Community Heat Pump Feasibility Study: Watchtower Headquarters, Ramapo, NY

Final Report | Report Number 23-11 | January 2023

NEW YORK STATE | NYSERDA

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Community Heat Pump Feasibility Study: Watchtower Headquarters, Ramapo, NY

Final Report

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Notice

Abstract

This report documents the Watchtower Headquarters Project Ramapo (HPR) PON 4614 Category B design efforts. Due to a 100,000 square foot (SF) increase to the HPR campus' Audio Video (AV) Studio, a redesign of the existing geothermal system commenced. The 215 boreholes, 800 feet deep, water-based geothermal borefield increased to 280 boreholes, 800 feet deep, with a 20 percent propylene glycol-water working fluid to meet the increased demand, while maintaining the campus' commitment to be fully electrified, free of fossil fuel, and carbon-neutral ready. All buildings on campus were designed to reduce heating and cooling peaks through high-performance facades, ventilation energy recovery, and other heat recovery strategies. By centralizing heat pumps serving the 16 buildings on campus, simultaneous heating and cooling loads can be leveraged to meet the non-dominant load on campus. Campus heating and cooling loads are met by three operating modes at the central energy plant (CEP): (1) simultaneous heating and cooling, (2) geothermal heating/cooling, and (3) electric boiler or cooling tower operation. Resulting from an 8,760-hour energy model, there are no predicted hours in which the third operational mode of heating and cooling is necessary. The report discusses the process of modeling the HPR campus, optimizing the geothermal system, and redesigning the CEP and campus thermal distribution network to accommodate the AV studio expansion.

Key words

Geothermal heat exchanger, geothermal borefield, heat pump, carbon neutral, electrification, centralized energy plant, heat recovery

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Acronyms and Abbreviations List

AV	Audio Video
BR+A	Bard, Rao and Athanas Consulting Engineers, LLC
BAS	Building Automation System
CEP	Central Energy Plant
CCP	Certified Commissioning Professional
CHW	Chilled Water
COP	Coefficient of Performance
CT	Cooling Tower
DOE	Department of Energy
DOE2	Department of Energy 2
DEC	Department of Environmental Conservation
DDC BMS	Direct Digital Control Building Management System
DES	Distributed Energy System
ERV	Energy Recovery Ventilator
GLD	Ground Loop Design
GSHE	Ground Source Heat Exchanger
GSHP	Ground Source Heat Pump
HP	Heat Pump
HPR	Headquarters Project Ramapo
HVAC	Heating, Ventilation, and Air Conditioning
HPGX	High Performance Geo Xchange
HW	Hot Water
LNG	Liquified Natural Gas
MEP	Mechanical, Electrical, and Plumbing
NG	Natural Gas
New York State	the State
NYSERDA	New York State Energy Research and Development Authority
SF	Square Foot
TMY3	Typical Meteorological Year, Third Collection
USGBC	United States Green Building Council
Watchtower	Watchtower Bible and Tract Society of New York, Inc.
WCCH	Water Cooled Chiller

Executive Summary

The Watchtower Headquarters Project Ramapo (HPR) Campus is a 1.7 million square feet (SF) new development that is being designed as an integrated work, live, play facility in Ramapo, New York. The campus will serve 1,200 full-time residents, housed in ten multifamily residential buildings. Five commercial buildings are planned to provide working and support spaces for residents. With the living and working facilities closely located and under one ownership, the HPR project provides significant opportunity to implement energy saving strategies that leverage centrally connected utilities and diversified loads.

Early in the design phase, the team recognized the significant energy savings available by use of geothermal technologies. The Owner (Watchtower) had a favorable experience with the small-scale deployment of a community-style geothermal borefield on their campus in the nearby Town of Warwick (completed 2014). That project demonstrated significant reduction in electricity use and fuel oil consumption due to the use of the geothermal system. With the new HPR project planned, the design team desired to implement a larger-scale geothermal field, with the goal of maximizing its benefit for the new campus. A significant advantage would be realized by eliminating the dependence on fossil fuels, which became a key focus for the team.

As the Owner's programming for the campus was refined, several hurdles were identified that challenged the goal of a site free of fossil fuel and fully electrified. To offset the additional design costs, Watchtower proposed and was awarded a contract under the NYSERDA Category B Site-Specific Design Study. The study that follows summarizes the significant effort of the design team to manage the project hurdles. The final deliverable results in a set of construction-level documents that exceed the Owner's expectations. The project now has a system design for cooling, heating, and domestic water heating that uses only geothermal processes, eliminating the need for fossil fuel usage. Further, during all modeled weather conditions, the system does not rely on electric resistance heat, reducing electric consumption and related utility costs.

