BEST PRACTICES

Geothermal or Ground Source Heat Pump Systems

The following document recommends methods and steps to implement energy-efficient, cost-effective, and reliable geothermal heating and cooling systems. More detailed information can be found in the NYSERDA Ground Source Heat Pump (GSHP) Program Manual.

Providing successful HVAC/comfort solutions requires a very comprehensive set of skills beyond the scope of this document; therefore, it is assumed that project designers possess additional expertise, including engineering of air distribution and hydronic distribution systems, awareness of relevant mechanical and safety related codes, the ability to calculate and estimate energy consumption and perform trade-off analyses, etc. The steps defined in this document are not meant to minimize the need for overall proficiency, but rather serve as a roadmap to maximize the return on investment using geothermal technology.

Step 1. Prospect

Identifying the thermal opportunities that can be served with a geothermal loop is key to increasing cost-effectiveness and return on investment. Especially for large systems, a large variety of thermal loads can be satisfied with low-grade (<140°F) thermal opportunities available with a GSHP. In addition to space heating and cooling, the following thermal energy synergistic opportunities should be considered where applicable:

- Domestic or service water heating (both large and small systems)
- Heating or cooling ventilation air
- Pool and spa heating
- Ice making (large ice rink applications)
- Snow melting
- Dehumidifying
- Refrigeration
- Cooling data centers
- Heating or cooling for beverage processing
- Capturing load diversity between buildings

For example, in a data center application, the electric energy that is converted to heat energy by computer servers is absorbed by the ground source loop cooling the server room. The thermal energy heat can then be used to heat perimeter office spaces during winter or to generate domestic hot water during warmer months.

Step 2. Model

All HVAC system designs can benefit from a heating and cooling energy model, but for larger geothermal systems (>75 Ton) it is essential for “right sizing” the loop field. Ideally, the HVAC designer will create a system that manages energy flows most efficiently. An energy model is the foundation for loop field design and is important for the following reasons:

- The size and cost of the loop field is directly related to accurately quantifying the amount of energy the loop field must absorb and provide to maintain an acceptable swing in entering water temperatures. The model should be used to properly size the loop field ensuring additional boreholes and costs are not included.
- The model is key to identify synergistic opportunities as well as avoiding poor design decisions that negatively impact overall cost and/or performance.
- Most HVAC energy modeling software do not have the capability to model all potential thermal loads identified in Step 1; therefore, it is incumbent upon the system designer to develop reasonable energy flows on an hourly basis and integrate those correctly into the total system model.

The energy model must be used to demonstrate actual performance, not just an exercise to compare System A vs. System B without regard to actual accuracy. The art of geothermal loop design requires an accurate energy model to serve as the foundation.

Step 3. Iterate and Employ Integrated Design Principles

A single energy model will identify opportunities but fall short in optimizing a design unless several iterations are used to explore the interactive energy dynamics. Once an initial model is developed, the mechanical engineer working directly with the architect early in the design process to optimize building envelope insulation and orientation will improve the efficiency, thermal load balance, and overall cost-effectiveness. For example, in a cooling dominated application, the south-facing window area that increases cooling load may be reduced or moved to the north side to create a better balance between heating and cooling loads resulting in a lower-cost loop field. It is essential that the provider of energy modeling services must also be skilled in the art of loop field design to effectively optimize a GSHP system.

Step 4. Estimate Using Proper Sources and Evaluate on a Life Cycle Basis

For GSHP systems, the major cost components may not be well defined through RS Means; therefore, obtaining a cost estimate for the system is critical so the project can be properly evaluated on a life-cycle basis. Loop field construction costs should be developed by techniques more commonly used when drilling for water or setting pilings. A life cycle cost analysis should include all significant capital and operational cash flows, including energy savings, maintenance and replacement costs, and environmental externalities for a minimum life of 25 years, capturing the value of the loop field's expected life of more than 100 years.

Step 5. Test Bore

A test bore is often a prudent investment; however, there are many circumstances where there is inadequate information or the project size is too small to justify the cost. Generally, if a project contains fewer than 10 bores (30 tons), the investment may not be prudent and is not required by the GSHP Rebate initiative. Local knowledge regarding the geology can provide a reasonable basis for thermal conductivity and diffusivity, the two quantifiable parameters that are factored into loop field calculations. These two parameters are sufficient to characterize the thermal feasibility of a project and are not the primary reasons to invest in a test bore.

