Deep Standing Column Geoexchange in a Dense Urban Setting

A Case Study of The Friends Center in Philadelphia

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For the
Pennsylvania Energy Development Authority
October 2009

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History and Objectives of the Project at Friends Center

The Friends Center complex of modern and historic buildings is located two blocks from City Hall in Center City, Philadelphia. It is a center for the work of the Religious Society of Friends (Quakers). The Center houses a total of 22 nonprofit organizations and provides meeting and conference facilities for numerous Quaker and non-Quaker grassroots groups. *[Illustration 1: Friends Center Complex]*

In the late 1990s, Friends Center began to prepare for the first major renovation, upgrade, and restoration since 1974. There was an intention of becoming more environmentally responsible, but not a deep understanding of what that might mean.

In 2004 Friends Center received the first "Green Initiatives" planning grant from the Kresge Foundation to study of the green potential of our campus. The "Green Charrette" funded by that grant brought owners and users of the building together with designers and engineers from around the country to envision a project that embodied the highest aspirations for sustainability. The grant also supported energy and daylight modeling that enabled design team to optimize the future building performance based on solid data. While none of the technologies in the Friends Center project is new or experimental, their combination and integration is elevating the campus to an unusually high level of green design.

As the planning proceeded, Friends began to see more clearly the connection between environmental responsibility and traditional Quaker concerns for peace and justice. Awareness that the wars of the 21st century are and will be over energy and water resources, strengthened commitment to modeling responsible use of those resources. Beyond significantly reducing Friends Center's contribution to environmental degradation caused by its buildings, the owners of Friends Center hope to make a contribution to market transformation toward sustainable building practices.

The preparation of this case study is part of the commitment of Friends Center to share its experience with other property owners, architects, and builders. Reducing the overuse of fossil fuel in the United States and the world, surely will contribute to reducing the causes of war. In the face of climate change, reducing the use of fossil fuel may be critical in the survival of life on earth.

We in the United States have a great opportunity to rethink our use of fossil fuels. We at Friends Center urge you not to be daunted by the complexity, cost, and risks documented in this case study. Instead we encourage you to see that we worked through the complexities, overcame the risks, and came out ahead in the cost projections over the life cycle of the system. The societal cost and risk of not eliminating the use of fossil fuel is even greater. As you consider the care of your properties, consider yourself as a living, breathing member of the commonwealth of life on earth and make your energy plans with that membership in mind.

Why Geothermal?

The owners and planners for Friends Center envisioned a system that would be fossil fuel free and highly efficient in use of energy. To meet that aspiration the engineers looked for a system that would operate on electric inputs only, and that could be powered by photovoltaic's or by purchased wind generated electricity. They determined that geothermal heat exchange best met these objectives,

Prior to the renovation, Friends Center was heated with steam from the steam loop and cooled by a centrifugal chiller. The engineers looked at replacing existing system in kind with newer more efficient equipment, and at installing a gas fired hot water boiler and replacing the chiller. In doing a life-cycle analysis of costs and energy consumption, it was concluded that over the long haul geothermal had the lowest operating costs, and depending on escalation of energy costs, a payback of 7-15 years.

Overcoming design obstacles
Once the planners realized that geothermal would be a good way of achieving project goals, they looked at feasibility and realized that Friends Center's site in the dense urban core did not provide enough space for typical geothermal well field. Deep standing column wells provided the opportunity to get more linear feet of heat exchange on the constrained site. Initially the plan laid out the wells in Friends Center's internal courtyard, but consideration of existing trees, a 19th century iron fence, and the foundation of the 19th century buildings on the site, they looked at other applications in New York City and focused instead on drilling in the sidewalk on 15th street. *[Illustration 2: Friends Center Courtyard from Race Street]*

Given the costs of drilling and the limitations of the site, it was desirable to make the system as small as possible. The overall plan for sustainability called for reducing energy loads in the building: reducing plug loads, replacing the windows, daylight harvesting, efficient electric lighting system, and increasing insulation. These measures enabled engineers to size the system in a space and cost efficient manner. Because the owner/occupants were known—this was not a building for a future unknown tenant—it was possible to consider a more stringent assumption of plug load. The owners agreed to abide by a 0.75 per square foot internal load, which probably saved one well as compared to a typical design.

Overcoming organizational obstacles
While Quakers have reputation for being somewhat advanced in their thinking on issues of peace and justice, like the rest of the U.S. population they have been uneven in coming to understand the urgency of the environmental situation. At the beginning of the planning for this renovation, conventional building practices were assumed except for the desire to reduce energy costs. As was typical at the time the planning started in 2003, the assumption was that the building would be a conventional and then, perhaps, to move toward more sustainable plans—perhaps at the time of this writing in late 2009 that pattern is starting to change and building owners start planning projects with an understanding that the "normal" thing to do is to build sustainably.

One or two voices among the decision makers were raised to urge being more aggressive with green design, but others raised questions about the need, the cost, and the reliability of green building strategies. When the opportunity arose to get a grant from the Kresge Foundation to test the potential for green building, there was a willingness to accept the grant, but still no commitment to green building.

The green charrette, which was funded by the Kresge grant, was a turning point for the project. It provided education about the urgency of the environmental situation, about the role of the built environment, and about potential strategies for greening the buildings of Friends Center.

Following the charrette , the majority of the stakeholders favored moving forward with green building strategies. However, the fiscal officers and others with an eye on the bottom line continued to have reservations about the potential added cost.

Management collaborated with the project engineer to create a life cycle cost analysis that revealed that if the project proceeded with conventional building strategies, the cost of operating the buildings for 20 years would be $50.5 million. If additional funds were borrowed to employ the energy strategies, operating costs including debt service would be $45 million over 20 years. With that, all reservations about the energy strategies, including the geoexchange, were withdrawn.

The green strategies also had a major impact on Friends Center's fundraising capacities. The fundraising feasibility study for the project as originally planned showed the fundraising prospects as limited. When the plans turned to being a landmark green building complex, the fundraising consultant projected a fundraising capacity of $1.5 to $2 million. In the end $4.1 million was raised. $1.3 million was donated for the geothermal wells alone.

Addressing people issues

The buildings of Friends Center were in active use during the drilling period, so arrangements had to be made to address needs and anxieties of staff regarding noise and other potential disruptions of working conditions. Some staff members were taken to a drill site in New York to experience the noise and vibration. Shortly before drilling was to begin, a meeting was held to which all employees of tenant organizations were invited. Management explained the process of drilling and the expected impact. Ear plugs made available and some employees were given the option of working offsite. In the end the noise proved to be tolerable for staff, even with the extended drilling schedule. The major impact on staff was working without daylight when the windows were covered. Otherwise, Friends Center's normal operations were able to proceed during the drilling period.