The final geothermal design includes 280 boreholes, each extending 800 feet deep, with a 20 percent propylene glycol-water working fluid. The heat pump equipment includes four 400-ton (nominal) centrifugal heat pumps and three 250-ton (nominal) screw heat pumps. The peak cooling capacity of the system is 2,098 tons and the peak heating capacity is 27.4 MMBtu/hr. To manage the peak demands and minimize the borefield size, all buildings on campus were designed to reduce heating and cooling peaks through high-performance facades, ventilation energy recovery, and other heat recovery strategies. By centralizing heat pumps serving the 16 buildings on campus, simultaneous heating and cooling loads are leveraged to meet the non-dominant load on campus. The report discusses the process of modeling the HPR campus, optimizing the geothermal system, and redesigning the Central Energy Plant (CEP) and campus thermal distribution network to accommodate the Owner's required programming changes.

Successful completion of the Category B Site-Specific Design Study and the resulting design documents concludes the Owner's construction document phase. Watchtower, as the contractor under this PON, intends on moving directly into construction activities upon obtaining the necessary building permits. It is Watchtower's plan to seek a contract award for the NYSERDA Category C Site-Specific Implementation Project upon submission of the Category B study.

The Owner wishes to thank NYSERDA for their support in moving this unique project forward. It is our hope that the research and lessons learned from our project will assist NYSERDA in advancing its goals related to accelerating market capacity and the adoption of community-style heat pump systems in New York State.

1 Objectives and Benefits

1.1 Campus Strategy

This section describes the overall campus strategy and how it ties together the buildings, central energy plant (CEP), and campus microgrid into a centralized, single community system.

The Watchtower Headquarters Project Ramapo (HPR) Campus is a 1.7 million SF new development complex that is being designed as an integrated work, live, play facility in Ramapo, New York. The campus will serve 1,200 full-time residents, housed in 10 mass-timber-framed multifamily residential buildings, and up to 1,200 daily visitors from around the world. Five commercial buildings are being designed to satisfy the needs of residents and guests, and to fulfill the work, live, play concept that is of forefront importance to the owner. These five commercial buildings include (1) an events facility, with a large commercial kitchen and gathering space for residents and guests; (2) a modular and adaptable office building which will allow residents to work on-campus within walking distance of the residential buildings; (3) an audio video (AV) studio, with six state-of-the-art production stages; (4) a fitness center for residents; and (5) a visitor center that will welcome visitors from across the globe. Following the 100,000 SF expansion to the HPR campus' AV studio, a redesign of the existing community geothermal heat pump system commenced.

Energy conservation, sustainability, and economic viability are driving elements of the campus design. For these reasons, Watchtower has committed the HPR Campus to be fully electrified, free of fossil fuel, and carbon-neutral ready, as defined by NYSERDA, from the first day of operation. These stringent internal sustainability goals are achieved thanks to a distributed energy system (DES), through which the heating and cooling for the entire campus will be centrally generated at a high-efficiency, fully electrified, geothermal Central Energy Plant and distributed to all buildings on campus. Centralizing the heating and cooling generation allows the campus to optimize energy recovery across the 16 different buildings (including the CEP) by transferring thermal energy from one building to another via centrally located, high-efficiency heat pumps. The campus is served by a single campus hot water (HW) and chilled water (CHW) loop, so every building's heating, cooling, and domestic HW loads (except the events facility and fitness center domestic hot water (DHW), which are independent systems) impact the performance of the entire system. Building and campus annual and peak heating and cooling loads were evaluated via energy modeling, for which the methods and results are explained in detail later in section 2.2.

Campus heating and cooling will be provided by means of premium, efficient heat recovery centrifugal and screw heat pumps. A connected geothermal borefield with 280, 800 feet deep concentric boreholes provides additional heating and cooling. The geothermal borefield, coupled with the CEP, can satisfy 100 percent of the campus heating and cooling peak and annual loads. To provide additional resiliency, cooling towers and electric boilers will be installed in the CEP, although this equipment is not expected to be used during normal operation. Emergency liquified natural gas (LNG) tanks and generators will also be installed for emergency use only.

The campus HVAC electrified system is powered by three sources: (1) Orange and Rockland Electricity Utility, (2) 3,275 kilowatts (kW) total, 4,500 megawatt-hours per year (MWh/year) photovoltaic (PV) arrays located on the events facility and AV studio, and (3) a 2.5 megawatts (MW) x 10 megawatt hours (MWh) industrial EOS Zynth Aqueous Zinc battery system. To support the electrified system, the campus is equipped with a grid-connected microgrid to optimize campus energy consumption and increase resiliency by reducing dependency on the grid. During normal operation, the microgrid operates connected to the utility grid and acts as a sophisticated controller, monitoring and balancing the use of the PV, battery, utility power, and generators. The microgrid is programmed with information such as the cost of and emissions from each source, so total campus energy costs and emissions can be tracked and optimized in real time. Although the final design of the microgrid is incomplete, the microgrid controller could, for example, have the ability to track real-time changes in the power prices of the utility grid (as supply/demand fluctuates) and make cost-effective decisions. In case of a utility grid-wide power outage, the microgrid can operate independently, powered by the PV installations, battery system, and emergency generators. Mechanical systems and CEP operations are controlled by a state-of-the-art direct digital control building management system (DDC BMS).

Beyond improved reliability and resiliency, PV energy generation and battery energy storage reduce both the amount of electricity purchased from the grid and shifts that purchase to nighttime hours. Purchasing energy at night eliminates the peak demand surcharge, lowering the cost per kWh.