The primary reason to invest in a test bore for a large project is to identify and quantify the specific drilling conditions so that construction bids are well-informed and contain less contingencies. The test bore should be located and constructed so it can easily be incorporated into the final design as a functioning borehole. Performing a Thermal Conductivity Test (TCT) serves the secondary motivation of confirming or adjusting the anticipated conductivity and diffusivity values. CSA 448.3 section 4.5 has guidance in Table 1. IGSHPA would recommend a test bore with TC testing. NYSERDA's current Program Manual requires TC testing at 30 tons.

Step 6. Recalculate

The results of the test bore, both insight into drilling productivity and thermal characteristics, need to be included in the previous calculations and estimates. The number of boreholes, depth, and spacing should be adjusted as needed to maximize performance and cost efficiency.

Step 7. Sustainable Design Approach

High-performance, cost-effective, and reliable GSHP solutions can meet sustainable design and net zero energy goals. While many different elements and strategies can be employed by a design engineer to incorporate geothermal into an energy solution, the design team must understand that every choice that impacts the heating and cooling loads or the mechanical systems can impact the GSHP system. Simply incorporating a geothermal loop field into a marginally performing conventional HVAC solution is missing what geothermal implies. For example, a level of unfounded concern regarding the performance or reliability of a geothermal loop field and consequently installing "back-up" boilers or cooling towers are often not necessary. These "safety net" approaches often add complexity, undermines GSHP performance and add to the myth that GSHP systems are too expensive.

Step 8. Detail

Details need to be illustrated in a set of construction documents, and geothermal specific details should include the following items. Additionally, the engineer should supply supporting calculations to the client.

- Reverse Return Manifold. This simple technique is used to provide a naturally balanced flow through each vertical loop. The detail should reflect specific pipe sizes between each tap to a loop. The sizes must be selected so 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). The other critical characteristic is to allow for flushing and purging. Historically, a minimum velocity of 2 feet per second in each section of pipe is required to purge air from the system; however, the industry is beginning a transition to specifying a velocity of 3 feet per second to be more effective. The pipe sizes in a reverse return manifold must be reduced throughout the length of the manifold, otherwise it may be impossible to reach the minimum required velocities.

- Interior Valved Manifold. It makes sense to find space inside a mechanical room to install the valved interior manifold (to collect all supply and return pipes and allow each group to be flushed and purged individually) vs. using a buried vault outdoors. In addition to the high cost associated with vaults, there are many examples of vaults that fill with water and accelerate the corrosion of components, ultimately creating a system reliability problem. The incorporation of balance valves on this manifold are strongly discouraged. Specifically, balance valves are only accurate to +/- 5%, have significant pressure drops (>= 5 Feet of Head) in a wide open position, and significantly increase first cost and pumping energy over the life of the system. A natural loop field balance can easily be achieved through proper pipe sizing, with more distant loops being served with two different diameter pipes to create equal pressure drop characteristics even if the number of loops within a group are different across all groups.

- Pump Selection and Control Strategies. Many different pumping strategies have been successfully applied to GSHP systems. As part of the construction documents package, the design engineer should provide total system pump power calculations at various loads. Specifically, these calculations should be performed at 10%, 25%, 60%, and 100% of full load. Specific circumstances may require some latitude, but at part load conditions, pump power should not exceed 20% of the total system power and be less than 10% at full load. GSHP systems have failed to meet expectations in many circumstances due to pumping energy use.

Step 9. Peer Review

In the scientific community, the foundation of credibility is the peer review process. Peer review should also be applied when designing and building energy systems that can last for hundreds of years; especially because low market penetration has not produced a level of widespread competence in the building design community. Peer review provides a valuable second opinion that explores and evaluates each of the many design details by another firm well versed in the technology designed. Even when the design team has previously designed GSHP systems, the review process will create a sharing of best practices, stimulate creative ideas, and improve the market penetration of cost-effective high performance GSHP systems.

Step 10. Construction

A GSHP system comprises elements common to more conventional HVAC systems as well as those that are unique. These new elements are built by individuals with specialized training and certification requirements. Specifically, the construction of a geothermal loop field requires skills in one or more of the following:

- Heat fusion of high density polyethylene (HDPE) pipe. Engineering specifications should stipulate that field technicians have been trained and maintain the International Ground Source Heat Pump (IGSHPA) Accredited Installer (AI) credential.

- Drilling a vertical bore. The drilling industry and associated regulations in New York State have been evolving over several years. Currently, the geothermal driller must meet Environmental Conservation Law (ECL) 15-1525, which stipulates passing a two-part National Ground Water Association (NGWA) Certification exam.