Efforts also were made in inform occupants of neighboring buildings and to address any concerns they might have. Nearby buildings include a hospital and medical school, a rehabilitation hospital, a high-rise apartment building, a k-12 private school, and both privately owned and city owned office buildings. CEOs and building engineers from neighboring buildings were invited to brunch to hear presentations from Friends Center, the engineer, and the driller. They were informed of traffic and noise issues that might result from the project. We found that these building managers were more curious about the technology and how they might apply it than worried about disruptions caused by the construction.

There is also an isolated single residential block immediately to the west of Friends Center. These neighbors were invited to a separate event hosted by the corner coffee shop. Their major concern was parking, and Friends Center agreed to pay for parking in a nearby lot to compensate for the loss of street parking during the drilling. In the course of the drilling no concerns were heard from the institutional or residential neighbors.

Planning the System

There are risks associated with drilling standing column geothermal supply wells. Their application is site specific. Due to the depth of the wells, there is a risk of finding unsuitable bedrock conditions somewhere along the 1500 feet. There is no way of truly knowing until the drilling is undertaken that the site is a good candidate. In fact, conditions can change from well to well on a given site, and did on this project. It is an expensive undertaking with the risk that once the initial wells are drilled it might be found that the system is not workable. Thus, in designing a geothermal system, the engineers wanted to know that the owners were committed to the project and ready to take on the risk.

AKF engineers had experience with deep standing column wells in Manhattan and Connecticut. Finding that the owners were committed to partnering with the team to accomplish the goal, they undertook to work with Friends Center in designing an overall fossil-fuel-free building including deep standing column wells for geoexchange.

Geological considerations

The first step in considering deep standing column wells is to have a reasonable assurance that the suitable geological conditions are present. Uncased deep standing column wells require competent consolidated rock relatively close to the surface (preferably within 100’). Incompetent and/or “weathered” bedrock creates the risk of small rocks falling into the well and obstructing its function. It is important to find bedrock close to the surface because the well has to be cased down to bedrock (adding cost) and because heat exchange occurs only in the un-cased portion of the well.

Further there needs to be groundwater near the surface and sufficient ground water to produce the desired yield in heat exchange (minimum of 10-15 gallons per minute). It is highly desirable to drill a test well to discover whether these minimal conditions are present.

In Friends Center’s case it was deemed to be prohibitively expensive to mobilize the drilling site, drill one well, test for capacity, and demobilize until design work was completed. Instead, the owners undertook an extensive literature review in the belief that surely someone had done studies of the geology under downtown Philadelphia. They found a 1991 publication of the U. S. Geological Survey, *Geohydrology and ground-water resources of Philadelphia, Pennsylvania*[*], which reported on test holes that were drilled on a north-south axis and east-west axis through Center City. The study showed good rock, adequately near the surface, and sufficient water flows to support geothermal wells. Since the Friends Center site is one block west of the north-south axis and three blocks north of the east-west axis, there was reasonable assurance that these conditions would be present at Friends Center.

Permitting Challenges

It was critical to the project schedule to apply for permits well before the scheduled start of drilling. This provided time to deal with complications and to have the permits in hand to keep the project on schedule. Site drawings were prepared and stamped by the architect or engineers and submitted by the general conditions contractor for permitting. It was helpful to get one person from the city assigned to the project. Thus, when we problems arose there was a contact who was informed about the project and we avoided having to at the beginning with a new person. *[Illustration 3: Site Plan Detail]*

Friends Center encountered the need for several important permits and clearances.

<u>Street Closure</u>: Friends Center applied to the Department of Streets, Highway Division Right-of-Way permit. This permit allowed the closing of the curb lane and footway on 15th street, between Race Street and Cherry Street for the placement of construction equipment. Friends Center benefitted from good timing in seeking this permit as the Philadelphia regulations about street closings are changing. Just after Friends Center's permit was granted a moratorium was put into place for street closings in Center City except on the weekends. Such a moratorium at the time of our drilling would have made it prohibitively expensive, if not impossible, to drill the wells in the sidewalk.

<u>Use of right of way</u>: Philadelphia requires a "Right of Way License" to install utilities under the street or sidewalk. This was a relatively new regulation and at first caused some confusion which was resolved through dialogue with the city agency.

<u>Utility clearance:</u> As with all excavations, the project team was required to notify "Pennsylvania One–Call (PA-1-call) to have underground utilities identified and marked in the street prior to drilling the wells. This process was performed during the site mobilization stage prior to the site closure. A site plan was prepared showing the utility lines and placing the wells to avoid danger of damage to active utilities.

<u>Groundwater discharge permit</u>**:** This permit from the Philadelphia Water Department was required prior to discharging any water from the drilling operation . The department maintains requirements for discharge limits, discharge conditions, reporting and representative sampling regulations. The discharge process was strictly monitored by the

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[*] Paulachok, Gary N. 1991. *Geohydrology and ground-water resources of Philadelphia, Pennsylvania*. U.S. Geological Survey Water-supply paper W-2346. Washington, D.C.: USGS.

Office of the Environmental Engineer, Industrial Waste Unit of the Philadelphia Water Department to insure that no contaminants were placed in the city water supply. At the first sign of water discharged from the first well and periodically thereafter, Friends Center was required to test the water and submit a report to the city engineer for drilling to continue. If the water quality had been unacceptable to the city engineer more extensive filtration methods would have been required at a potentially significantly greater expense to the project. Friends Center engaged a professional testing agency to do this analysis. A copy of the testing report can be found in Appendix D.

<u>Historical commission:</u> The entire Friends Center site is on the Philadelphia Register of Historic Places. Thus, any work on the exterior of the building is subject to their review. However, because the wells are not visible except for seven steel access covers flush with the sidewalk, the wells were easily approved.

<u>Union Clearances</u>: Because our driller was from a different jurisdiction, they were obligated to notify the local union business agent and alert them to their presence in their district. Often the local business agent will recognize the other union and allow them to proceed. However, in the case of this project the local union required that local labor be added to the project. This was resolved by the contractor working with the Philadelphia union.

Challenges of engaging a drilling contractor

Friends Center sent out a request for proposals to drillers throughout the region and received no positive responses. On being pressed to be part of this new approach to geothermal heat exchange, some drillers responded that they did not have the equipment to drill to a depth of 1500 feet while others did not want to work on the constrained urban site. Friends Center explored whether we could hire a local driller, rent the equipment, and have the driller trained by a Connecticut driller with experience in Manhattan who was willing to provide the training. This option failed when it was discovered that vendors for drilling equipment had no equipment available as it all was employed on projects in New York.