Each building is designed with state-of-the-art technology, keeping in mind energy efficiency and sustainability as the driving factors. To ensure the most value from the owner's capital resources and effectiveness of design, the contractor and subcontractors have worked diligently to reduce the buildings' heating and cooling demand on the CEP. The campus hydronic system is coupled with heat recovery and overall efficiency measures at the individual building-level to lower the overall heating demand on campus. These building-level measures are as follows:

- Envelope: High performance envelopes have been applied to every building. Thermally broken assemblies are detailed in individual building design documents and all constructions meet or exceed prescriptive NYSECC-2020.
- Ventilation/Airside Systems: The residences, events facility, audio video studio, and offices all have a dedicated outdoor air system (DOAS) coupled with fan coil units or chilled beams to achieve reduced heating and cooling loads by de-coupling space conditioning from ventilation.
- Exhaust Airstream Energy Recovery: The offices have dual wheel energy recovery and the events center and audio video studio are considering dual wheel energy recovery. The residences' AHUs have an energy recovery wheel.
- Hot Water Heat Recovery: Passive DHW heat recovery will be used in the residences' shower units to reduce the DHW heating load. Passive HW heat recovery will also be incorporated into the events facility commercial kitchen drains, and integration with the fitness center shower drains is under consideration. Active heat recovery was studied; however, it was realized as an ineffective cost solution compared to the passive heat recovery system.
- Events Facility Kitchen Heat Recovery: There is a heat recovery glycol loop in the commercial kitchen hood exhaust. Heat is extracted from the exhaust air stream, sent to a water source heat pump, and then recovered to the campus cooling loop to balance heating loads. A campus-wide control sequence will optimize this recovery to only when the campus is heating dominated. There is also heat recovery from the commercial kitchen coolers and freezers. Instead of having the equipment reject heat to the space, waste heat is rejected to the cooling loop to balance the simultaneous campus heating and cooling load.

Through the above optimization of each building's energy consumption, the contractor and subcontractor (BR+A) successfully reduced the overall annual and peak heating and cooling loads on the CEP and heat pump system.

At the onset of the campus energy distribution system design, an ambient loop system was considered, which requires a single distribution pipe rather than the four pipes required by the HW and CHW distribution system that was ultimately selected. It was found that for this project, the most efficient system was a centralized plant and a four-pipe campus distribution system since it offered the best opportunity for balancing loads across the campus, was most cost-effective, and simplified equipment operation and maintenance. An ambient loop system would require a heat pump at each of the 16 buildings to serve the loads of each building. A centralized system allows for the loads of the campus to be aggregated and offers increased opportunity for simultaneous heating and cooling and load balancing. Additionally, in a decentralized system, each building would require a larger mechanical room and an equipment operator. By locating all heat pumps in the CEP, there is only one location for plant operational and maintenance work, which reduces the aggregate size and cost of the equipment operation and maintenance staff, and heat pump selections could be combined into fewer, larger pieces of equipment. The centralized plant offers the opportunity to serve the campus heating and cooling needs via large centrifugal heat pumps, which have higher efficiencies than smaller screw or scroll heat pumps that would be installed to service each building, lowering the overall energy use of the campus comparatively. Since all campus buildings are under single ownership, there is no need to divide operations, maintenance, and utility costs between buildings, which is more easily achievable with an ambient loop system. Additionally, while ambient loop systems have the advantage of lower thermal distribution gains and losses, the Watchtower HPR project leverages two strategies to reduce these distribution gains and losses. First, the distribution pipes are insulated with 2 inches of polyurethane foam, which reduces the heat gain or loss of the system, as discussed in section 2.2. Secondly, the HW loop is maintained at a lower supply temperature of 128°F, also discussed in section 2.2. This lower distribution temperature reduces the temperature differential between the HW distribution supply and the ground, lowering the overall heat transfer of the system.

The community layout is illustrated by the site plan in appendix A, page A-1.

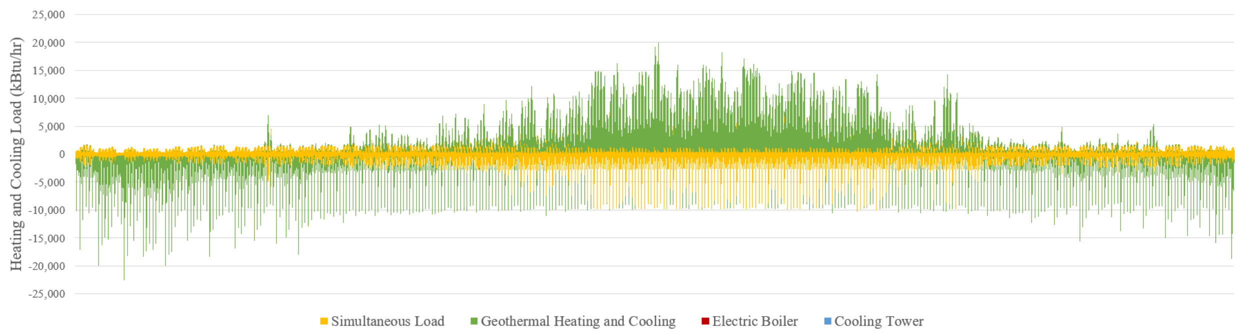
The high-level campus construction schedule is reported in appendix A, page A-2.