- Inserting a geothermal loop and grouting. The engineering specifications should include compliance with both NGWA and IGSHPA Standards and training certifications regarding these activities.

- Flushing and Purging. In addition to the IGSHPA AI credential, the contractor must have appropriate equipment, including separation vessel, pump, flow meter, and filtration suitable for the size of the project. The construction documents should clearly state the flushing/purging flow rates and corresponding pressure drops such that the contractor bids and plans accordingly.

It is also vitally important to require contractor competence, training, and certifications in all the related construction trades, including pipe fitting, refrigerant handling, duct installation, electrician, and controls hardware and software.

Step 11. Testing and Commissioning of System

There are two critical tests that should be performed to demonstrate the integrity of a geothermal loop field:

- Pressure Test: A competent contractor may elect to perform progressive testing on an ongoing basis to manage risk; however, a very specific test performed in accordance with ASTM F2164 must be performed on the entire assembled loop field.

- Flow/Pressure Drop Verification: This test is designed to demonstrate that a circuit of piping, which typically has multiple parallel loops, has the anticipated flow and pressure drop relationship. If pressure drops are higher than anticipated (>10%) there may be a blockage in the piping that must be located and rectified.

Commissioning and testing/balance protocols are also appropriate strategies to test and verify operation and performance and should be incorporated as dictated by the size and scope of the project.

Step 12. Quality Assurance

The promise of a high-performing, cost-effective, and reliable GSHP system can only be realized if quality control is exercised throughout the process. Focusing on the post-installation phase, a GSHP system has three areas that require diligence:

- Mechanical systems: Each piece of hardware, such as pumps, fans, heat pumps, valves, etc., has its own specific maintenance requirements as stipulated by the respective manufacturer. Following these procedures is the responsibility of the system owner.

- Fluid integrity: The heat transfer fluid, typically a water/antifreeze mixture, is quite often the weak link in the long-term reliability of the GSHP system. The most commonly cited problems are:
  - Dirt and debris in the fluid. A lack of proper flushing, purging, and filtering of the entire system that needs to be properly specified and executed in the field.
  - Biological contamination. The mild antifreeze concentrations specified for both cost and performance considerations are not a biocide and quite often can be a source of explosive bacterial growth. The use of sterilization protocols during the installation process can reduce this risk.
  - Corrosion. Proper corrosion inhibitors must be specified, installed, and maintained as dictated by the piping and component materials. The use of state-of-the-art materials instead of conventional steel piping can be very effective at reducing this risk. Water quality testing and treatment procedures must be a part of ongoing maintenance procedures.
  - Monitor, verify, and optimize. Monitoring basic operating parameters, whether with simple data loggers or sophisticated energy management systems, is critical to verify system performance and to adjust and optimize performance. For example:
  - Water and air flow can easily be adjusted and overall impact to both system efficiency and comfort can be observed and optimized.
  - On larger projects, a variable frequency driven pump is often controlled by a differential pressure sensor located out in the system piping. The actual setpoint should be as low as possible and can only be accomplished after the system is installed.
  - It should be frequently monitored to evaluate all operating scenarios. If a single heat pump is dictating a high differential pressure and balance valves are being used to reduce flow through the remaining heat pumps, then applying a small booster pump on the more restrictive heat pump and eliminating balance valves on the less restrictive heat pumps can result in significant pump energy savings as well as lowering the BTU load on the loop field.

References

1. ANSI/CSA C448 Bi-national Standard for Design/Installation of Geoexchange Systems

2. ASHRAE Geothermal Heating and Cooling: Design of Ground Source Heat Pump Systems, Steve Kavanaugh and Kevin Rafferty

3. ASHRAE Geology and Drilling Methods for Ground Source Heat Pump Installations: An Introduction for Engineers, H Sachs

4. IGSHPA Closed-Loop/Geothermal Heat Pump Systems Design and Installation Standards 2016

5. IGSHPA Residential and Light Commercial Design and Installation Manual

6. IGSHPA Design and Installation Standards

7. IGSHPA Soil and Rock Classification Field Manual

8. IGSHPA Grouting for Vertical GHP Systems

9. IGSHPA Understanding Geothermal Exchange Heating and Cooling

10. ASTM F2164 Standard Practice for Field Leak Testing of Polyethylene (PE) and Crosslinked Polyethylene (PEX) Pressure Piping Systems Using Hydrostatic Pressure