AKF engineers had done deep standing column wells for geothermal heat exchange in Manhattan where they had worked with the William Stothoff Company of Flemington, New Jersey. Stothoff agreed to bid on the job.

Ideally, the project would have a general contractor for whom the well contractor would be a subcontractor. However Friends Center's project schedule called for getting the drilling underway before the general contractor for the project was selected. Friends Center entered into separate contracts with the drilling contractor and with a general contractor solely to provide general conditions.

Having found only one qualified drilling contractor, Friends Center was in a position of weakness for negotiating a complex and expensive drilling project. Hopefully future building owners would find more drillers to bid on their project.

In retrospect, in this instance of having only one bidder, it would have been helpful to have a third party professional estimator review the drawings to allow the owner to be sure that all of the documentation is complete and correct and to provide a baseline for price negotiation. As it was, the owner had little basis for evaluating and responding to the proposed cost and schedule for the drilling.

As in any construction contract, care was needed in how the contract addressed change orders and pricing of change orders. Friends Center's contract provided for compensation to the driller if the project was delayed by Friends Center, but did not provide for compensation to Friends Center if the driller exceeded the schedule causing additional general conditions costs and impacting the overall project schedule. Similarly, the contract provided a linear foot cost for extending the drilling depth, but did not provide for a deduction if the wells were not drilled to the depth specified in the contract.

Drilling the Wells

Logistics of drilling in the dense urban setting

The first logistical issue was drilling on a narrow site. The city allowed only the parking lane to be closed. The site was enclosed by the building on the west, 8 foot hurricane fencing with sound attenuation blankets on the other three sides, and jersey barriers on the east between the drill site and traffic. The length of the worksite from Race Street to Cherry Street was 288 feet. The width of the working site consisted of 10 feet of existing sidewalk and 10 feet of a captured city parking lane allowing for a 20 foot wide working area for a total of 5,760 square feet. Signs were erected to direct traffic and pedestrians. A sign also was erected to inform the public about drilling for geothermal heat exchange. *[Illustration 4: Preparation of the drilling site]*

This narrow site had to accommodate fencing, a dumpster, multiple drilling rigs, heavy duty compressed air trailers, trucking, and portable power equipment. And it had to be organized to allow for this equipment to move on and off the site. Cut sheets of all of the planned drilling and support equipment were used to layout the placement of the equipment on the site with the drilling sequencing in mind. The more room that can be provided the better. On the Friends Center site all equipment had to move single file through gates at the north and south ends. The confined site presented many difficulties, but by having daily planning meetings with the project team these problems were minimized by relocating/ moving heavy equipment into place during the very early morning hours.

Once approvals were secured and the perimeter fencing installed, all trees, sign posts, parking meters, and light posts had to be removed from the site. Windows on the drilling side of the building were covered with 3 inch rigid insulation panels both to protect the glass and for sound abatement. To avoid damaging the original brick face of the 1974 building we used a wooden compression design attached to the insulation so it would fit tightly into the window opening. This avoided using mechanical fasteners that would have damaged the brick.

During drilling under certain weather conditions the ventilation system was shut down to avoid drawing diesel fumes into fresh air intakes and into the air handling units. This was monitored daily and done only when the prevailing wind caused a problem. This proved to be a very effective method of maintaining fresh air to the building while keeping harmful fumes out when necessary.

Drilling the wells

The drilling process had to deal with challenges from the very beginning. The driller experienced delays in completing a project in New York and did not have equipment available to begin at the scheduled start date in January 2008. This created extra general conditions costs because the site was prepared and ready to go and the general conditions contractor was on standby. The drilling was begun in February.

Evaluation and selection of drilling methods and equipment is site specific. The design of the wells called for a 12 inch surface casing down to the depth of where consolidated rock was encountered. Often the drilling and installation of the casing are done sequentially. However, because the nature of the soils was unknown there were concerns that the soils may collapse into the bore hole. Since the drilling was being performed within several feet of the foundation of the building there was a desire to avoid subsidence due to loosening of the soils which might destabilize the foundation of the building

Therefore, a specialty subcontractor using a dual rotary rig was engaged to take the hole to the top of the rock and to install the surface casings. The dual rotary rig has the ability to drill the bore hole and simultaneously insert the casing as the drilling progresses. This subcontractor took the well down to consolidated rock, roughly 95 feet, and drilled the rock socket into the bedrock. The 8 inch diameter casings were set and cement pressure grouted in place to prevent surface water from getting into the aquifer. Before they reached 300 feet substantial quantity of water was encountered and they could not drill further with this equipment. *[Illustration 5: Dual rotary drill rig]*

The principal drilling contractor then followed with a conventional air rotary drill equipped with greater depth capability, additional hoisting capability, and rotational capacity than most standard water well rigs. *[Illustration 6: Air rotary drill rig]*

Drill cuttings were evacuated from the bore hole using high pressure compressed air. The well head was fitted with a diverter that allowed the water and drill cuttings that were generated to be evacuated and diverted into a sealed container. The container and diverter were specially designed by Stothoff for use in urban settings. When the compressed air is forced into the well, water and tailings are discharged at a rate of up to 5000 feet per minute which on an open site may be thrown 400-500 feet. Therefore, the pipes were fitted with an energy dissipater or manifold, to slow the flow of the water and cuttings and allow them to be contained in the container. The container is designed to allow the cuttings to settle and the water to be decanted. The water is then pumped off and filtered for discharge into the sewer system in accordance with the requirements of the city. The water was periodically tested and reported to the city water department, and, fortunately, the water flowing from these wells was essentially clean. Contamination would have required additional filtration through bag filters and carbon filters at a significantly higher cost. *[Illustration 7: Drill Site]*

The cuttings were accumulated in the 20 yard drill container and removed as needed, a total of 35 times or roughly 5 per well. Cuttings were transported to an abandoned quarry and used as part of the quarry reclamation process.

The abundant water flows (up to 300 gallons per minute in come cases) are a great advantage for heat exchange, but presented challenges for the drilling. The downhole hammers need to have a minimum differential pressure to allow the piston to actuate. Due to the volume of water, they had difficulty developing enough differential pressure. Auxiliary air compressors to add more air and booster compressors to add more force were required. The rig itself ordinarily produces 350psi. With the additional equipment it was possible to generate up to 1500 psi. The drilling on this site typically ran at about 900 p.s.i. *[Illustration 8: Flushing cuttings from a well]*

The first wells drilled to depth were #2 and #3. Well #2 encountered unconsolidated rock at just short of 1000 feet. After consultation among the driller, the engineer, and the owner it was agreed to leave well #2 at that depth given the greater heat exchange capacity that would be possible with the stronger than expected water flow.