1.2 Hourly Loads (8,760) from Energy Models

To fully and confidently determine the sizing of the geothermal borefield and its heat pumps, it is necessary to accurately calculate the size of the heating and cooling loads served by these systems. To estimate the campus' heating and cooling loads, both the peak design building loads and an 8,760 hourly load profile were required to determine the characterization of the geothermal heat pump system.

To obtain peak and 8,760 hourly building-level load profiles, energy models for all buildings were created using eQuest 3.65, a Department of Energy (DOE) software. eQuest results were entered into a proprietary Excel post-processing program to calculate peak loads for each building and for the entire campus. All building loads were combined to develop an 8,760 hourly campus load profile to inform the sizing of the Ground Source Heat Exchanger (GSHE) and other campus equipment and infrastructure. All models are based on the latest available Mechanical, Electrical, and Plumbing (MEP) and architectural design drawings. Modeling methods, assumptions, and parameters are detailed later in section 2.2. Figure 1 below illustrates the 8,760 hourly required CEP operation, by heat pump operation, to meet the campus heating and cooling load profiles.

Figure 1. Annual Heating and Cooling by Source



The 8,760 hourly profile above shows the simultaneous heating and cooling in yellow that operates throughout the year. This operation is limited by the non-dominant load on the CEP. Green represents geothermal heating and cooling. Heating is represented negatively, while cooling is positive. There is no electric boiler operation required for typical peak heating conditions. There is no cooling tower operation because the equipment never enters water cooled chiller operation, in which heat is rejected to the cooling towers. All heat rejection is to the GSHE. As detailed later in section 3.2, electric boilers and cooling towers are incorporated into CEP design only for unanticipated situations in which additional heat generation or rejection is necessary. As shown in Figure 1 above, the peak heating and cooling load on the plant is 22.6 MMBtu/hr and 20.0 MMBtu/hr, respectively.

In task 2, milestone 2/3, the borefield cooling and heating capacity and electric boiler size were varied and hourly plant operation by source was analyzed for each configuration. Six options were considered, but the configuration that yielded the hourly profile in the Figure 1 was selected. Figure 1 above results from option 6 from task 2, milestone 2/3, which has a borefield with 280 boreholes, 1,625 tons cooling capacity, 25,731 kBtu/hr heating capacity, and no electric boiler nor cooling tower in use during normal operation. The options were analyzed from financial, operational, technical features/infrastructure, flexibility, and reliability/resiliency standpoints. The selection process is explained in detail in task 2, milestone 2/3. Option 6 was ultimately selected due to its flexibility, reliability/resiliency, and that it falls within the electrical load letter limit (discussed in the next section), even with backup electric boilers operating.

The 8,760 hourly campus load profile enabled the Geo-Consultant MEP Associates of Salas O'Brien to study the long-term effect of the geothermal system on the ground temperature. The load profile does not only help identify the combined peak heating and cooling loads, but also helps the team certify that the annual heat input and output from the ground is balanced.

Energy recovery methods were included in the energy models to properly account for their balancing effect on the overall campus heating and cooling loads. The campus-wide methods accounted for were(1) heat rejection from the coolers and freezers in the events facility commercial kitchen, (2) events facility commercial kitchen exhaust heat recovery system, and (3) residential DHW passive heat recovery. These energy recovery systems, in addition to other building-specific heating and cooling reduction strategies (e.g., high-performing envelope and efficient airside systems with energy recovery), offer a more balanced heating and cooling profile for a better performing and properly sizedgeothermal borefield.

As peak loads and 8,760 hourly load profiles were finalized using the methodology discussed above, additional factors were also taken into consideration to completely inform minimum CEP heating and cooling capacity requirements. As discussed later in section 2.2, the impact of campus piping distribution losses was studied, and appropriate factors of safety were applied to ensure reliable heating and cooling.

1.3 Site Constraints

The following site constraints have been identified:

- Commitment to carbon-neutral ready, 100 percent free of fossil fuel.
- Load letter limit from utility: 3.3 MW maximum electrical capacity for central plant operation.
- Residential DHW usage causes heating peaks in the morning, coincidental with cold morning space heating peaks.
- Space constraints.
- Geothermal borefield site.
- Financial feasibility of the overall design.
- High lift conditions limit the heat pump selection.
- Resiliency requirements.

In this section, each constraint identified in the list above is expanded. However, the solutions that consider these constraints are not detailed in this section, but rather in section 2.1. The final design solution best satisfies these constraints and produces the best option for the owner and the occupants served by the community heat pump system.

As mentioned previously, Watchtower has committed the HPR Campus to be fully electrified, fossil fuel-free, and carbon-neutral ready, as defined by NYSERDA, from the first day of operation. This commitment constrains the design by limiting equipment to electric options.

