karpinski ENGINEERING

DESIGNING & MODELING A GEOTHERMAL SYSTEM

AT A GLANCE

- 350,000 SF high school renovation and addition completed in August 2017
- HVAC system is a 750 ton modular heat recovery chiller plant served by a 190 borehole hybrid geothermal system
- Used DesignBuilder to construct a large, complex energy model with 21 airside loops and four waterside loops
- DesignBuilder's interoperability with Revit, gbXML, and GLD streamlined the modeling process

BACKGROUND

With this project, the Cleveland Heights-University Heights (CH-UH) School District has reimagined its high school for new generations of students.

The old school building had consisted of the original 1926 school building, along with piecemeal additions. Many of the building systems were past their service lives, very few areas had air conditioning, and heating was provided by three aging natural gas fired steam boilers installed in the 1970s.

The new Heights High retains and renovates the original 1926 school building, placing it at the center of the design. It is flanked by 216,000 SF of new construction.

In undertaking this project, the school district and community prioritized sustainability and energy efficiency. Community groups were involved in early eco-charrettes, and they advocated specifically for a geothermal system. As designers, our challenge was to work with the existing building footprint and a landlocked site, while providing a geothermal system large enough to serve a 350,000 SF building.

Why a Hybrid Geothermal System?

All HVAC systems require a source of heat in the winter time and a heat sink in the summer time to operate. A geothermal system takes advantage of the constant moderate temperature of the ground to efficiently provide both a heat source and a heat sink for a building. While often a more expensive option in terms of first cost, the high efficiency of geothermal systems can be a worthwhile investment for institutions that are in a position to make investments whose simple payback may be as long as 10 to 15 years.

During the initial phases of design, two challenges emerged:

1. The site didn't have enough space to accommodate a geothermal borefield large enough to meet the peak cooling load.
2. The cost of a full geothermal system would have strained the project budget.

As a result, the design team and the school district selected a hybrid geothermal system. The borefield is sized for the heating season, and in the cooling season a fluid cooler

PROJECT BASICS

LOCATION: Cleveland Heights, Ohio (Climate Zone 5a)

HVAC SYSTEM SERVING:

- Classrooms and offices via 4-pipe fan coil units; indoor DOAS units with heat recovery and heat pipes for ventilation; VAV CO2 control
- Gyms and cafeteria via single zone 4-pipe VAV AHUs
- Natatorium via water-cooled DX pool dehumidification unit
- Auditorium via single zone 4-pipe VAV displacement ventilation system

PERFORMANCE CRITERIA

- LEED Gold Certification (in progress; earned 14 EAc1 credits)
- Energy Star 95

PROJECTED ENERGY USAGE

- EUI = 33 kBTU/SF/year
- 60% site energy savings
- 38% source energy savings
- 33% cost savings

HVAC SYSTEMS COST: $13 million

PROJECT COST: $102.5 million

supplements the capacity of the borefield. **In this case, the hybrid system will provide approximately 90% of the energy savings of a full geothermal system, but for approximately 60% of the cost.**

APPROACH AND ANALYSIS

Once the school district selected a hybrid geothermal system, the design team needed an energy modeling tool that could perform more sophisticated calculations than the tool they had used for the initial design phases.

That's where DesignBuilder came into the picture. It offered two important features that attracted the design team's attention:

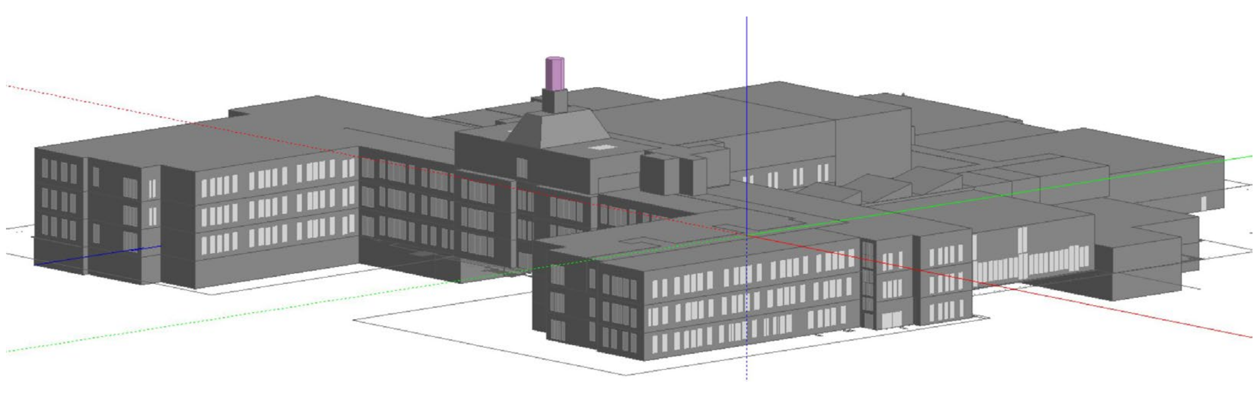
1. **Advanced modeling capabilities.** DesignBuilder allowed the team to leverage the complexity and flexibility of the EnergyPlus engine*, such as a 4-pipe fan coil units, dedicated outdoor air units, and a water-to-water reversible chiller connected to a vertical borefield. While the team still had to find some workarounds, they could include more features directly into the model by using EnergyPlus than by using other simulation methods.
2. **Compatibility with geothermal borefield design program (GLD).** The team could design the borefield's exact layout and characteristics in the GLD design program, then export it to an IDF file. The IDF file could then be imported into DesignBuilder, carrying over the borefield geometry and thermal characteristics without error.