In well #3 unconsolidated rock was encountered at 1000 feet. Now knowing that the gravel bed might extend to other wells it was decided to insert grout to consolidate the rock and drill through the grouted rock. This was done and the well was drilled to the specified 1500'. *[Illustration 9: Driller's log]*

When wells #2 and #3 were complete, the drilling was shut down for a week to do flow testing and thermal conductivity testing. This testing would provide information for the design of the rest of the system. The thermal conductivity of the rock was better than assumed, that is, we could transfer heat more easily in and out of the rock. A hydrologist tested for yield finding as much as 300 gpm in some wells. With more water the system could do more bleed to increase heat exchange capacity. *[See testing reports, Appendix D]*

With the greater conductivity and water flow, not as many feet of well were needed to achieve the desired exchange capacity. This quantitative information allowed the team flexibility to work with the balance of the issues that were discovered.

The drill encountered zones of weathered (loose) bedrock. These needed to be stabilized by pressure grouting with neat cement (cement and water with no aggregate) which allowed the drill to further advance the depth of the remaining boreholes. Based upon the performance data we were able to leave the wells at a shallower depth. Unconsolidated rock near the surface was grouted and drilled through. When unconsolidated rock was encountered in the vicinity of 1000 feet the wells were left at that depth.

Well #4 was drilled to 1180 feet, well #5 to 1025, well #6 to 1050. Anticipating that the weathered bedrock zones would be encountered at an even shallower depth on well #7, it was decided to make #7 the diffusion well, it was drilled to 675' and the rig returned to well #1 to make it a production well which reached 1300'.

Additional occasional difficulties were encountered with the equipment. When well #3 was completed and the rods drawn up and loaded on the flatbed—an activity requiring half a day—it was discovered that the bit had not come up with the rods. The next day the rods were reinserted in the hole in what turned out to be a successful effort to retrieve the bit. The rental booster didn't do the job and was replaced with a piece of the driller's own equipment.

In all, what was anticipated to be a seven week drilling period extended for more than eight months from February into October of 2008.

Connecting the wells to the building systems

Pumps were installed in the wells to draw water up from the bottom of the wells and into the building. Each pump is suspended just below the static water level of the well. The pumps are fitted with pvc porter shrouds and dip tubes that extend to the bottom of each well. Well water is pumped from the bottom of each well through individual piping circuits to a header in the basement of the building. The water is routed through a plate and frame heat exchanger and returned to each well through individual return pipe circuits. *[Illustration 10: Schematic drawings of wells]*

The plate and frame heat exchanger isolates the well water from water circulated inside the building. The building circulation loop runs through the stainless steel plate heat exchanger and distributes water to the water-to-water heat pumps in the penthouse of the office building and to the water-to-air heat pumps located throughout the meetinghouse building. The heat exchanger is stainless steel to avoid corrosion from salts dissolved in the ground water.

Piping from the wells to the building was installed under the sidewalk in 15th Street. Adaptations to the plan were made in response to conditions in the field. When the order of the wells was changed moving the diffusion well from the north end to the south end, the piping scheme had to be redesigned. *[Illustration 11: Trenching and pipes]*

Similarly, the initial plan called for bringing the water through a pump room internal to the building core. Non-non ferrous pipe (HDPE) was used to avoid corrosion. Because it is desirable to limit the use of that pipe inside the building, the entrance point was relocated to room on the outside wall. This required some reprogramming of office spaces on the lower level and increased attention to sound attenuation.

In retrospect, the mechanical room could have been designed for better sound attenuation and to protect the surrounding facility should a failure of any part of the system cause water to discharge at a high rate.

The pipes enter through the east wall of the foundation, each with its own shut off valve. The groundwater water flows to a heat exchanger and then is returned to the wells. There is no mixing and cross contamination of the ground water and the internal water system. The pump room also contains circulating pumps for the building side of the heat exchanger. The pumps and heat exchanger were sized based on the flows established for the wells. *[Illustration 12: Pump Room]*

The flow is from well to heat exchanger and back to the well, the conditioned water goes from the heat exchanger to heat pumps, and from the heat pumps to air handling unit and terminal units for the office building. For the meetinghouse the conditioned water goes direct from heat exchanger to water to air heat pumps located in that building. *[Illustrations 14: Equipment in penthouse mechanical room; Illustration 15: water to air heat pumps in basement of meetinghouse.]*

Phasing the project

A challenge of this particular project was working with occupied buildings that could not be left without heating and cooling while the heating and cooling systems were being replaced with a single system. It was recognized early on that it would be crucial to retain the existing air handling unit in the penthouse and the main supply and return riser that served the building. From that decision developed a design that enabled reuse those existing components upgrades to meet new requirements: filtration efficiency, heat recovery, high efficiency motors and variable speed drives, new dampers, new controls, new dual temperature heating/cooling coil.

When the time came for putting the system into operation, the wells had to be cleared of fine particles which turned out to be a six weeks process. Once cleared there has been no further problem with sediment.

The clearing process required some redesign. To begin with the pumps were simply turned on with the expectation that the regular filters would clear the flow of water, but those filters clogged quickly, sometimes in less than half an hour. Dual filters were fitted in each pipe so that a clogged filter could be replaced without shutting down and coarser filters were used to allow clearing to proceed more efficiently. It took six weeks to fully clear the wells. One well, #6, did not clear and it was decided not to return water to that well, thus not washing more silt down the walls of the well with the return water. This decreased the thermal capacity of the system by about 8%, not significant as the overall capacity proved to be greater than expected. After six weeks the system was fully functional.

In retrospect it would have been desirable to design for flushing process right up front by installing one big filter for the flush out process.

Utilizing the existing air system proved critical for phasing. The changeover was done during the shoulder season between heating and cooling when outside air could be used for the cooling system. Since loads were low it was possible to maintain reasonable comfort.

Design and operation of HVAC system

The meetinghouse building had existing water cooled air conditioning units for individual zones. These were replaced with water-to-air heat pump units some of which were relocated the basement where they are easier to service and maintain. Hot water radiators in the worship room were replaced with fan coil units connected to the geothermal system.

For the office building, existing main duct risers and main horizontal duct distribution were retained. New terminal units and downstream ductwork and diffusers were provided to accommodate the new office layouts. Radiant heating panels were used above the sections of the existing curtain wall that has floor to ceiling glass to provide supplemental heating. Terminal unit heating coils and the radiant heating panels were sized to operate with the lower hot water temperatures of the geothermal system compared to the previous steam system.