The subcontractor (BR+A) received a load letter limit from the utility, Orange and Rockland. After allocating energy to the campus buildings for normal operation, 3.3 MW of electrical capacity was allocated for CEP operation. With the commitment to complete electrification under consideration, this electrical capacity limit places a significant constraint on the size and quantity of electric heating and cooling equipment, and therefore requires efficient and optimized CEP operation to meet peak heating and cooling demands.

Heating peaks are often driven by DHW on the coldest days because hydronic heating and DHW are served by the same campus HW distribution loop. This results from the DHW heating schedule, which models high DHW peaks in the morning as residents wake up and shower before work, as the commercial spaces begin to heat up for the day. The DHW-driven peak heating load dictates the CEP's required heating capacity.

The CEP footprint covers the allotted site space and the equipment layout is fully optimized. The subcontractor (BR+A) worked closely with the CEP manufacturer to optimize the layout and overall design of the structure. Any expansion of the CEP beyond the current design would likely require building vertically, which has a steep cost premium. Site planning and maintaining all equipment within the existing CEP structure was an important constraint for design under the Category B effort.

Space constraints in the mechanical spaces of the residences no longer allow for the placement of thermal buffer tanks, which could be used to increase the heat capacity of the campus to meet the residences-driven HW demand during peak heating. Further, it was determined that burying buffer tanks was not a viable solution. Locating buffer tanks in other buildings on campus would be ineffective because the primary HW load is located at the residences. Thus, the design was limited from considering buffer tanks.

The contractor required that the geothermal borefield is contained completely within the footprint of the AV studio, as discussed in section 2.1. This would allow for the future expansion of the AV studio in any direction, if desired at a later point, without impacting borefield operation.

As with any new construction project, the budget and the financial feasibility of the overall design is a constraint. The budget limited aspects of the design, such as the number of borefield bores. A breakdown of the CEP cost estimate is provided in Appendix A, page A-3. The significant cost overrun reported therein demonstrates the need for NYSERDA Category B financial assistance.

High lift conditions constrained the GSHP selection. For example, during geo heating, the limiting operating mode, the screw heat pumps face a maximum lift condition of 95 °F (124 °F leaving condenser minus 29 °F leaving evaporator). This constraint is detailed in section 2.1 and the heat pump operating modes are detailed in section 3.2.

Several constraints were placed on the design, in coordination between the contractor and subcontractor (BR+A), with the intent of boosting campus resiliency. These are listed below:

- A 10 percent factor of safety was applied to the total campus heating load. Considering the peak campus heating load of 22.6 MMBtu/hr, this constraint increased the required CEP heating capacity to 24.9 MMBtu/hr. The factor of safety was applied to the heating load because the design is heating-driven.
- It was required that the CEP agility heat pumps are sized to N+1 in cooling operation; the community heat pump system must be capable of serving the peak campus cooling load with one heat pump offline. Since the agility heat pumps have greater capacity than the screw heat pumps, the screw heat pumps are also sized to N+1 in cooling operation.
- Most campus and CEP pumps were sized to handle more flow than modeling suggests they will be required to handle during peak heating or cooling. The factors of safety applied to inform CEP pump selections are detailed later in section 3.2.
- While the heat pumps were designed to meet the peak heating demand, as modeled in task 2, milestone 2/3, two 810 kW electric boilers were included for redundancy and additional resiliency.
- Although the heat pump capacity was designed to allow for N+1 cooling operation and the need for cooling tower operation is unexpected during peak cooling, it was desired to include two cooling towers in the design for additional redundancy and resiliency.
- Liquified natural gas (LNG) tanks and natural gas (NG) generators were incorporated into the design to provide additional resiliency in case there is a utility-level power outage that extends beyond the PV and battery storage capacities.

1.4 Site Opportunities

A significant site advantage is that the contractor is the final user. Throughout design and construction development, this has allowed for the final user to provide high-level decisions driven by factors that go well beyond financial considerations, such as resiliency and occupant comfort.

1.5 Results of Exploratory Ground Borehole

To measure the characteristics of the ground serving the GSHE, a 499-foot-deep test borehole was drilled on the site in March of 2021. Table 1 below, provided by Geo-Consultant MEP Associates of Salas O'Brien, reports the ground loop design (GLD) results.

Table 1. Exploratory Ground Borehole Results

Calculation Results	
Thermal Conductivity (Btu/(h*ft*°F))	1.37
Thermal Diffusivity (est.) (ft^2/day)	0.91
Average Heat Flux (W/ft)	20.0
BH Thermal Resist (BTR) (h*ft*°F/Btu)	0.22
Average Flow Rate (gpm)	8.18
Test Duration (hr)	35.5
Calculation Interval	12.0 – 47.5 Hours
Borehole Input Parameters	
Undisturbed Ground Temperature (°F)	50.5 (User-Estimated)
Depth (ft)	499.0
Borehole Diameter (in)	5.75
Pipe Size	1 ¼ in (32 mm)
Grout Thermal Conductivity (Btu/(h*ft*°F))	1.11
Drilling Method	Air Rotary
Drilling Time (hr)	10.0
Diffusivity Input Parameters	
Soil/Rock Specific Heat – Dry (Btu/(°F*lbm))	0.220
Soil/Rock Density – Dry (lb/ft^3)	165.0
Moisture (0-100) (%)	0.0
Flow Rate Input Parameters	
TC Unit Model Name	GeoCube Standard

2 Hurdles and Challenges

2.1 Thermal Energy Challenges and Solutions

Thermal energy challenges and solutions are tabulated below and are detailed in this section.

