NEW YORK STATE OF OPPORTUNITY. | Geothermal Clean Energy Challenge

Geothermal Clean Energy Challenge: Best Practices and Lessons Learned for Large Scale Geothermal Installations

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Prepared for:

New York Power Authority (NYPA)

and

New York State Energy Research and Development Authority (NYSERDA)

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Table of Contents

List of Figures

List of Tables

1. Introduction

The New York Power Authority (NYPA) and the New York State Energy Research and Development Authority (NYSERDA) launched the Geothermal Clean Energy Challenge (the "Challenge") in December 2017 to stimulate and finance the installation of best-in-class, large-scale geothermal systems.[1] As part of the Challenge, NYPA and NYSERDA developed resources to facilitate installation of geothermal, also known as ground source heat pump (GSHP) systems, and this ***Best Practices and Lessons Learned*** document is one of the resources developed for the Challenge.

The information presented in this document is intended to help engineers, architects, and other stakeholders understand key design considerations that can have a major influence on the successful performance of GSHP systems. The document includes a brief summary of GSHP operating principles and benefits, followed by a discussion of best practices and lessons learned.

The Geothermal Clean Energy Challenge supports GSHP installations at sites with a heating or cooling capacity of at least 100 tons, and this document is focused on installations of this scale.[2] While the document is oriented towards relatively large systems, much of the information is also relevant for smaller GSHP installations.

2. Operating Principles and Benefits

A geothermal system transfers heat between the earth and a building or buildings to maintain comfortable indoor temperatures.[3] In New York State, ground temperatures remain near 50 ^{o}F throughout the year.[4] This stable ground temperature allows GSHP installations to provide energy efficient heating and cooling year-round.

Figure 1 shows a simplified schematic for a GSHP installation. In this arrangement, a piping network buried in the ground is connected to one or more buildings. Water, typically with an antifreeze additive, is circulated in the piping network to transport thermal energy to indoor heat pumps that are located throughout the conditioned space. When operating in cooling

[1] New York Power Authority. (n.d.). The Geothermal Clean Energy Challenge. Retrieved from https://www.nypa.gov/about/geothermalchallenge.

[2] As a rule of thumb, a 100 ton GSHP system will serve the heating and cooling loads for a building that has approximately 40,000 square feet of conditioned space.

[3] Large geothermal systems with capacities of 100 tons or more often consist of multiple buildings connected to a single ground loop.

[4] Geothermal Heat Pump Consortium. (2007). Information for Evaluating Geoexchange Applications. New York State Energy Research and Development Authority.

mode, the circulating water transfers heat from the building to the ground, and in heating mode, the circulating water transfers heat from the ground to the building.

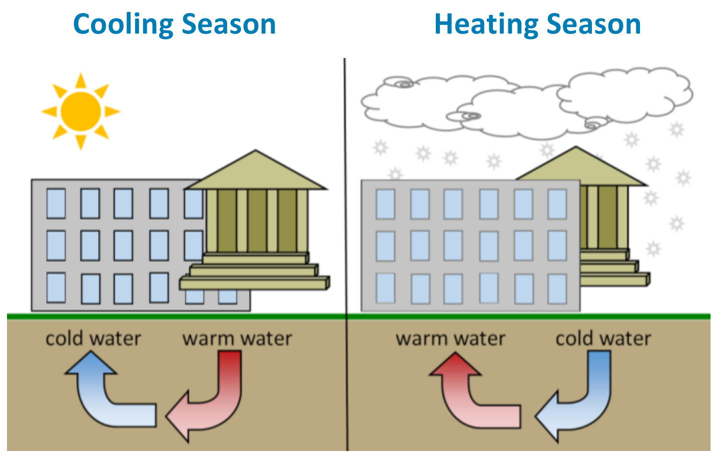

Figure 1. Simplified GSHP Schematic

GSHP systems offer a number of benefits compared to conventional heating, ventilating, and air-conditioning (HVAC) designs. For a single building, or group of buildings, with a space conditioning load greater than 100 tons, a conventional HVAC central plant will typically have one or more fossil-fired boilers and one or more electric chillers.[5] Compared to conventional HVAC equipment, GSHP installations offer several benefits (list is representative and not all inclusive):

- Reduced energy costs
- Increased equipment life
- Increased reliability and reduced maintenance
- Reduced greenhouse gas emissions
- Reduced central plant footprint

Each of these benefits is described, in turn, below.

Reduced Energy Costs

GSHPs are more efficient and have lower energy costs relative to conventional HVAC systems. For every unit of electrical energy used to power a GSHP system, the GSHP system can deliver/extract 3 to 5 units of thermal energy to/from the facility. Energy used for water pumping in GSHPs can be significant, but pump energy can be reduced with the use of multiple relatively small, high efficiency pumps that operate near peak efficiency. In addition, variable speed or frequency drives can be implemented to minimize electricity consumption.

Compared to a fossil fuel-fired HVAC system, in heating mode a GSHP system avoids the entire need for heating fuel. In cooling mode, a GSHP system may obviate the need for a separate cooling energy source and its associated energy use and costs.

[5] Natural gas is a common fossil fuel used for boilers that heat buildings. Oil, propane, and to a lesser extent, coal, are also used.

Increased Equipment Life

GSHP system components, both outdoor and indoor, are designed for a long life. The typical life expectancy of indoor components is 20 years or more.[6] Heat pumps should have a minimum life of 20 years, but their life may be shortened if the circulating water is contaminated, which may lead to fouling, scaling, or corrosion. These problems are most common in open loop systems that use untreated water. For closed loop systems, the water (typically with an antifreeze additive) can be treated and re-used to minimize issues.

