 5.6 years, with a total savings over 20 years of $405,893. If natural gas costs were to rise to $10.00 per MMBTU, with no other changes, the simple payback improves to 5.0 years, with a total savings over 20 years of $478,552.

Taken in combination, the effect of minimizing maintenance cost savings and increasing operating cost savings (by using higher natural gas prices) increases the simple payback and decreases the total savings over 20 years. If the maintenance cost savings are eliminated entirely and the natural gas cost is assumed to be $10.00 per MMBTU, with no other changes, the simple payback becomes 10.4 years and the total savings over 20 years becomes $113,203.

9.0 OVERALL SYSTEMS COMPARISONS

As discussed above, the application of the geothermal system for this building is limited by the capacity of the available well field (in this case, 233 tons). The cooling load for the entire building is estimated to be 550 tons; therefore, evaluation of the overall geothermal system costs (Capital, Maintenance, Operating and Life Cycle) must address the type of system to be used for the balance of the building.

In addition, the NPS and NJSCC have expressed interest in comparing the pros and cons of several different HVAC systems, including their system costs (Capital, Maintenance, Operating and Life Cycle). PS&S has developed order-of-magnitude opinions of these costs for the following systems:

System 1: "Traditional" boilers, air-cooled chillers, 2-pipe fan coils for Classrooms and packaged DX rooftop units with gas-fired heat for other spaces. Dedicated Outdoor Air units for Classroom ventilation (with energy recovery and CHW and HW coils). This system is used as the baseline for comparisons.

System 2: same as System 1, but with higher efficiency modular boilers in place of "traditional" boilers.

System 3: same as System 2, but with thermal (ice) storage and reduced chiller plant size (partial storage system).

System 4: Same as System 1, but with gas-fired absorption chiller-heaters in place of "traditional" boilers and air-cooled chillers.

System 5A: GLHE heat pumps for Classrooms and Corridors (in place of 2-pipe fan coils and central plant chillers and boilers) and packaged DX rooftop units with gas-fired heat for other spaces.

System 5B: GLHE heat pumps for Classrooms and Corridors (in place of 2-pipe fan coils) and roof mounted CHW/HW air handling units for other spaces (with modular boilers and air cooled chillers with thermal ice storage to provide HW and CHW to the units).

A summary of our systems comparisons is presented in Table A.7.

Capital Costs for Systems 1, 2, 3 and 4 were developed by Hanscomb. Capital Costs for Systems 5A and 5B were developed by PS&S by combining the Capital Costs for the geothermal system (developed in Table A.2) with costs developed for the balance of the building.

Maintenance Costs for System 1 and the Classroom areas of Systems 5A and 5B were developed as part of this study in Table A.3, following the procedure described in ASHRAE 2003 Applications Handbook Chapter 36.5 Table 5. This same procedure was then followed for the remaining systems. The results of this procedure were then checked with a professional HVAC maintenance service firm, who confirmed the results except for those associated with the heat pumps. Table A.7 uses the Maintenance Cost information develop with the HVAC maintenance service firm, as it is more representative of the costs that will be encountered than the information developed in accordance with ASHRAE.

Operating Costs for System 1 and the Classroom areas of Systems 5A and 5B were developed as part of this study in Table A.4. Operating Costs for System 2 were estimated by evaluating the net effect of the increased efficiency of the boiler plant over the boiler plant estimated in System 1. Operating Costs for Systems 3 and 4 were developed from data provided by potential equipment vendors for these types of systems. Operating Costs for Systems 5A and 5B were developed by PS&S by combining the Operating Costs for the geothermal system (developed in Table A.4) with Operating Costs developed for the balance of the building.

Simple Payback was calculated by dividing each system's increased cost (over and above System 1) by each system's first year operating and maintenance savings (as compared to System 1). In the case of System 4, with higher Operating and Maintenance Costs than System 1, there is no potential Payback.

Life Cycle (20 Year Ownership) Costs were calculated using the same procedure used in Table A.6 of this study, with the same assumed parameters (i.e., an energy escalation rate of 3%, an inflation rate of 2.5%, and a 7% interest rate for the debt service calculation).