Table 2. Thermal Energy Challenges and Solutions

Number	Thermal Energy Challenges	Solutions
1	Utility load letter limit of 3.3 MW for CEP electrical capacity.	Determine peak electrical demand via energy modelling and compare the peak electric consumption of various design options to the load letter limit.
2	Risk of freezing geothermal working fluid (water) during winter. With this temperature constraint on the working fluid, the GSHE only met 49% of the peak heating demand.	Use of 20% propylene glycol-water solution for circulation through the GSHE and installation of campus-CEP HW and CHW heat exchangers.
3	Increased heat pump lift conditions due to the introduction of the 20% propylene glycol GSHE working fluid.	Replace Trane Polytherm scroll heat pumps with Trane RTWD screw heat pumps.
4	Campus distribution piping heat gains and losses.	Evaluate campus piping heat gains and losses and apply appropriate factors to peak loads.
5	DHW-driven peak heating demand.	Determine peak heating demand via energy modelling. Optimize borefield to meet peak heating demand, considering the footprint constraint.
	Insufficient space for thermal storage tanks at residences.	
	Size of borefield limited to AV footprint.	

2.1.1 Thermal Energy Challenge 1

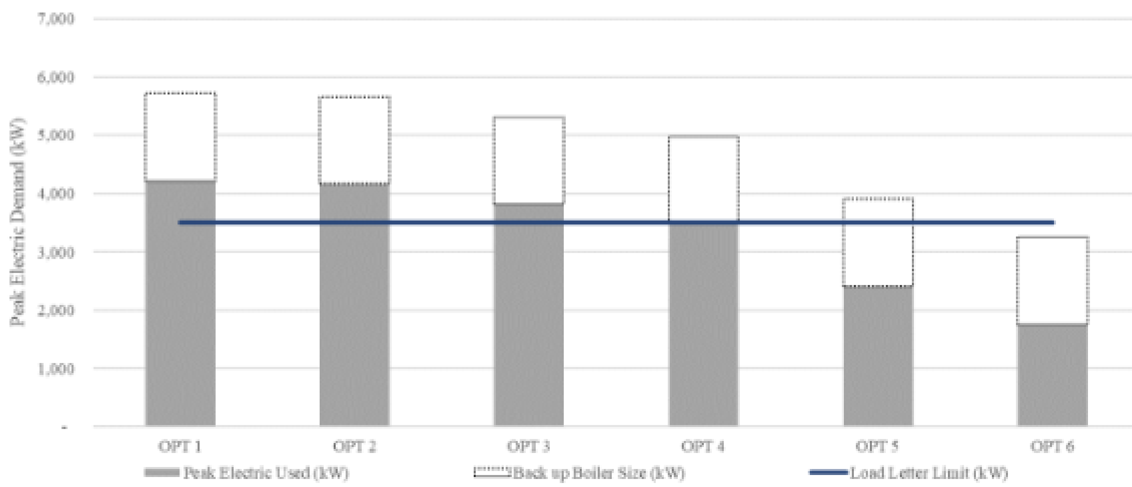
As previously mentioned, there is a limit to the load letter that the contractor received from the utility; 3.3 MW maximum electrical capacity for CEP operation was allotted based on the letter. This significantly constrains campus heating and cooling equipment and general design, such as the usage of emergency electric boilers, considering the limited electrical capacity of the CEP. Consequently, as examined in task 2, milestone 2/3, electrical usage during peak heating load was analyzed for six different design options, which are as follows:

- Option 1: 280 borefield boreholes–water borefield working fluid with electric boiler operation during peaks only.
- Option 2: 280 boreholes–water with 20 percent electric boiler operation throughout heating season.
- Option 3: 215 boreholes–20 percent propylene glycol-water solution borefield working fluid with electric boilers during peaks only.

- Option 4: 235 boreholes–20 percent propylene glycol with electric boiler operation during peaks only.
- Option 5: 260 boreholes–20 percent propylene glycol with electric boiler operation during peaks only.
- Option 6: 280 boreholes–20 percent propylene glycol with electric boiler operation during peaks only.

This analysis was informed by peak heating demand, determined from energy modeling, which is further detailed in section 2.2. The use of water versus 20 percent propylene glycol as the borefield working fluid is discussed in the next challenge. The electrical usage results for each option are plotted below against the load limit.