The life expectancy of the outdoor ground loop is 50 years or higher, depending on the material used and provided the loop is installed correctly.[7,8] Proper installation includes several factors, such as correct adhesives, proper pipe welding, and the use of appropriate well grouting materials and techniques.

Increased Reliability and Reduced Maintenance

GSHP systems have low operation and maintenance costs and require minimal operator attention. Routine maintenance includes checking for leaks, replacing filters, and sampling water properties.[9] If the GSHP system is integrated with a conventional HVAC system, additional operator attention may be required to properly control and sequence operation.

GSHP systems utilize heat pumps located throughout the conditioned space. Heat pumps use compressors and fans, creating noise which can lead to complaints in occupied spaces. However, sound levels from heat pumps can be minimized with correct heat pump selection and installation. One example is the use of vibration isolation dampers that help reduce heat pump noise attributed to vibration. Another example is the use of low speed fans, which come with the added benefit of reducing the potential effects of drafts. There are many successful examples of GSHP systems where heat pumps have been located within conditioned spaces that require low background sound levels, such as school classrooms and libraries.

Reduced Greenhouse Gas Emissions

Unlike conventional fossil-fired HVAC systems, GSHP systems only consume electricity and emit no on-site carbon emissions. There are carbon emissions associated with the generation of grid electricity, but the carbon footprint for grid electricity has been steadily decreasing in New York State as the penetration of renewable generation, such as solar and wind, has increased. Increasing the use of GSHP systems is expected to play a major role in achieving

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[6] U.S. Department of Energy. (n.d.). Geothermal Heat Pumps. Retrieved from https://energy.gov/energysaver/geothermal-heat-pumps.

[7] High density polyethylene (HDPE) is typically used for GSHP loop fields.

[8] U.S. Department of Energy. (n.d.). *Geothermal Heat Pumps*. Retrieved from https://energy.gov/energysaver/geothermal-heat-pumps.

[9] For closed loop systems, chemical additives may periodically be required to maintain proper antifreeze protection and avoid fouling, scaling, or corrosion.

Governor Andrew M. Cuomo's goal to reduce New York State's greenhouse gas emissions 40% by 2030 and 80% by 2050 relative to 1990 levels.[10]

Reduced Central Plant Footprint

Another advantage of GSHP systems is that they have minimal central plant requirements. In a typical GSHP system, the above-ground central plant hardware consists of mixing valves, pumps, and controls. The footprint required for this above-ground GSHP hardware is significantly smaller compared a conventional central plant that contains one or more boilers and one or more chillers. In addition, GSHP systems require no fuel storage, which is a requirement for central plants that have boilers using oil, propane, or coal.

3. Best Practices

This section highlights best practices related to the design and implementation of GSHP systems. There is a substantial body of information related to GSHP best practices, and this section only touches on a few factors that can have a major influence on the successful performance of GSHP systems. There are several excellent sources listed in the References section at the end of this document that provide more details on best practices for the design, implementation, and operation of GSHP systems.

3.1 Energy Auditing and System Modeling

All GSHP projects should start with a detailed energy audit of the building (or group of buildings) that will be served by the GSHP system. This energy audit should identify all heating and cooling loads and evaluate how the loads may interact. Once these loads have been evaluated, a comprehensive energy model should be developed. This model should then be used throughout the design process to continuously evaluate and refine design choices.

Potential Heating and Cooling Loads

GSHP systems are designed primarily to meet space heating and cooling loads, but other loads can be served, including:

- Domestic water heating
- Pool/spa water heating
- Refrigeration (e.g., ice rink)
- Walkway and road conditioning (e.g., snow melting)

[10] New York State. (2016). *Governor Cuomo Announces Establishment of Clean Energy Standard that Mandates 50 Percent Renewables by 2030*. Retrieved from https://www.governor.ny.gov/news/governor-cuomo-announces-establishment-clean-energy-standard-mandates-50-percent-renewables.

Understanding all potential thermal loads within buildings connected to the GSHP system, and how these loads vary and interact over time, is essential for proper sizing of a geothermal loop. If each load is treated separately, the geothermal loop will likely be oversized resulting in excessive capital expenditures and operating costs. If all potential thermal loads are evaluated holistically, balancing opportunities will likely be identified that will help prevent oversizing of the loop. As an example, heat removed from a conditioned space in summer months can be used to heat domestic hot water, thereby reducing the overall thermal energy required from the geothermal loop.[11]

Evaluation of Seasonal Thermal Balance – Load and System Modeling

After potential thermal loads have been identified and assessed, a comprehensive energy model must be developed. Understanding energy flows and designing a GSHP control strategy to efficiently manage these energy flows is critical to developing a cost effective GSHP system.

In the energy model, the requirements of each potential load should be estimated on an hour-by-hour basis throughout a whole year (i.e., 8,760 hours). This hourly load model will show seasonal variations for individual loads and help to identify synergistic opportunities for offsetting loads (i.e., heat rejected from one load used to satisfy another load).

Analysis of multiple configurations using an energy model is a critical step in the successful design and installation of a properly sized, and cost effective, GSHP system. The energy model should be used to assess different combinations of heating and cooling loads, along with different hardware performance characteristics, to optimize technical performance, capital costs, and operation and maintenance costs.

It is important to remember that for closed loop systems the ground acts as a thermal storage device. Therefore, GSHP loops should be designed based on net heat extraction and rejection loads, not on peak loads. GSHP loops that are incorrectly designed on peak, rather than net, loads will be oversized and more expensive than necessary. GSHP capital costs tend to be proportional to capacity. Oversizing a GSHP system can be a costly mistake that impacts project feasibility.