Why Energy Modeling Matters for Geothermal Design

When designing a geothermal system, one of the key parameters is to maintain the storage of heat in the borefield. If too much heat is extracted, the heat pumps could lose the ability to heat the building. Inversely, if too much heat is rejected to the ground, the borefield could become unable to cool the condenser water enough to create sufficient chilled water. The design team needs to understand how the load varies throughout the year, not just on the design days, in order to manage the balance between the heating and cooling loads. Energy modeling helps with that process, allowing the team to test and refine their design.

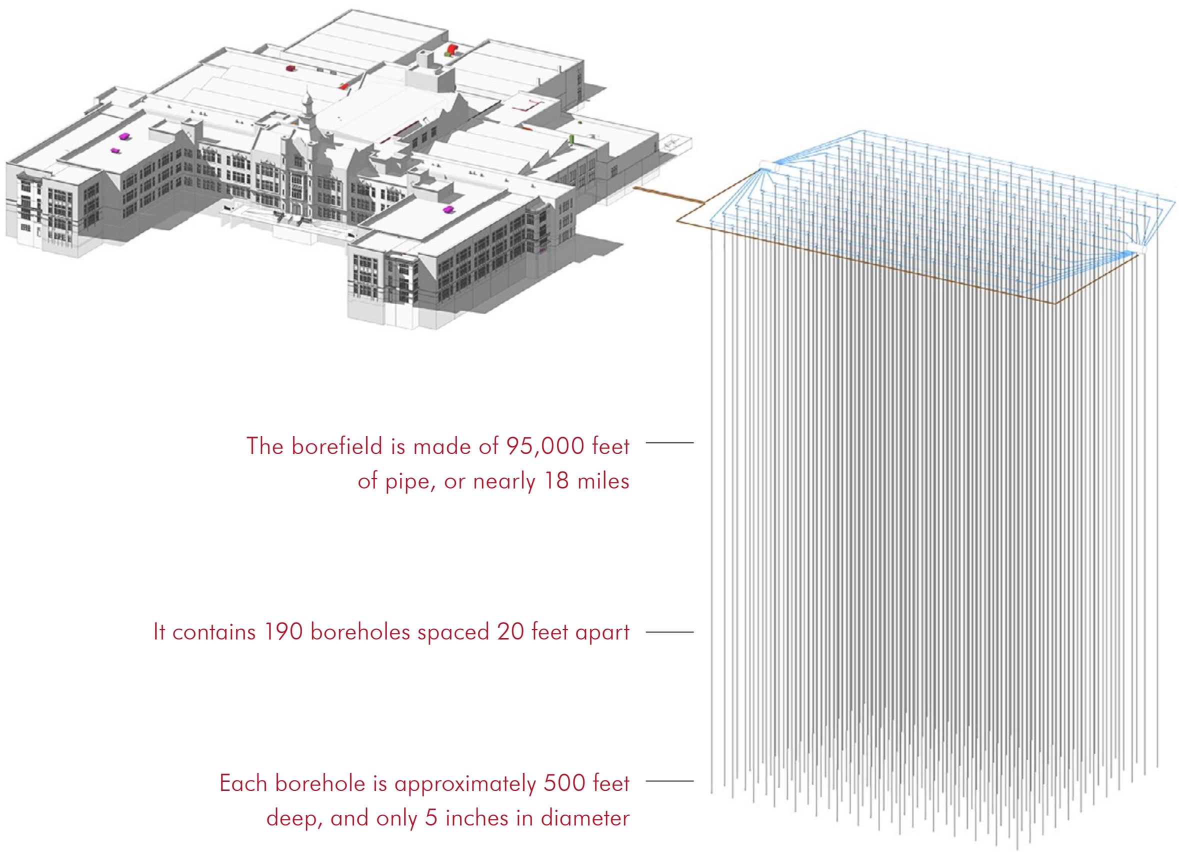
**Throughout the case study, references to DesignBuilder assume the use of EnergyPlus.*

Below: Working view of Heights High School in DesignBuilder.