Figure 2. Peak Operation Electrical Usage for Design Options 1–6



Options 1, 2, 3, and 4 were found to be not viable, since they are not within the load letter limit during normal operation. Option 5 exceeds the load letter if the two 810 kW backup electric boilers turn on while all typical operation equipment is in use. Option 6 is the only option that fits within the load letter while both the standard equipment and both electric boilers are operating. Further, option 6 optimized the size of the borefield to handle 100 percent of the campus peak heating and cooling loads, so it does not rely on the usage of electric boilers during heating and on the cooling towers during cooling. These were significant factors in ultimately selecting option 6, which provides a solution to the load letter limit challenge.

2.1.2 Thermal Energy Challenge 2

A significant challenge was the GSHE's ability to meet the campus peak heating demand. After the expansion of the AV studio, the geothermal working fluid (water) was expected to face sub-freezing temperatures during winter to meet the peak campus heating demand. With a minimum temperature constraint of 36°F on the working fluid, the GSHE met 99 percent of the annual heating load and 100 percent of the annual cooling load, but only met 49 percent of the peak heating demand.

In response to this challenge, it was decided to use a 20 percent propylene glycol-water solution for circulation through the GSHE and to install HW and CHW heat exchangers between the campus and CEP loops. The introduction of 20 percent propylene glycol increased the GSHE's capacity by allowing the temperature of the geothermal fluid to drop below freezing, increasing the borefield's heat exchanging capacity. While water has a freezing temperature of 32°F, 20 percent propylene glycol has a freezing temperature of 18°F. After the new working fluid was introduced, it was necessary to install heat exchangers between the campus and CEP loops to allow for the use of water in the campus HW and CHW loops. The use of water in the campus loops was preferred because 20 percent propylene glycol is more expensive and more energy-intensive to pump. The required size of the borefield, considering the use of the new borefield working fluid, was examined in design options 3–6 mentioned in the previous challenge, to meet peak demand.

2.1.3 Thermal Energy Challenge 3

Resulting from the introduction of the 20 percent propylene-water solution for use in the GSHE, heat pump lift conditions increased because lift is the CHW supply temperature subtracted from the HW supply temperature. The increased lift condition constrained heat pump selection. Another resultant challenge is that when acting as heat pumps, heat pump capacity decreases as lift increases.

Before the borefield working fluid design change, Trane Polytherm scroll heat pumps and Trane centrifugal Agility heat pumps were used in the CEP. After the design change, Trane RTWD screw heat pumps replaced the Trane Polytherm scroll heat pumps because the scroll heat pumps could not handle the increased lift.

2.1.4 Thermal Energy Challenge 4

Given the strategy to employ a centralized energy system, a resultant thermal energy challenge is that CHW supply experiences heat gains and HW supply experiences heat losses as the fluid travels through the campus distribution piping, which is unaccounted for in the eQuest energy modeling. Consequently, this demands greater heating and cooling capacity. In response to this issue, campus piping heat gains and losses were evaluated, and appropriate factors were applied to peak heating and cooling demand loads. This evaluation is described in detail in the next section of the report.

2.1.5 Thermal Energy Challenge 5

High heating demand peaks are expected during the winter, driven by high DHW demand from the residences. This results from the work, live, play philosophy for the campus because residents are on similar work schedules, so high peak heating demands are expected due to weekday morning showers across the residences being concentrated around the same time before work. To consider this issue, the peak heating demand was determined, including DHW, via energy modeling, as mentioned previously and as detailed in section 2.2. This allowed for the development of an informed design that satisfactorily meets the peak heating load.

Early in the design process, a thermal buffer tank was considered in the mechanical room of each of the residences to help curtail the DHW demand. However, as the design developed, a space constraint emerged in the mechanical rooms, which led to these tanks no longer being a viable design option. Installing buffer tanks at other building locations was deemed ineffective since the demand is concentrated at the residences.

Consequently, burying the buffer tanks outside the residences was considered. Another solution considered to address the DHW-driven peak heating load was to expand the borefield GSHE. A study was conducted in which the cost of introducing buried buffer tanks was compared to the cost of installing additional geothermal bores, with both equivalent in terms of heat capacity. The analysis found that the cost of installing additional bore holes is comparable to installing buffer tanks, and expanding the borefield was ultimately selected.

A related challenge is that the contractor required that the geothermal borefield be contained completely within the footprint of the AV studio. This is desired because it would allow for the future expansion of the AV studio in any direction without impacting borefield operation. As discussed earlier in this section, the borefield size was studied and optimized to meet peak heating and cooling loads. With 800 feet deep bores, the 280 required boreholes can fit within the AV studio footprint, as discussed further in section 3.1.

Ultimately, design option 6 from task 2, milestone 2/3 demonstrates that the optimized geothermal borefield, coupled with the CEP equipment, can satisfy 100 percent of the campus heating and cooling peak and annual loads without thermal buffer tanks.

A variety of heat recovery system solutions were employed campus-wide to reduce annual and peak heating and cooling loads and generally address the thermal energy challenges described above. These systems are detailed later in section 4.1.