3.2 Building Interior HVAC Design

Indoor hardware for a GSHP installation typically accounts for the largest portion of the entire system cost.[12] In retrofit situations, the design of the existing air conditioning and space heating systems will have a significant impact on the technical scope and the installed cost of the interior portion of the GSHP system. **Table 1** and **Table 2** summarize information

[11] This example assumes that the GSHP system is intended to provide both space conditioning and domestic hot water heating.
[12] Based on interviews with industry specialists.

pertaining to interior HVAC design and retrofit considerations for air conditioning and heating systems commonly found in commercial and institutional buildings.

Table 1. Air Conditioning Equipment
Considerations when replacing existing A/C equipment with heat pumps

Existing A/C Equipment	Thermal Distribution	System Interconnection	Heat Pump Type	Comparative Cost	Special Considerations
Water Cooled Chiller	Forced Air [1]	Chilled Water Supply & Return Lines	Water-to-Water [2]	Low	Heat pump energy efficiency may be lower than some chillers which would likely make GSHP conversion uneconomic.
Air Cooled Chiller	Forced Air	Chilled Water Supply & Return Lines	Water-to-Water	Low	---
Unitary – Rooftop or Indoor	Forced Air	None - Direct Replacement	Water-to-Air [3]	Lower	---
Unitary - Split	Forced Air	None - Direct Replacement	Water-to-Air	Lower	---
Unitary Water Source Heat Pump	Forced Air	None - Direct Replacement	Water-to-Air	Lowest	May not be financially feasible unless existing heat pumps are approaching the end of their useful lives.

Notes:
1. **Forced Air Systems:** Heated or cooled air is circulated through ducts for space conditioning.
2. **Water-to-Water Heat Pumps:** Produces hot water for use in hydronic or radiant heating systems for space heating or chilled water for use in air conditioning systems. Water-to-water heat pumps are used in buildings with two-pipe or four-pipe systems.
3. **Water-to-Air Heat Pumps:** Heats or cools air in forced-air ducting systems. Heat pumps are available that are designed to be direct replacements for unitary rooftop or indoor self-contained HVAC systems. No major modifications to the existing ducting systems would be required.

Table 2. Heating Equipment
Considerations when replacing existing heating equipment with heat pumps

Existing Heating Equipment	Thermal Distribution	System Interconnection	Heat Pump Type	Comparative Cost	Special Considerations
Steam	Radiators/ Forced Air	Not Applicable	Water-to-Water	High	Heat pumps cannot produce steam. Separate low temperature hot water distribution may be required.

Existing Heating Equipment	Thermal Distribution	System Interconnection	Heat Pump Type	Comparative Cost	Special Considerations
Circulating Hot Water	Radiators/ Forced Air	Not Applicable	Water-to-Water	High	Some heat pumps cannot produce high temperature water. Separate low temperature water distribution may be required.
Unitary -- Rooftop, Indoor, split	Forced Air	Direct Replacement	Water-to-Air	Low	---
Unitary -- Water Source Heat Pump	Forced Air	None Required	Water-to-Air	Lowest	May not be financially feasible unless existing heat pumps are approaching the end of their useful lives.

The following bullets summarize a few considerations related to building HVAC design:

- **Hydronic Heating System Temperature:** Hydronic heating systems in the U.S. are designed to circulate 180 ºF water to radiators. Water-to water heat pumps are generally capable of producing hot water at a maximum of 120 to 130 ºF. Larger capacity water-to water heat pumps are capable of producing hot water as high as 175 ºF. If an existing building with hydronic heating system is to be converted to GSHP service, all radiators must be replaced with units that have greater surface area in order to deliver an amount of heat equivalent to the original radiators. Alternatively, if a building with a hydronic heating system also has central air conditioning, it may be possible to equip the air handling units with heating coils designed to use low-temperature water to supplement the existing radiators that would use the low-temperature hot water produced by the heat pumps. Both systems could then be used to meet heating loads.
- **Steam Radiant Heating Systems:** GSHP systems cannot produce steam. Buildings with steam radiant heating systems would not be GSHP retrofit candidates unless a separate hydronic system is installed that is designed to utilize the low-temperature hot water produced by heat pumps. Alternatively, if a building with steam radiant heating also has central air conditioning, it may be possible to equip the air handling units with heating coils designed to use low-temperature water to supply heat to the building.
- **Chiller System Efficiency:** The energy efficiency of water-cooled chillers (typically over 20 IEER) will almost always exceed that of a GSHP systems, which typically have IEERs ranging from 15 to 17.[13] Buildings that are air conditioned by chilled water from water

[13] Energy Efficiency Ratio (EER) is a measure of efficiency in the cooling mode that represents the ratio of total cooling capacity (Btu/h) to electrical energy input (Watts). Integrated Energy Efficiency Ratio (IEER) is a measure of the cooling part-load EER on a basis of weighted operation over various loads. Seasonal Energy Efficiency Ratio (SEER) is a measure of equipment energy efficiency over the cooling season.

cooled chillers would not be GSHP retrofit candidates. Buildings that use air-cooled chillers may be better candidates because air-cooled chillers often have lower IEER ratings than heat pumps.

- **Water Source Heat Pumps Systems**: If a building equipped with water source heat pumps is converted to a GSHP system, the need for a cooling tower and supplemental heating could be eliminated. Such a conversion would result in lower average loop temperatures during the heating season, which would reduce heat pump capacity, potentially below peak heating design day requirements. The energy cost savings associated with such a conversion may not be attractive, unless the existing heat pumps are near end of life. In this case, new heat pumps can be installed that are designed to operate as required with the lower loop temperatures.
- **Building Loop Design:** Building loops can be designed as a two-pipe system or a one-pipe system.[14] Two-pipe systems allow greater temperature control, but one-pipe systems are less costly and may consume less electricity. Pump motors can consume over 50% of total GSHP system electricity, and alternative loop designs should be carefully considered to minimize electricity use.
- **Centralized versus Decentralized Systems:** An advantage of GSHP systems is that heat pumps are located within the conditioned space rather than in a central location. In this decentralized configuration, air required for heating and cooling is conditioned within the zone, significantly minimizing fan requirements and the associated energy that would be required to move air from a central location. Individual zones can be controlled easily as they can receive exactly the thermal energy required, eliminating the need for reheat to achieve zone control. If multiple heat pumps are arranged on the same single piping loop, thermal load synergies can be achieved. As noted previously, synergies between heating and cooling loads can reduce GSHP capacities and costs.