At the time of this writing the system has operated satisfactorily through a complete cooling season. Water temperatures from the wells stayed within the design parameters. Throughout the season the engineers and building operations manager worked to get the correct balancing; however, the main complaint of occupants was of being too cold so the wells were effectively carrying the load.

Maintenance of the wells

The driller recommends annual assessment of the system and its efficiency operation.

The predicted service life of the pumps is 4-7 years. The driller recommends beginning to replace the pumps one per year after 5 years starting with the one that is operating least efficiently. In the cycle of replacement, the pumps can be rebuilt and reused, though the motors will have to be replaced. The cost of replacing a pump including labor would be in the area of $7000 per pump at 2009 prices. It is recommended to do this rotation on a planned basis rather than in an emergency.

The steel casings which are cement grouted and not subject to water movement should last100 years or more. Dip tubes and porter shrouds made of PVC are likely to last forever.

While wells drilled through bedrock last hundreds of years, the most expensive repair would be any required attention to the bore holes. Everything else is replaceable. The main risk in the Friends Center wells is the risk that the grout will become scoured by the water and become unstable. To correct such a problem would require remobilizing the site and bringing back the drill rig.

Energy and Dollar Cost Over Time

It is difficult to capture all of the variables that go into a full and correct life-cycle analysis of the costs and energy use for construction and operation of a building. The true impact of a project includes the energy embodied in the existing buildings, the energy needed to manufacture and transport the equipment and materials, and the energy expended in installation. These issues are part of every system and every project, whether it aspires to be sustainable or not. In understanding the full impact of any choice all of these factors need to be considered.

Energy to create the system compared to energy savings

In looking at sustainability, the energy inputs for creating the system are an important part of the equation. Because the hardness of the rock and the water pressure required a second diesel-powered compressor more fuel was consumed than initially anticipated. The driller reports using up to 600-650 gallons per day of drilling. Taking in to account drilling, generators for well testing, and fuel for excavation and restoration of the sidewalk, the driller estimates that 60,000 gallons or more of diesel fuel was consumed

By removing Friends Center from the steam loop, approximately 16,240 CCF of natural gas or 12,163 gallons oil will not be burned each year. By this calculation it will take less than 5 years to recover the carbon expenditure in the drilling of the wells. There are also savings in electricity for summer cooling and in gas for heating hot water, so the energy payback period is quite favorable and confirms the initial assessment that geothermal heat exchange meets the objectives of highly efficient use of energy.

Lifecycle costs

When deep standing column wells were first considered in 2005 the anticipated drilling cost was approximately $500,000 not counting architect, engineer, and administrative costs. When the contract was let for the drilling the bids for drilling and general conditions totaled $1,316,733. The final billings for drilling and general conditions were $1,878,544 plus testing fees of $42,645 for a total of $1,921,189. Soft costs for the overall project came in at about 20%, adding 20% to drilling costs brings the approximate total cost for the wells at $2,305,000.

Clearly the escalation reflects how easy it is to be naïve about costs of a complex construction project, even though these numbers were generated by experienced professionals. The 30% increase between the bid and the final billing reflects inexperience both of the driller and the owner leading to underestimating the costs of difficulties and delays.

Nonetheless, Friends Center regards the wells as a positive investment. Because the wells were a pioneering application for Pennsylvania, Friends Center received $1,331,000 in direct grants for the geothermal system. Net cost of $1,055,000 will be recovered in fuel costs in approximately nine years depending on fuel cost escalation in that period. Even if Friends Center's costs were the full $2.3 million it would be recovered in sixteen to eighteen years, which is less than the predicted 20 year life cycle for heating and cooling equipment. The life cycle of the wells themselves may be hundreds of years.

Recommendations for Planning Deep Standing Column Geoexchange

- Drilling deep standing column wells has inherent risks that cannot be fully anticipated or mitigated in advance. Be clear about your goals and select experienced professionals to evaluate your site and design and install the system.
- Drilling wells is very site specific, even changing from well to well. Do your homework in studying the suitability of this technology for your site. If feasible, drill a test well.
- Engage a driller as early as possible so that the driller's experience can contribute to the planning process.
- Establish a realistic budget for the project. Do not stint on professional support from architect, engineer, and owner's representative. Consider submitting the plans to an independent cost estimator for a completeness review and an estimate. An independent reviewer may identify problems that a bidder may not reveal and that may turn up later as a change order. Include adequate contingency in the budget—things happen.
- If at all possible, hire an experienced owner's representative who understands the owner's needs. In complex situations the owner's representative can pay for him/herself through maintaining project schedules and being alert to issues that an owner may be unfamiliar with.
- Spend the time to do it right up front. Cutting design cost (a common error) often causes design misses that eventually cost you much more as a change orders during the actual construction of the project. Spend as much time as finances will allow in planning and clearly detailing the drawings.
- Plan for redundancies in the system. For example, plan the site to allow for an additional well if, upon testing, the thermal capacity of the wells is less than expected or plan to go deeper to get additional heat exchange.
- Get permits well in advance so that problems can be ironed out without delaying the project schedule.
- Give attention to people issues. Who will be impacted by the drilling—occupants of the building, others on your campus, neighbors, traffic? Address issues up front to avoid potential delays.
- Address union issues early and write it into the contract with the drilling contractor that labor issues and costs are the responsibility of the contractor.
- Pay attention to site preparation issues, protection of the building, windows, foundation. Anticipate noise and air quality issues.
- Hire a general contractor experienced with deep standing column wells to with the drilling contractor as a subcontractor to the general contractor.
- Seek at least three bids on the drilling.

- Visit the active sites of the selected bidders both to inform yourself of what to expect and to evaluate the way the driller works and how the site is kept. Talk with the building owners about their experience.
- Make the well contractor clearly responsible for all of the connections of the system from the plate heat exchanger out to include in particular all electrical connections.
- Establish a clear and realistic project schedule and build into the contract appropriate penalties and damages agreed to in advance.
- Have regular meetings of the project team. The owner’s representative and general contractor’s superintendent should be in contact on a daily basis.
- Give attention to placement of mechanical systems inside the building to mitigate noise and to minimize risk of flood from a major failure which might discharge water at a high rate.
- Hire a commissioning agent to make sure that all of the components of the system are working harmoniously with each other to achieve the optimum operating efficiencies.
- Track performance and keep longitudinal data in order to gauge the effectiveness of the system in maintaining comfort, saving fuel, and saving money.
- Plan and budget for a regular preventative maintenance, repair, and replacement schedule to keep the system operating at peak efficiency.