HEIGHTS HIGH SCHOOL'S GEOTHERMAL BOREFIELD

Model is to scale



By using DesignBuilder, the team could model their high-performance HVAC system design natively in the program. This allowed them to capture energy-efficiency components such as the amount of energy recovered on the ventilation system while running at variable speed to manage CO2 levels. It also reduced the number of spreadsheet calculations for special circumstances, which saved the team time and produced more precise results.

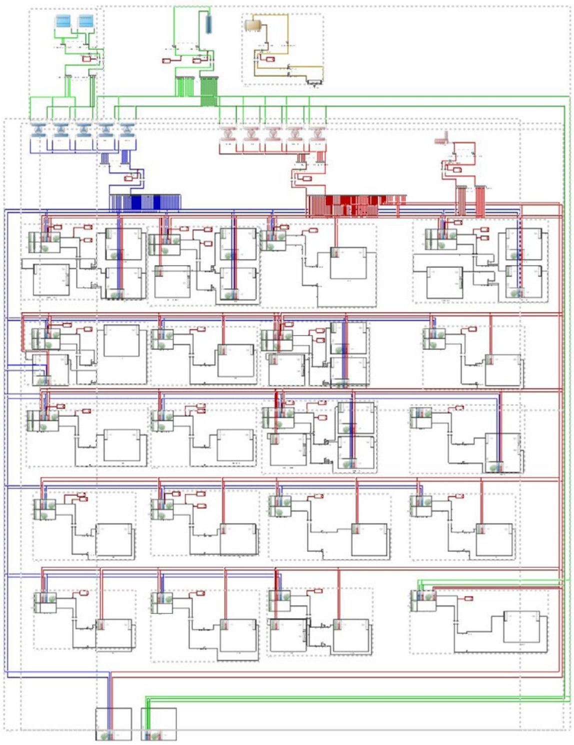
Taking DesignBuilder for a Test Drive

DesignBuilder is a sophisticated building simulation program that has a geothermal borefield module, and GLD is a sophisticated borefield design program that has some HVAC components built into it.

To help validate the modeling approach and IDF import tool, the design team wanted to verify that the program could model the borefield behavior as well as the borefield design program. They built a test model: a 125,000 SF school building with 120 boreholes, on a condenser loop running three water-to-water heat pump chillers.

The test model allowed the team to compare how GLD and DesignBuilder modeled the same geothermal system, since they differ in the complexity and approach. Looking at the condenser supply and return temperatures, the variation between the models was on average 1.6F (σ = 1.6) for the entering condenser water and 1.5F (σ = 1.0F) on the return water temperature. This variation is acceptable in context of the accuracy of typical immersion temperature sensors and the slow control response times of typical HVAC systems. Both temperatures were, on average, higher in the DesignBuilder model.

Based on these results, the design team felt confident proceeding with DesignBuilder.



Top: Schematic of the geothermal system in DesignBuilder. Center: The borefield under construction. Bottom: Moduclar heat recovery chiller

RESULTS

The design team was able to size the borefield with confidence.

In any geothermal system, an annual building load profile is required to help determine the heat balance of the system in order to size the heat exchanger. An ideal borefield would have its heat rejection closely match the amount of heat supplied in the winter. In the case of this hybrid system, the borefield is sized to meet the heating needs of the building, and fluid coolers supplement the resulting imbalance.

In calculating the heating loads, the designer needs to fully account for all the heat recovery mechanisms that exist in the system. DesignBuilder allowed the team to effectively model the air side and water side of the system natively, as well as make an in-depth analysis of the results. These functions helped the team verify the correct operation of the model and gave them confidence in using the results as a basis for the borefield design.

The design team was able to refine the sequence of operation based on what the model showed.

When designing any complex system, especially with modern digital control systems, designers make many decisions about how to control that system. The ubiquity of variable speed drives, modulating valves, and dampers allows for near infinite flexibility in system operation. By using the sub-hourly results that EnergyPlus provides, the design team was able to refine the system's sequence of operation.

In this instance, having two heat rejection options in the fluid coolers **and** the geothermal borefield added a layer of complexity that was not typical. The general rule in central plant optimization is to let the smaller motors (cooling tower fans) work harder to make the larger motors (chiller compressors) more efficient. Given the flexibility allowed for in the detailed HVAC design, we were able use DesignBuilder to test different scenarios, giving the geothermal borefield and the fluid coolers varying levels of priority based on load and time of year, to find the most energy efficient sequence.

Overall, DesignBuilder helped us to design a high efficiency system that was awarded 14 LEED points, allowing us to comfortably pursue LEED Gold certification.

About Karpinski Engineering

Karpinski Engineering designs environments that inspire. We partner with organizations and design professionals to develop spaces for healing, learning, business, and discovery. Our team provides mechanical, electrical, plumbing, technology, and civil engineering design services, along with an array of specialty services. Learn more at www.karpinskieng.com.