3.3 Geothermal Loop Design Issues

Verify Soil Thermal Properties

Test Boring

Thermal conductivity[15] and thermal diffusivity[16] are two key ground characteristics that need to be assessed to determine if a GSHP system is feasible. If these ground characteristics are not satisfactorily available for the intended loop field location, a test bore will be necessary. In addition to thermal conductivity and diffusivity, a test bore will provide valuable information on drilling conditions at the site. Information from a test bore can reduce drilling risks or uncertainties, thereby helping to reduce well drilling and completion costs. If a test

[14] Mescher, K. (n.d.). Design of Commercial Ground Source Heat Pumps. Retrieved from http://illinoisashrae.org/images/meeting/041514/2013_14_Documents/12_steps.pdf.
[15] Thermal conductivity is the property of a material (e.g. soil and rock) to conduct thermal energy (hot or cold).
[16] Thermal diffusivity is a measure of the rate of transfer of thermal energy (hot or cold).

bore is commissioned, the well site should be located such that the test well can be included in the final loop field if the GSHP project moves forward. This will reduce costs.

Test boring should be performed by a qualified and experienced contractor that is registered under New York State Water Well Driller Registration Law.[17] This registration means that the contractor has passed a two-part National Ground Water Association Certification, or equivalent, examination and is registered with the State to drill wells of this type.

Thermal Conductivity Test (TCT)

As part of a test boring study, a TCT should be performed to determine, or confirm, the thermal conductivity and thermal diffusivity of the ground. In this test, a U-tube heat exchanger is installed in the planned geothermal loop field location. A heat load is then placed on this U-tube and the ground's temperature response is measured. The data from this test are then used to calculate the expected thermal conductivity and thermal diffusivity for the geothermal loop field.

Test Boring and TCT Results Evaluation

Results of the test boring and TCT are used to inform the geothermal loop design, resulting in estimates for the depth and diameter of the wells and the total number of wells required. Multiple loop configurations should be considered to identify a geothermal loop design that optimizes performance and capital costs. It is far less expensive to make adjustments in the design at this stage, rather than changing the design after construction or commissioning has started. It is also far better to understand the economic value and capital costs at this stage and make a "go, no-go" decision accordingly.

Geothermal Exchanger Options

There are three main options for geothermal exchangers – open loop, standing column wells, and closed loop.[18]

Open Loop System

In an open loop system, water is pumped from a well, pond, or river to heat pumps located in the conditioned space. Return water from the heat pumps is not re-used (see closed loop system below). Rather, the return water is pumped back to an available surface source (pond or river) or reinjected using a discharge well.

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[17] New York State. (n.d.). NYS Water Well Driller Registration Law (ECL 15-1525). Retrieved from http://www.dec.ny.gov/lands/5345.html.

[18] Geothermal exchangers or thermal energy exchangers are where thermal energy (hot or cold) is transferred between a solid and a fluid or between two fluids. There may be direct contact between the two materials or separation with a pipe or barrier of some type.

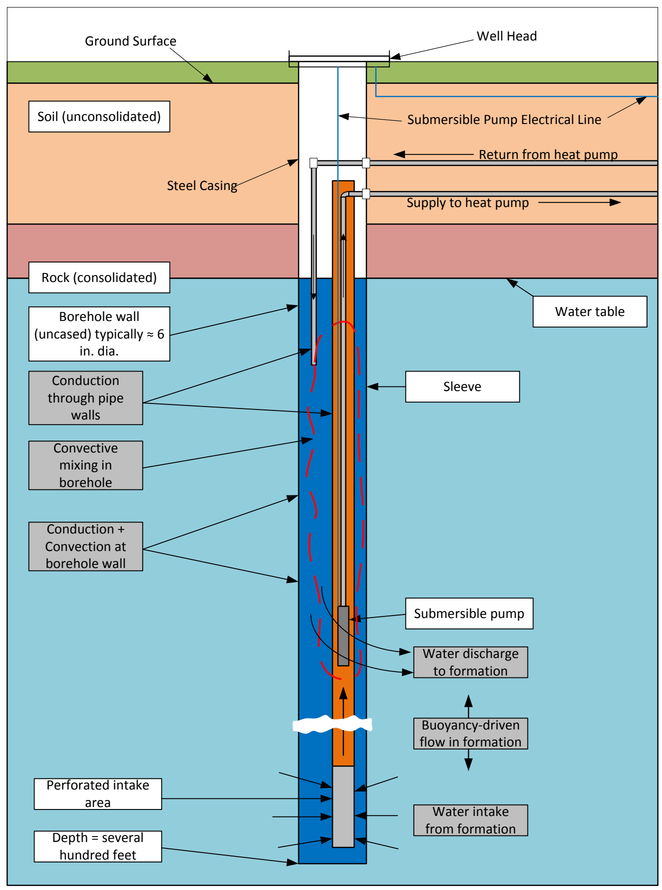
Open loop construction costs are typically lower compared to standing column and closed loop systems. However, operating costs tend to be higher due to higher pumping costs. Many locations do not allow the use of surface water for open loop systems and require that water from an open loop system be re-injected into an approved discharge well.