In addition to the Cost data summarized in Table A.7, there are other pros and cons to each system (some of which are included in Table A.7 under the "Remarks" heading). These include:

System 1:
- PRO:
  1. Lowest Capital Cost.
  2. Owner/Operator familiarity.
- CON:
  1. Highest headroom required in Boiler Room.
  2. Large Areaway required for future removal/replacement.

System 2:
- PRO:
  1. Smaller Boiler Room footprint required.
  2. Smaller Areaway required.
- CON:
  1. Long Payback (23 years).
  2. No significant Operating Cost/energy savings.
  3. Life Cycle Cost higher than baseline.

System 3:
- PRO:
  1. Second lowest Capital Cost.
  2. Shortest Payback.
  3. Lowest Life Cycle Cost.
  4. Operating Cost savings of 15% $\pm$.
  5. Reduced noise from smaller rooftop chiller plant.
- CON:
  1. Need 800 to 900 SF additional space for storage tanks.

System 4:
- PRO:
  1. Operating Cost savings of 21% $\pm$.
  2. May be able to eliminate licensed boiler and/or refrigeration operators.

CON: 1. Highest Capital Cost.
2. Highest Maintenance Cost.
3. Highest Life Cycle Cost.
4. No potential for Payback of initial investment.
5. Requires Cooling Towers to operate.

System 5A: PRO: 1. May be able to eliminate licensed boiler and/or refrigeration operators.
2. Operating Cost savings of 12.5% $\pm$.
CON: 1. Compressors in Classrooms are a potential noise source.
2. Requires maintenance of multiple refrigeration systems (with compressors and reversing valves) spread throughout the building.
3. Third highest Capital Cost.
4. Long Payback (14.8 years).
5. Life Cycle Costs virtually equal to baseline.

System 5B: PRO: 1. Lowest Operating Costs (23.5% below baseline).
CON: 1. Compressors in Classrooms are a potential noise source.
2. Requires maintenance of multiple refrigeration systems (with compressors and reversing valves) spread throughout the building.
3. Second highest Capital Cost.
4. Long Payback (10 years).

Review of the data in Table A.7 reveals the following:

Capital Costs: With the exception of System 4, the Capital Costs of all systems are within 3.6% or less of the baseline. System 4 has Capital Costs that are 5.7% more than the baseline. The system with the lowest Capital Cost is the baseline system. For the level of estimating possible at this time, it is reasonable to approximate the Capital Costs as $4.7 million for System 1, $4.8 million for Systems 2 and 3, $5.0 million for System 4, and $4.9 million for Systems 5A and 5B.

Maintenance Costs: Systems 1, 2, 3, 5A and 5B have Maintenance Costs that are within approximately 2% of each other, while System 4 has Maintenance Costs that are approximately 50% higher than System 1.

Operating Costs: There are significant potential operating Cost savings when compared to the baseline (as expected). System 2 has Operating Costs within approximately 3% of System 1, but Systems 3 and 5A have approximately 15% and 12.5% savings (respectively), and Systems 4 and 5B have approximately 21% and 24% savings (respectively). The system with the lowest Operating Cost is System 5B.

Of all the systems considered, System 5A offers the best possibility of reducing the boiler plant and chiller plant size to an extent that may allow the elimination of a licensed Boiler Operator or Refrigeration Engineer (or both). The potential effect of this reduced operating would be to lower the Operating Cost for System 5A to 22% below the baseline, essentially the same as System 5B. (System 4 also offers this possibility;

however, the Capital Costs and Maintenance Costs are so high that the positive effects of eliminating licensed operators for this system do not significantly improve its evaluation.)

Simple Payback: All of the systems except System 4 (and the baseline) demonstrate a potential payback on the increased investment over System 1. System 3 has the shortest Payback (5.4 years) while the System 5A and 5B Payback periods are 14.8 and 10 years (respectively), followed by System 2 (23 years). Considering the more generous Maintenance Cost data generated by the ASHRAE method, lowers the Payback period for System 5B (5.6 years) and System 5A (6.2 years). Considering the impact of potential Operating Costs savings for elimination of Boiler Operator and/or Refrigeration Engineer licenses, lowers the Payback period for System 5A (9 years). In all cases, System 3 has the shortest Payback (5.4 years).