Appendix A
Illustrations

Illustration 1: Friends Center
Main entrance 15th and Cherry Streets, Philadelphia
Architect's rendering of site

Illustration 2: Friends' Center Courtyard from Race Street

Illustration 3: Site plan detail

Illustration 4: Preparation of the drilling site

Illustration 5: Dual rotary rig

Illustration 6: Air rotary drill rig

Illustration 7: Drill site

Illustration 8: Flushing cuttings from a well

Illustration 9: Driller's log

Illustration 10: Schematic drawings of wells

Trenching and pipes

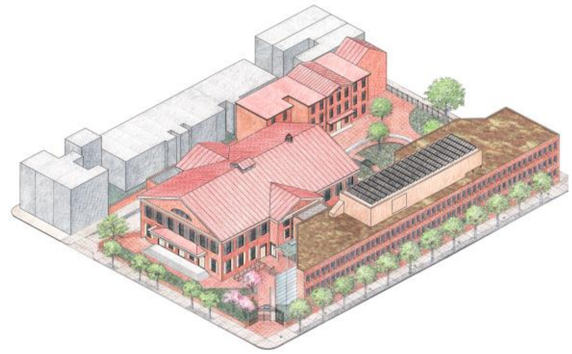
Illustration 11: Trenching and pipes

Illustration 12: Pump Room
Piping array entering the building
Finished piping and valving system
Circulation pumps

Illustration 13: Penthouse mechanical room
Water-to-water heat pumps
Control panels
Pumps

Illustration 14: Heat pumps in meetinghouse basement

Illustration 1: Friends Center Complex



Main entrance 15th and Cherry Streets, Philadelphia

Architect's rendering of site

Illustration 2:
Friends' Center Courtyard from Race Street

Illustration 3: Site plan detail

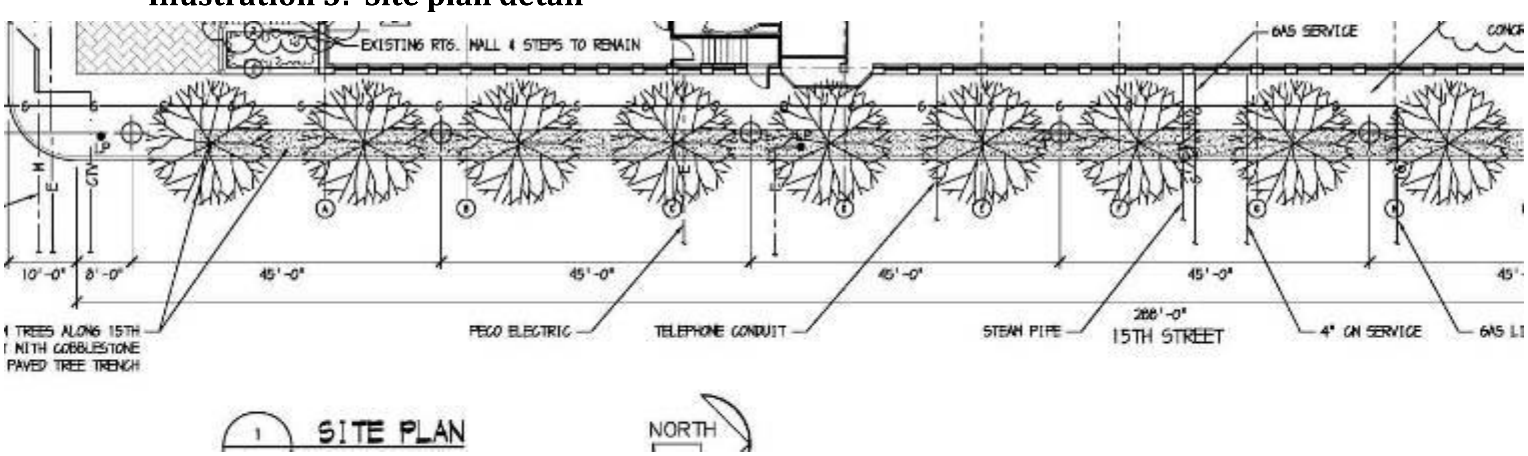




Illustration 4: Preparation of the drilling site

Illustration 5: Dual rotary rig

Rig at work

Bit

Capped well awaiting next phase

Illustration 6: Air rotary drill rig, two views


Illustration 7: Drill site

Rig and fencing

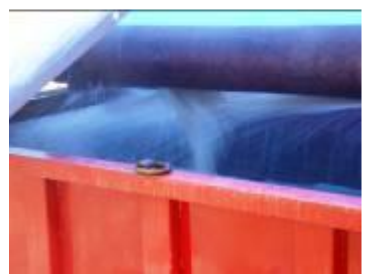
Flatbed with rods
Dumpster for tailings

Water in/water out

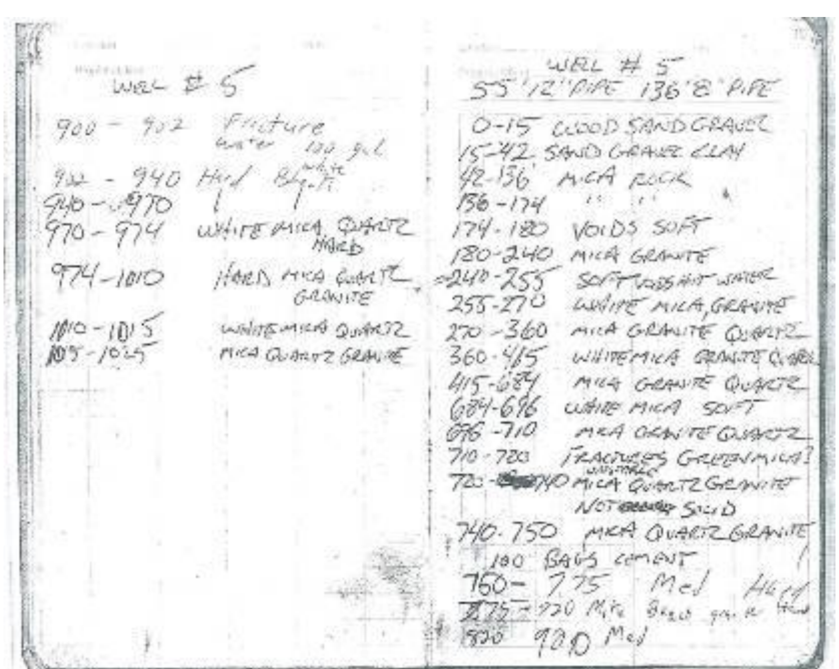
Auxiliary compressor

Illustration 8: Flushing cuttings from a well

Releasing pressure in bore hole



Water and tailings being captured in dumpster custom designed by the driller (David Stothoff)