Because open loop systems use untreated water, water quality concerns can be more common than in other types of exchangers. Untreated water can contain high levels of minerals (e.g., iron or calcium), bacteria, or organic contaminants, which can lead to fouling, scaling, or corrosion. Open loop systems should only be used if the water quality is carefully tested and determined to be acceptable for a GSHP system.

Standing Column Wells

A standing column well (SCW) consists of a vertical borehole that is filled with groundwater up to the level of the surrounding water table (see Error! Reference source not found.). An SCW, also referred to as semi-open loop system, uses a single well for both extraction and rejection of thermal energy, whereas an open loop system uses separate wells for thermal energy extraction and rejection.

Figure 2. Standing Column Well Schematic



Source: Earth River Geothermal. (n.d.) – (redrawn for clarity)

A SCW system can be thought of as a hybrid between a closed loop system and an open loop system. During much of the year, a SCW operates by recirculating water between the well and the heat pump. However, during peak temperature periods, a SCW can "bleed" some water from the system to induce groundwater flow. This causes groundwater to flow to the column from the surrounding formation to make up the flow. This cools the column and surrounding ground during heat rejection in the summer, and heats the column and surrounding ground during heat extraction in the winter, thus restoring the well-water temperature to the normal operating range and improving the system performance.[19]

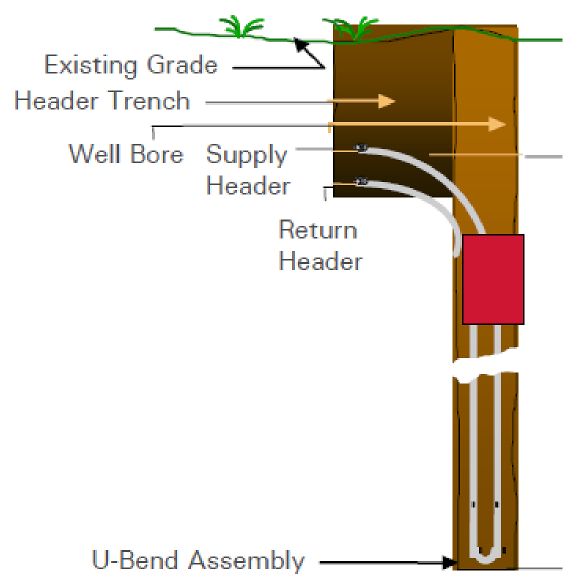
Because groundwater is being used directly, water quality concerns should receive particular attention with SCW systems for similar reasons as with open loop systems. Poor water quality from high levels of iron, calcium, and other minerals, as well as bacteria and other organics, can result in mineral deposits, fouling and corrosion. Another consideration for SCW systems is that they are not typically suited for sandy soils where the borehole may crumble.

While capital costs for SCW systems are typically lower than closed loop systems, maintenance and operations costs may be higher. More maintenance may be required because the water flowing in the SCW thermal loop is untreated groundwater, which may cause fouling and contamination of the heat exchangers, pumps, and other equipment. Also, because groundwater is used, it is normal to have an intermediate heat exchanger between the well field and the heat pump, and this additional piece of hardware needs periodic maintenance.

Closed Loop System

Closed loop systems have a horizontal pit or trench with buried piping, a vertical borehole, or a horizontal bore. Most systems for commercial or institutional buildings have vertical boreholes. Water, typically with an antifreeze additive such as propylene glycol, is circulated through the closed loop.

Figure 3. Closed Loop Schematic



Source: (Arizona Geological Survey, n.d.)

In a vertical closed loop system, a pair of pipes connected by a U-tube at the bottom is placed vertically within the borehole and grouted into place (see Error! Reference source not found.). Water is pumped down one of the pipes and returns through the other. Heat is transferred between the water and the surrounding ground through the pipe wall. High density polyethylene (HDPE) is the most common type of pipe used for GSHP loop fields. The grout used in a vertical closed loop well needs to be carefully considered. Use of thermally enhanced bentonite grout instead of standard bentonite grout will help reduce

[19] O'Neill, Z. D., Spitler, J. D., & Rees, S. J. (2004). Modeling of Standing Column Wells in Ground Source Heat Pump Systems.

thermal resistance and improve heat transfer performance. In some cases, sand or similar aggregate may be used as part of the grouting process.

Because water is recycled in a closed loop system, concerns with equipment fouling, mineral deposits, and reduced operational efficiency tend to be minimized compared to open loop and SCW systems. For a closed loop system, selection of the antifreeze, and appropriate concentration, should follow ASHRAE guidelines.[20]

Ground Loop Configurations

There are three basic choices for configuration of the GSHP ground loops:

- Single ground loop for multiple buildings
- Separate ground loop for each building
- Combination system

Single Ground Loop for Multiple Buildings

In this configuration, all heat pumps in all buildings are connected to a common circulating loop, which in turn is connected to a single ground loop.[21] Because all heat pumps are on the same loop, there are opportunities to maximize the diversity and synergy between the thermal loads, providing the highest overall efficiency. Because of piping connections required, this design is most suited to a building (or buildings) with compact floor plans, which will help minimize capital costs and reduce pumping costs.

Separate Ground Loop for Each Building

For sites such as schools and university campuses, where buildings may be spread out, a design where each building is connected to a dedicated ground loop may be appropriate. This approach may help minimize difficulties and installation costs that could be encountered when running a central loop between buildings that are not located near one another. However, by serving each building with a separate ground loop, there is no possibility for synergy and diversity between loads. The geothermal loops in this this design will likely have a combined capacity significantly larger than a single loop that could serve all buildings.