Life Cycle (20 Year Ownership) Costs: With the exception of System 4, the Life Cycle Costs of all systems are within 2% or less of the baseline. System 4 has Life Cycle Costs that are 8.2% more than the baseline. The system with the lowest Life Cycle Cost is System 3; however, for the level of estimating possible at this time, it is reasonable to approximate the Table A.7 Life Cycle Costs as $11.9 million for Systems 1, 2 and 5A, $11.7 million for Systems 3 and 5B, and $12.8 million for System 4.

Given all of the above, there is no single clear choice for the best system for the project (although it is clear that System 4 is the least desirable choice, and System 2 is not particularly attractive, either). If budget constraints alone dictate the choice of a system, then System 1 is the best choice (albeit by a slim margin). If Maintenance Costs are the primary concerns, then Systems 2, 3, 5A and 5B are virtually identical choices (although Systems 5A and 5B may be more difficult to maintain in practice). Operating Costs are subject to wide variations with slight changes in basic assumptions such as utility rates and inflation, and should not be used as the sole factor in selecting a system. System 3 has the most attractive Simple Payback (5.4 years). Life Cycle (20 Year Ownership) Costs are subject to wide variations with slight changes in basic assumptions in much the same way as Operating Costs; still, System 3 has the lowest Life Cycle Cost ($11,672,269), with Systems 5B and 5A virtually even ($11,708,782 and $11,728,228 respectively).

A case can be made for selecting either System 1, 3, 5A or 5B, depending upon the NPS and NJSCC's dominant criteria; however, it is our opinion that System 3 offers a number of advantages over the other systems and that these advantages are not as likely to be affected by potential deviations from the assumptions of this report as are those offered by Systems 5A and 5B.

Table A6

Lifecycle Cash Flow Analysis

	Initial Cost**	Annual Operating Costs	Annual Maintenance Costs	Interest Rate	Energy Escalation	Inflation Rate
(B) Conventional 2 Pipe System	$2,037,873	$31,934	$29,566	7.00%	3.00%	2.50%
(A) Geothermal Heat Pump System	$2,176,093	$22,701	$15,264	7.00%	3.00%	2.50%

	(B) Conventional 2 Pipe System					(A) Geothermal Heat Pump System					System
YEAR	Replacement Cost	Operating Cost	Maintenance Cost	Debt Service	Total Costs	Replacement Cost	Operating Cost	Maintenance Cost	Debt Service	Total Costs	A over B Savings
0	$2,037,873					$2,176,093					
1		$31,934	$29,566	($179,776)	$241,276		$22,701	$15,264	($191,970)	$229,935	$11,342
2		32,892	30,305	($179,776)	$242,973		23,382	$15,645	($191,970)	$230,997	$11,976
3		33,878	31,063	($179,776)	$244,718		24,084	$16,036	($191,970)	$232,090	$12,628
4		34,895	31,840	($179,776)	$246,511		24,806	$16,437	($191,970)	$233,213	$13,297
5		35,942	32,636	($179,776)	$248,353		25,550	$16,848	($191,970)	$234,368	$13,985
6		37,020	33,451	($179,776)	$250,248		26,317	$17,269	($191,970)	$235,556	$14,692
7		38,130	34,288	($179,776)	$252,194		27,106	$17,701	($191,970)	$236,777	$15,417
8		39,274	35,145	($179,776)	$254,196		27,920	$18,144	($191,970)	$238,033	$16,163
9		40,453	36,024	($179,776)	$256,252		28,757	$18,597	($191,970)	$239,324	$16,928
10		41,666	36,924	($179,776)	$258,367		29,620	$19,062	($191,970)	$240,652	$17,715
11		42,916	37,847	($179,776)	$260,540		30,508	$19,539	($191,970)	$242,017	$18,523
12		44,204	38,793	($179,776)	$262,773		31,424	$20,027	($191,970)	$243,421	$19,353
13		45,530	39,763	($179,776)	$265,069		32,366	$20,528	($191,970)	$244,864	$20,205
14		46,896	40,757	($179,776)	$267,429		33,337	$21,041	($191,970)	$246,348	$21,081
15		48,302	41,776	($179,776)	$269,855		34,338	$21,567	($191,970)	$247,875	$21,981
16		49,751	42,821	($179,776)	$272,349		35,368	$22,106	($191,970)	$249,444	$22,905
17		51,244	43,891	($179,776)	$274,912		36,429	$22,659	($191,970)	$251,057	$23,854
18		52,781	44,988	($179,776)	$277,546		37,522	$23,225	($191,970)	$252,717	$24,829
19		54,365	46,113	($179,776)	$280,254		38,647	$23,806	($191,970)	$254,423	$25,831
20		55,996	47,266	($179,776)	$283,038		39,807	$24,401	($191,970)	$256,178	$26,860
		Total over 20 Years			$5,208,854		Total over 20 Years			$4,839,290	
									Total Savings over 20 Years		**$369,564**