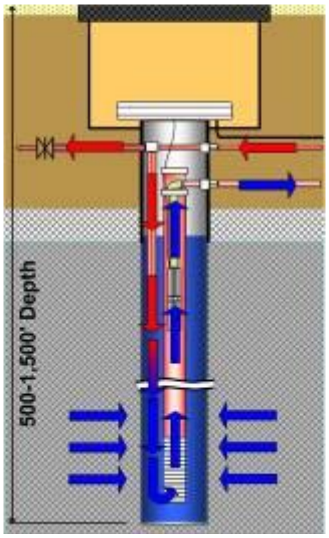


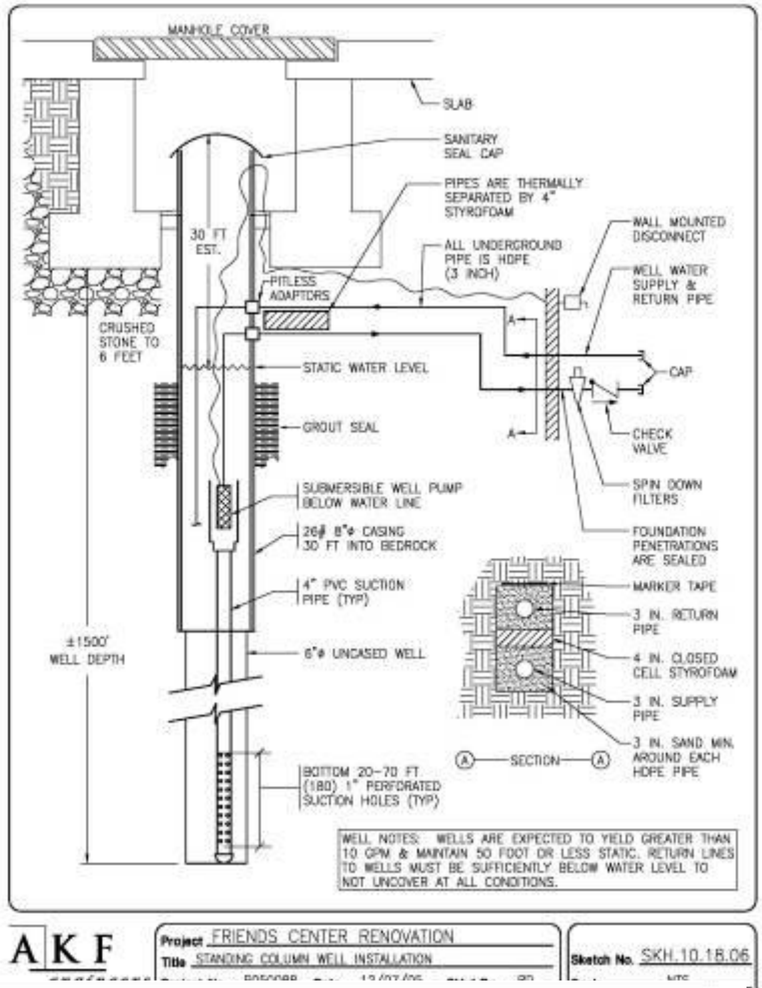
WELL # 5
900 - 902 Fracture water 100 gal
902 - 940 Hard white Bl[illegible]
940 - 970
970 - 974 WHITE MICA QUARTZ HARD
974 - 1010 HARD MICA QUARTZ GRANITE
1010 - 1015 WHITE MICA QUARTZ
1015 - 1025 MICA QUARTZ GRANITE

WELL # 5
55' 12" PIPE 136' 8" PIPE
0-15 GOOD SAND GRAVEL
15-42 SAND GRAVEL CLAY
42-136 MICA ROCK
136-174 " "
174-180 VOIDS SOFT
180-240 MICA GRANITE
240-255 SOFT VOIDS HIT WATER
255-270 WHITE MICA, GRANITE
270-360 MICA GRANITE QUARTZ
360-415 WHITE MICA GRANITE QUARTZ
415-684 MICA GRANITE QUARTZ
684-696 WHITE MICA SOFT
696-710 MICA GRANITE QUARTZ
710-720 FRACTURES GREEN MICA?
720-740 MICA QUARTZ GRANITE NOT SOLID
740-750 MICA QUARTZ GRANITE
100 BAGS CEMENT
760 - 775 Med Hard
775 - 920 Mica [illegible]
920 - 900 Med