Combination System

A combination system has some heat pumps connected to one ground loop, and other heat pumps connected to a separate ground loop rather than all of the heat pumps being connected to the same ground loop. This configuration can be tailored to suit the specific circumstances and layout of a large building or group of buildings. If designed correctly and if

[20] ASHRAE. (n.d.). Geothermal Heating and Cooling: Design of Ground-Source Heat Pump Systems. Retrieved from https://www.ashrae.org/resources--publications/bookstore/geothermal-heating-and-cooling-design-of-ground-source-heat-pump-systems.

[21] The ground loop typically consists of multiple ground coupled wells.

practical given the relative locations and proximity of loads, this configuration may offer synergy and diversity between compatible loads, helping to minimize overall size and cost of the system.

3.4 Integrating Building Interior and Geothermal Loop Design

Pump Selection and Control Strategies

Several different pumping strategies have been successfully applied to GSHP systems, and a thorough discussion of all approaches is beyond the scope of this document. For any pumping strategy, however, power calculations should be performed at 10%, 25%, 60%, and 100% of full load. Specific circumstances may require some latitude; however, at each part- load condition, the pump power should not exceed 20% of the total system power. The pump power should be less than 10% of total system power at full load.[22] These calculations will highlight potential problems in the design, which may prevent high pumping energy use and potential geothermal system failure.

Manifold Design

Two common manifold designs are “reverse return” and “interior valved.”

- **Reverse Return Manifold**: -This simple technique is used to provide a naturally balanced flow through each vertical loop. Sizes need to be selected such that the total pressure drop of the manifold plus all supply and return piping is approximately 30% or less of the total pressure drop (indicating that the pressure drop of the vertical loop is 70% or greater of the total). In addition to pressure drop, the other critical characteristic is allowance for flushing and purging. While not an industry consensus, a velocity of 3 feet/sec is generally considered to be effective for flushing debris from piping. The pipe sizes in a reverse return manifold must be reduced throughout the length of the manifold to maintain minimum velocities.

- **Interior Valved Manifold**: -The purpose of an interior valved manifold is to collect all the different supply and return pipes serving each group of vertical loops and to allow each group to be flushed and purged individually. Valves are required to allow for this individual flushing and purging. Before choosing to incorporate balance valves on this manifold (as opposed to using more cost-effective means to create balance), the design engineer should perform calculations to clearly understand advantages and disadvantages of balance valves. For perspective, balance valves are only accurate to +/- 5%, have significant pressure drop (≥ 5 feet of head) in an open position, have a significant upfront cost, and lead to increased energy use for pumping. Calculations will indicate if the advantages of balance values offset the disadvantages.

[22] Recommendations on standard design practices are from a GSHP industry specialist with New York State experience.

Supplemental Heating and/or Cooling

If supplemental heating and/or cooling is used with a GSHP installation, careful consideration must be made as to how the complete system will be controlled. In some retrofit situations, boilers and/or cooling hardware may exist, and it can be tempting to integrate this legacy hardware in a new GSHP installation.

In most cases, a GSHP installation without supplemental heating or cooling is preferable. This type of installation will avoid the cost and complexity of integrating conventional HVAC equipment. However, there may be cases where it is not possible to design a GSHP system to cover an entire building or group of buildings, where there is insufficient space in which to locate the loop fields, or it is not practical or cost effective to serve certain loads with a GSHP system.

4. Lessons Learned

This section summarizes lessons learned from the installation of GSHP systems. The intent is to help architects, engineers, and other stakeholders learn from previous experiences, and avoid common pitfalls. This section is by no means all inclusive. The References section at the end of this document lists several sources for further reading.

4.1 Reduced Heat Pump Life Due to Short Cycling

Poor design can result in excessive energy use and heat pump compressor failure due to short cycling. A common example is when multiple heat pumps are integrated incorrectly such that none of them operate for a cycle sufficiently long to become adequately lubricated. This is called short cycling, and the resulting lack of lubrication can cause increased energy use and premature failure of heat pump equipment.

Lesson Learned: Check design of indoor equipment and control strategy to avoid short cycling of heat pumps.

SHORT CYCLING DUE TO POOR DESIGN

"Three of the heat pumps were staged together at the first stage which meant that most of the time, they ran for only a few minutes before satisfying the call for cooling. This short cycling contributed greatly to their early demise."

Source: Nelson Mechanical Design, Inc.

4.2 Undersized Ground Loop

Deficient sizing of the geothermal loop will not allow sufficient thermal energy to be transferred between the geothermal loop and the building loads, resulting in inefficient operation, higher energy use, inadequate space conditioning (i.e., too hot or too cold), and possible failure of the GSHP system. Ground heat exchanger size plays a dominant role in loop performance, and undersized loops are the primary cause of loop temperature excursions outside design specifications.[23]

Well drillers may want to stop drilling once sufficient water flow has been obtained. However, the surface area of the well, which depends on the well depth, is critical for ensuring that a well functions properly over the intended life of the GSHP installation. Geothermal wells transfer heat along the entire depth, and heat transfer capacity increases with well depth. Short well depths reduce heat transfer capacity and may reduce overall output capacity of the system.[24]

Lesson Learned: During the geothermal well design process, consider both water flow and heat transfer factors to ensure proper well performance.

4.3 Central Chiller Connected to Ground Loop

Some GSHP systems have been designed with a central chiller cooled by a geothermal loop. Chilled water is then delivered from a central plant to the conditioned space, similar to the design used for conventional HVAC systems. This design approach is less energy efficient compared to using individual heat pumps located throughout the conditioned space.

Lesson Learned: Avoid designing a GSHP installation with a central chiller connected to a geothermal loop. Instead, use heat pumps located in the conditioned space.