** Includes Geothermal Rebate of $580 per Ton

Table A5

Lifecycle Costs

Conventional Two Pipe Fan Coil System		Geothermal Heat Pump System		
Construction Costs	$2,044,428	Construction Costs	$2,311,881	
Rebate $28/Ton (for 1.1 kW/Ton chiller)	$6,555	Rebate $580/Ton	$135,788	
Yearly Maintenance Costs	$29,566	Yearly Maintenance Costs	$15,264	
Yearly Operating Costs	$31,934	Yearly Operating Costs	$22,701	
Construction Cost Differential w/Rebates	$138,220			
Geothermal Maintenance Cost Savings	$14,303			
Geothermal Operating Cost Savings	$9,232			
Yearly Savings	$23,535			
Simple Payback	5.9			

Table A4

Operating Costs

Max Heating Load	2458	MBTU	Max Heating Load	2458	MBTU
	205	Tons		205	Tons
EFLH Heating	440	hrs/yr	EFLH Heating	440	hrs/yr
Boiler efficiency	80	%	HP Efficiency	0.8	kW/Ton
Gas Price/MMBTU	$7.00				
Max Cooling Load	234	Tons	Max Cooling Load	234	Tons
EFLH Cooling	550	hrs/yr	EFLH Cooling	550	hrs/yr
Air Cooled Chiller efficiency	1.1	kW/ton	HP Efficiency	0.8	kW/Ton
Cooling Tower/Pump Usage	0	kW/ton			
Winter ElectricRate	0.1	$/kWh	Winter ElectricRate	0.09	$/kWh
Summer Electric Rate	0.12	$/kWh	Summer Electric Rate	0.1	$/kWh
Heating/Cooling Dist Pmp Energy	0.1	kW/ton	Heating/Cooling Dist Pmp Energy	0.15	kW/ton
Heating & Cooling Fan Energy	0.15	kW/ton	Heating & Cooling Fan Energy	0.15	kW/ton
Conventional Two Pipe System			**Geothermal Heat Pump System**		
Yearly Boiler Fuel Consumption	1,352	MMBTU/yr	Yearly Heating Electric Consumption	72,108	kWh/yr
Yearly Fuel Cost	$9,464	per year	Yearly Heating Electricity Cost	$6,490	per year
Yearly Chiller Electric Consumption	141,641	kWh/yr	Yearly Cooling Electric Consumption	103,012	kWh/yr
Yearly Chiller Electricity Cost	$16,997	per year	Yearly Cooling Electricity Cost	$10,301	per year
Yearly Pump Electric Consumption	21,890	kWh/yr	Yearly Pump Electric Consumption	32,835	kWh/yr
Yearly Pump Electricity Cost	$2,189	per year	Yearly Pump Electricity Cost	$2,955	per year
Yearly Fan Electric Consumption	32,835	kWh/yr	Yearly Fan Electric Consumption	32,835	kWh/yr
Yearly Fan Electricity Cost	$3,283	per year	Yearly Fan Electricity Cost	$2,955	per year
Total Yearly Operating Cost	**$31,934**	per year	**Total Yearly Operating Cost**	**$22,701**	per year