Illustration 9: Driller's log

Illustration 10:
Schematic drawings of wells





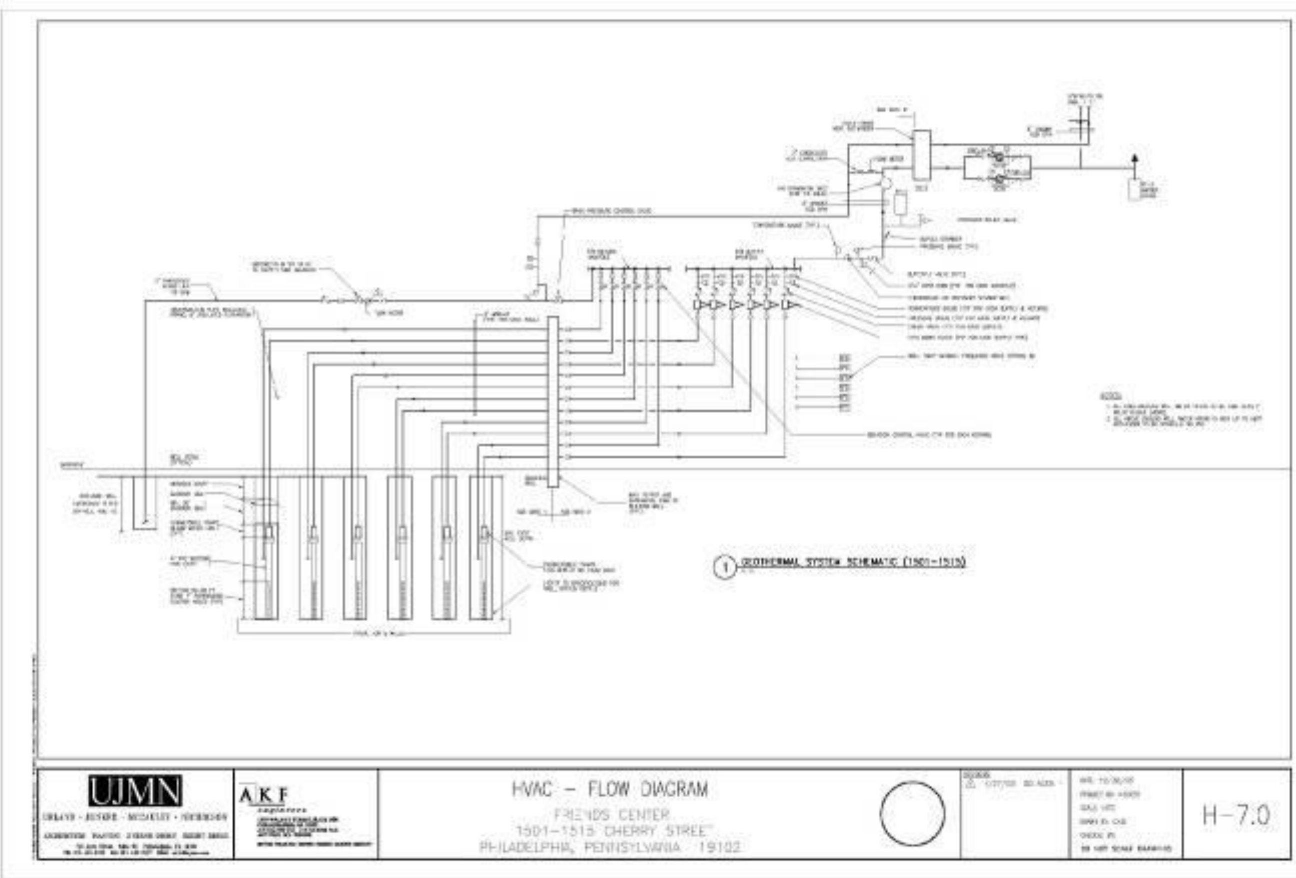


Illustration 11: Trenching and pipes




Illustration 12: Pump Room

Piping array entering building

Finished piping and valving system

Circulation pumps

Illustration 13: Penthouse Mechanical Room

Water to water heat pumps

Control panels

Pumps

Illustration 14: Water-to-Air Heat pumps in meetinghouse basement

Appendix B
Details of Friends Center Green Design

I. The design began with retaining as much of the embodied energy of the existing buildings at Friends Center as possible. That is, we intended to retrofit the existing buildings and not replace them. Historic preservation of the Race Street Meetinghouse was also a goal of the project.

II. Because we are located in the city's core, easily accessible to public transit, Friends Center is a model for low-energy commuting to work and worship. Many of our employees arrive by foot and bicycle and most others arrive by public transportation.

III. We next looked at reducing energy consumption in our buildings, including:
   a. *Changes to the building envelope*: insulating the attic in the historic meetinghouse and installing historically compatible interior storm windows, insulating walls of the office building and replacing windows with high-efficiency spectrally selective glass, installing an energy star roof on the office building topped with a vegetated roof;
   b. *Reduced electrical lighting:* new windows and open-office design will contribute to increased daylighting, which will be combined with high efficiency lighting fixtures and daylighting controls;
   c. *Reduced plug loads:* With the help of our engineers Friends Center designed a "plug load whitepaper" that is being used to help the occupants of the building reduce energy consumption from office and personal equipment.

IV. Through integrated design and reduced energy consumption Friends Center has become able to effectively operate the building without the use of fossil-fuels:
   a. *Deep standing column well geothermal exchange*: This technology allows geothermal heating and cooling in dense urban environments where there is insufficient real estate for the more typical shallow-well systems. The system is expected to reduce carbon emissions for space conditioning to zero.
   b. *Purchased sustainably generated electricity:* Since 1999 Friends Center has purchased sustainably generated electricity, eliminating our reliance on fossil fuels for all other energy needs.
   c. *A photovoltaic array* installed on the penthouse roof of the office building supplements grid supplied electricity with 11,000 kW hours per year directly from the sun's energy.

V. Friends Center has worked with the Philadelphia Water Department and the Pennsylvania Department of Environmental Protection on watershed protection, to creat plans to significantly reduce stormwater runoff.

a. *The vegetated roof* handles 90% of the rain events hitting the office building roof by absorption and transpiration back into the atmosphere. It also reduces the urban heat island effect and passively cools the building.
b. *Stormwater collection and reuse:* Stormwater hitting the sloped roofs of the meetinghouse is collected in cisterns in the basement, filtered, and used for toilet flushing.

VI. The project gave careful attention to the materials that came into the building project and construction waste that left the site.
   a. We have insured a safe and healthy indoor environment by carefully selecting materials that are free of toxins such as the volatile organic compounds, phlalates and formaldehydes that are prevalent in many building materials.
   b. Materials such as drywall, carpet, and ceiling tiles were chosen for their high recycled content and other materials, such as cork and linoleum have been chosen because they are made from rapidly renewable resources. Casework and countertop cores will be made from wheatboard, a product made from agricultural waste. Wood products, such as doors and millwork, will all be made from wood that comes from Forestry Stewardship Council certified, sustainably harvested forests.
   c. All of the demolition and construction debris from the project were managed to insure that anything that is recyclable or reusable finds its way into a productive future life.

At the time of this report Friends Center's LEED* Status is pending, the project has been submitted as a LEED Platinum project.

*(LEED: Leadership in Environmental and Energy Design standards of the United States Green Building Council).

Appendix C
Specifications for Geothermal Wells

Well Specification

The design intent is to create six high production wells at 1,550-foot water column depth, with a combined heat transfer capability for each Standing Column Well of thirty-five (35) tons; in addition one 660 foot diffusion. The well shall have a minimum yield of ten and one-half (10.5) US gpm, without substantial reduction in the water column length as measured from the bottom of the bore to the top of the water. Wells shall be eight (8) inch casing, six (6) inch uncased well with four (4) inch porter shroud and submersible well pump with a flow capability of 105 gpm. The shroud bottom end shall be perforated with one hundred-eighty (180) one-inch circular holes near the bottom of the shroud. The holes will be in the +20 feet to +70 feet as measured from the bottom of the borehole. We anticipate 280 Btu/hr per ft average heat transfer.

The final installation yielded six high production wells at 1,175-foot water column depth, with a heat transfer capability for each Standing Column Well of approximately thirty-eight (38) tons; in addition, we were able to achieve one (1) 680-foot diffusion well. The higher than anticipated heat transfer capability is resultant of large zones of unconsolidated rock and greater water flow through the rock formations. The thermal test indicates potential heat transfer of 392 Btu/hr per ft.

Appendix D
Technical Reports

1. Thermal Testing
2. Well testing
3. Water Analysis

Attached .pdf files

Appendix E
Geothermal Well Design and Construction Team

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