4.4 Biological Fouling and Scaling

Biological fouling and scaling of geothermal wells and heat exchangers reduces heat transfer performance, which reduces energy efficiency and can ultimately lead to hardware failure.[25] An example of biological fouling occurred at Standard Microsystems Corporation (SMSC) in Hauppauge, New York.[26] SMSC installed a 300 gpm (gallons per minute) open loop GSHP system that experienced fouling caused by iron reducing bacteria. Injection well fouling increased back pressure and reduced water flow, and heat exchanger fouling reduced heat transfer efficiency.

The solution developed to correct fouling problems with SMSC's system was to use intermittent infusion of iodinated air bubbles. This method, developed by Air Fluid Innovation, had previously been used in the health industry.[27] Periodically, the protocol removed bio-film and minerals from internal surfaces, allowing SMSC to continue operation of its 300 gpm open loop GSHP system.

[23] Kavanaugh, S., & Kavanaugh, J. (2012). Long-term Commercial GSHP Performance. ASHRAE Journal, 28-45.
[24] Harvard. (2007). Geothermal Wells at Harvard- Lessons Learned. Cambridge: Harvard Office of Sustainability.
[25] Biological fouling and scaling occurs when biological materials such as algae or bacteria coat parts within the geothermal wells and heat exchangers and reduce their heat transfer capabilities. Other fouling and scaling may occur from minerals in the water such as calcium and iron.
[26] I2 Air Fluid Innovation, Inc. (n.d.). Retrieved from http://www.i2airfluidinnovation.com/
[27] Ibid.

Open loop and SCW systems are particularly prone to issues with scaling as the groundwater passes directly through the heat exchangers, and any impurities in the water (e.g., iron, calcium, etc.) can cause scaling and fouling.

Closed loop systems can also be impacted by scaling resulting from poor quality water. In a closed loop system, the concern is typically not the main refrigerant-to-water heat exchanger, but the desuperheater. Water is circulated through the desuperheater and back to the main hot water heater to provide a portion of the domestic hot water heating needs. In large commercial or institutional systems, the groundwater is isolated from the building loop using a plate-and frame heat exchanger. This design eliminates the potential for scaling in the heat pump units. In addition, it reduces the maximum temperature to which the groundwater is exposed, thus reducing scaling potential.[28]

Lesson Learned: Water chemistry should be evaluated during the design phase to identify potential problems with biological fouling and scaling. A water quality control plan and inspection schedule should be developed to mitigate problems due to water quality. During implementation, the inspection schedule should be carefully followed. In a closed loop system, additives should be used to keep water chemistry within design specifications.

4.5 Unnecessary Vault and Incorrect Manifold Sizing

The sizing of pipework throughout the GSHP system is important to allow for correct functioning and performance of the system and to allow for flushing when necessary. In a recent installation in New York State, the engineer broke the system into two sections each with a separate vault. He also had 17 loops in a group where the reverse/return manifold was three inches throughout, without any reduction in size toward its end. The loop installing contractor spotted this potential problem and stopped the installation. Because of the large diameter of the piping proposed with no reduction in diameter towards the end, the flow required to reach the minimum purge velocity of two feet/sec would have required an estimated two firetrucks to flush and purge the 17 loop circuit.[29] In this installation, a single vault would have been sufficient and saved capital cost. Redesigning the pipe diameter reduced the flushing and purging requirements.[30]

Lesson Learned: Care should be taken in design to minimize capital costs. Systems should also be designed to allow for flushing and purging with adequate purge velocity.

[28] Rafferty, K. (2000). Scaling in Geothermal Heat Pump Systems. CHC Bulletin, 11-15. Retrieved from https://pdfs.semanticscholar.org/afde/1c6f0c47ba65a5667994e657ea857fc7a121.pdf.

[29] Based on interviews with industry experts, current industry practices now recommend a three feet/sec flushing velocity.

[30] This brief case study was derived from interviews with a GSHP expert.

4.6 Corrosion

HARVARD GSHP INSTALLATIONS – LESSONS LEARNED – BRACKISH WATER

Salinity was encountered in some of Harvard University's Wells. Heat pumps and piping for several Harvard projects were not designed for brackish water, leading to unplanned maintenance and re-design.

Source: Harvard, 2007

Some GSHP systems are installed in locations with brackish water. Brackish water is corrosive, and premature equipment failure will occur if GSHP hardware is not designed and protected for operation under brackish conditions. Corrosion is particularly an issue with open loop and SCW systems, where water is pumped directly from the ground through the GSHP system. If there is no intermediate heat exchanger, water will be pumped directly through the heat pump. Brackish water pumped through a heat pump or heat exchanger not designed to withstand the salinity will corrode, increasing maintenance costs and downtime and potentially causing early equipment failure. Materials for intermediate heat exchangers should be selected to avoid corrosion (e.g., naval bronze, brass, or Inconel), and all components within the GSHP system that will be in contact with brackish water should be selected accordingly.

Lesson Learned: During the design phase, a water quality expert should measure water salinity. If brackish water is present, GSHP materials and equipment should be selected to tolerate prevailing water conditions. If corrosion is a potential problem, a "coupon" rack should be installed and monitored to assess corrosion levels.[31] A coupon rack can provide early detection of potential corrosion problems, and mitigation steps can then be considered to prevent equipment failure due to corrosion.

4.7 Avoid Designs that Result in Air Traps

In a school project in northern New York State with 300 vertical bores, the well installer only drilled the wells to about 150 feet due to the geology of the area. Rather than change loop pipe diameter to ¾" and keep the wells all in parallel, the engineer responsible opted to stay with 1¼" pipe and install three wells in series, resulting in 100 parallel circuits with each circuit having three 1¼" vertical loops in series. Unfortunately, this resulted in two enormous air traps in series. Over time dissolved air came out of solution, rose to the top of these air traps (under low load) and eventually disabled a number of the circuits before it was noticed that loop field temperatures became more extreme because a very significant part of the loop field had no flow.[32]

[31] A coupon rack holds corrosion coupons, which are the simplest and most commonly used form of corrosion measurement today. According to Global Water Technology, Inc., corrosion coupons are small bars of various metals or alloys that are introduced into the system through a side stream coupon rack." For more information, see: https://www.gwt-inc.com/resources/corrosion-coupons/.