Table A3

Maintenance Cost

C=Total Annual Building HVAC Maintenance Cost ($/ft2)*

	where	C= Base system maintenance costs($.3338/ft^2)		
		+ (Age adjustment factor - $.0018/ft2) x (Age in years n)		
		+ Heating system adjustment factor h		
		+ cooling system adjustment factor c		
		+ Distribution system adjustment factor d		
	Conventional 2 Pipe		**Geothermal HP**	
n	0.0000		0	
h	0.0077	Water Tube Boiler	-0.0969	Heat Pump
c	0.0000	Centrifugal Chiller	-0.0472	Water Source HP
d	-0.0277	2-Pipe Fan Coil	-0.0277	2-Pipe Heat Pump
C	0.3138	$/ft2 (1983)	0.162	$/ft2 (1983)
	CPI(1983)	100.10		
	CPI(2003)	115.10		
C	0.3608	$/ft2 (2003)	0.1863	$/ft2 (2003)
	$29,566	yr	**$15,264**	yr

* from 2003 ASHRAE Applications Handbook Chapter 36.5 Maintenance Costs and Table 4

Table A2					
Capital Costs					
		Conventional	Quantity	Unit	Unit Cost
ITEM	Geothermal HP System	Two Pipe System	ft2	$/ft2	$
Major Equipment		$573,587	81,941	$7.00	$573,587
Pumps & Piping	$282,696	$245,823	81,941	$3.00	$245,823
Ductwork & Diffusers/Registers Grilles	$860,381	$860,381	81,941	$10.50	$860,381
Return & Exhaust Fans	$53,262	$53,262	81,941	$0.65	$53,262
Terminal Equipment		$245,823	81,941	$3.00	$245,823
GCHP Water Source Heat Pumps	$292,939		81,941	$3.58	$292,939
GLHE Geothermal Wells	$791,550		81,941	$9.66	$791,550
Misc General Construction	$12,291	$12,291	81,941	$0.15	$12,291
Misc HVAC	$53,262	$53,262	81,941	$0.65	$53,262
Misc HVAC Credits (See Below)	-$34,500				
Subtotal	$2,311,881	$2,044,428			
$/Ton	$9,875	$8,733			
$/SF	$28.21	$24.95			
			Quantity	Unit	Unit Cost

TABLE A1						
Ground Loop Heat Exchanger System Parameters and Capacity Calculations						
Ground Parameters	Value	Units				
Formation Thermal Conductivity	1.47	Btu/hr-ft-^{o}F				
Formation Heat Capacity	31.3	Btu/ft^3-^{o}F				
Formation Thermal Diffusivity	1.13	ft^2/day				
Undisturbed Ground Temperature	56.5	^{o}F				
Well Parameters (DHE)						
Borehole Depth	440	ft				
Borehole Diameter	6	in				
Borehole Casing Material	CS	Sch 80				
Thermally Inhanced Grout Fill	0.85	Btu/hr-ft-^{o}F				
Heat Exchange Piping Diameter	1.25	in				
Branch Circuit Pipe Diameter	2	in				
Manifold Diameter	4	in				
Heat Exchange Piping Material	HDPE	SDR 11				
Insulation Thickness (Pipe above grade)	1	in				
Insulation Material	Rubatex	R-180-FS				
Borehole Length per Ton	284	ft/ton				
Borehole per Ton Correction Factor	1					
Annular Fill Correction Factor	1					
Well Field Parameters						
Field 1 Perimeter Loop						
Length of Sidewalk Perimeter	1670	ft				
Well Spacing	15	ft				
Number of Wells	115					
Field Shape	1 x 115					
Field 2 Great Courtyard						
Length of Field	120	ft				
Width of Field	80	ft				
Area of Field	9600	ft^2				
Well Spacing	20	ft				
Number of Wells	35					
Field Shape	7 x 5					
GLHE Sizing						
Total Number of Wells	**150**					
Total Heat Exchanger Loop Length	**66147**	**ft**				
Total Cooling Capacity	**233**	**Tons**				