[32] This brief case study was derived from interviews with a GSHP expert.

Lesson Learned: During construction, if there is a change in design required due to geology or other factor, carefully consider any "fixes" before they are implemented to ensure they do not create future problems.

4.8 Migration of Contaminated Water

Water quality in the area surrounding a geothermal well, especially a SCW well, can significantly impact the performance of the well. The installation of new trenches, local construction, and the boring of additional wells may impact groundwater quality.[33]

Contaminated water can migrate through several paths, especially during construction or expansion of an existing GSHP system. The drilling process could allow polluted groundwater or surface water to spread. For example, if well bores are not properly grouted, polluted water can migrate through the well bores. Trenches with gravel bases are another migration pathway, as highly permeable gravel beds can act as conduits for the flow of contaminated water.

Lesson Learned: Wells must be properly grouted. While proper grouting is necessary for all well completions, it is particularly important when drilling in carbonate aquifers in New York, where large open spaces (from a cavern or large fracture) may be encountered.[34] It may be difficult or impossible to seal a well bore that passes through a cavern or large fracture, although success has been reported with pea gravel and bentonite chips.[35]

[33] Pennsylvania Department of Environmental Protection. (2001). Ground Source Heat Pump Manual.
[34] U.S. Geological Survey. (n.d.). Aquifer Basics. Retrieved from https://water.usgs.gov/ogw/aquiferbasics/ext_nycarbon.html.
[35] Wisconsin Department of Natural Resources. (2012). Geothermal Briefing. Madison: Wisconsin Department of Natural Resources. Retrieved from https://dnr.wi.gov/topic/Wells/documents/GeothermalTrendsandEmergingTechnology.pdf.

4.9 Subsurface Disturbances

Subsurface disturbances can occur from drilling or trenching activities. Drilling can introduce or stir up suspended solids. Although most rock types will be unaffected from disturbances, a few types will be more susceptible to increased turbidity from drilling. Carbonate rocks, such as limestone and dolomite, are especially vulnerable to disturbances.[36]

Well drilling can cause turbidity problems for nearby wells, especially wells drilled in carbonate rock formations. Digging trenches can also affect turbidity conditions in the groundwater. This turbidity may be a short-lived and minor problem; however, for a groundwater supply well it can be a serious problem, even if short-lived. Over time, turbidity problems often subside for rock formations where turbidity is not normally a persistent problem.

HARVARD GSHP INSTALLATIONS – LESSONS LEARNED – CONSTRUCTION DEBRIS CONTAMINATION

While installing a second set of wells, heat pumps at a nearby existing building at Harvard University were affected by excessive mud, rocks, and dust trapped in the condensing water filters

Upon investigation, it was discovered that drilling the new wells generated debris that was drawn into the existing wells (exacerbated during periods of bleed)

Source: Harvard, 2007

Lesson Learned: Water conditions should be closely monitored in nearby wells when drilling is underway. If possible, do not bleed neighboring wells when new wells are being drilled.

4.10 Insufficient Well Instrumentation

Adequate instrumentation should be installed to measure performance of the GSHP system. It is particularly important to have adequate instrumentation on the ground loop at the time of its original installation, because subsurface GSHP system components can be difficult and expensive to access after construction is complete. Instrumentation is necessary to monitor GSHP system performance, and to identify or prevent potential underperformance. As an

[36] Pennsylvania Department of Environmental Protection. (2001). Ground Source Heat Pump Manual.

example, geothermal wells are sometimes bled to restore performance.[37] Bleeding will lower the level of water in the well. If groundwater fails to flow into the well at a sufficient rate, the water level in the well could fall below the pump causing overheating or pump failure. This type of failure can be prevented with adequate instrumentation and control safeguards.

Lesson Learned: During the design phase, specify instrumentation that will measure key performance parameters for the complete GSHP system, and in particular, the ground loop. Accessing the ground loop after installation can be difficult and expensive, and instrumentation should be installed during construction.

HARVARD GSHP INSTALLATIONS - LESSONS LEARNED – INSUFFICIENT INSTRUMENTATION

Specify and install adequate well monitoring and controls, including:

- Flow rate and temperature for:
  - Supply
  - Return
  - Bleed
- Flow switch on well supply line
- Level meter on each well

Resist temptation to eliminate controls and metering during value engineering.

Source: Harvard, 2007

4.11 Poor Control Strategy for Supplemental Heating and/or Cooling

If a supplemental boiler and/or chiller is integrated with a GSHP system, a control strategy must be designed that will ensure efficient operation of the entire, combined system. If the control strategy is not properly designed, the two systems (GSHP and supplemental heating/cooling) may operate against each other. For example, the GSHP system may be trying to provide cooling, while the boiler may be trying to provide heating, leading to inefficient and expensive operation. Situations have been noted where controls have failed, and supplemental heating boilers have been found to be heating not only the building, but also the geothermal loop field. [38]

Lesson Learned: If supplemental heating and/or cooling hardware is used, carefully design the control strategy to ensure that the supplemental heating and/or cooling equipment does not operate against the performance of the GSHP system.

[37] Ideally, GSHP systems should be designed to have zero bleed requirements by sizing the geothermal field sufficiently and/or fracturing the wells to increase groundwater flow.
[38] This brief case study was derived from interviews with a GSHP expert.

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