2.2 Energy Modeling Methods, Results, and Impacts

To estimate the campus' heating and cooling loads, both the peak design building loads and an 8,760 hourly load profile are required to determine the characterization of the geothermal heat pump system. To capture the energy efficiency measures in each building, Department of Energy 2 (DOE2) eQuest Energy models were created for each building, which generate 8,760 hourly load reports. All models are based on the latest available MEP and architectural design drawings. The hourly reports were tallied and processed using a proprietary excel-based plant performance spreadsheet, as summarized in Community Heat Pump Category B task 2, milestone 2/3 and in task 3, milestone 4/5. This allowed the team to calculate the performance of the campus during all 8,760 hours of a typical year and evaluate the annual and peak energy consumption of the CEP. The calculated CEP coefficient of performance (COP) for generating HW for the heating and DHW systems (excluding the DHW for the events center and fitness center) is 5.81. The calculated central plant COP for generating CHW is 7.94. As mentioned previously, campus distribution heating losses and cooling gains were calculated following USGBC guidance, which recommends that manufacturer performance specifications should be the basis for calculating distribution losses. The calculated gains and losses were applied to peak campus heating and cooling loads to determine required campus heating and cooling energy generation.

The methodology behind the energy modeling software is as follows:

1. The heating and cooling load post-piping losses and building specific heat recovery strategies at a specific hour are obtained from the DOE2 energy modeling software, eQuest 3.65 Build 7175.
2. The load is distributed among the various sources present in the central plant in the following order: simultaneous heating and cooling, geothermal heating/cooling, electric boiler/ water-cooled chillers with cooling tower rejection.
    - The non-dominant load (either heating or cooling) determines the maximum available capacity for simultaneous heating and cooling. In simultaneous heating and cooling the heat pump condenser rejects heat back into the hot water loop and sends chilled water output from the evaporator to the chilled water loop. In simultaneous heating and cooling, a higher heating output is achievable due to the heat of compression from the condenser. Electrical consumption of the equipment in this operation is divided proportionally to each loop's demand on the specific heat pump at any given hour.
    - Any remaining load is satisfied using the geothermal borefield, up to the maximum capacity of the borefield. In this mode, during the heating season, heat is extracted from the borehole network and sent out to the hot water campus distribution loop. During cooling season, heat is rejected to the ground via the condenser. An 8,760 hourly load profile was input into GLD, which in turn output an 8760 hourly of the borefield ground temperature. This 8,760hourly ground temperature profile was entered into the central plant modeling tool to calculate the exact ground loop heat exchanger performance for every hour of the year. The model accounts for both peak and off-peak performance and is specifically tailored to each hour's conditions.
    - The remaining heating and cooling after the borefield capacity has been maxed out is satisfied by either the electric boilers or the water-cooled chillers (with cooling tower rejection). The water-cooled chillers connected to cooling towers are also used during the year to balance the heat that goes into and out of the ground. For the borefield layout chosen in task 2, 280 bores, each 800 feet deep with a 20 percent propylene glycol working fluid, the electric boilers and water-cooled chillers with cooling tower rejection are not expected to operate under typical conditions.
3. With the knowledge of how much heating and cooling is being satisfied by each source, the load is then split among the different heat pumps based on staging and heating and cooling capacities.
4. The efficiency of each heat pump is calculated at their operating point based on load and lift using manufacturer-provided efficiency curves. When the heat pumps operate in simultaneous heating and cooling, the electrical consumption of the equipment is based off the evaporator load and is split proportionally between "heating" and "cooling" based on demand at the heat pump for that hour.

5. The pumping power is also calculated from the total pump power installed and flow through the plant at every hour. Pumping power calculated in the plant operation spreadsheet tool includes four categories of pumps: (1) geothermal pumps, (2) primary pumps attached to each heat pump (one per condenser and one per evaporator), (3) secondary pumps to circulate working fluid throughout the CEP, (4) campus distribution pumps to distribute the hot and chilled water to each building. Pumping power does not include additional pump energy required for pumping the 20 percent propylene glycol solution throughout the geothermal field and CEP. Campus distribution pumps, which will operate with 100 percent water working fluid, make up the majority of the pumping power required (~80 percent) for all options. Any additional pumping power required for the 20 percent propylene glycol solution is expected to be minimal compared to the total pumping power already accounted for.
6. The total electric consumption of the plant heating and cooling equipment is calculated on an hourly basis based on the load and efficiency of each piece of equipment and on the total pumping power.

Mechanical, architectural, and DHW modeling assumptions and energy efficiency measures for each building are tabulated in appendix B. Due to the early design stage of the AV studio, fitness center, and Visitor's Center buildings, major assumptions were made based on information provided by the contractor.

CEP auxiliary energies are not accounted for in any electrical analysis. Heating and cooling loads from the CEP are accounted for in the load profiles. However, the analysis does not account for auxiliary power for building ventilation, controls, and lights in the CEP.

Specific manufacturer performance data sheets (including part-load efficiencies used in the model) were incorporated into the model. These equipment selections are discussed in section 3.2.

Energy recovery methods were included in the energy models to properly account for their balancing effect on the overall campus heating and cooling loads. The campus-wide methods accounted for were (1) events facility commercial kitchen coolers and freezers compressor heat rejection, (2) the events facility commercial kitchen exhaust heat recovery system, and (3) residences DHW passive heat recovery. These energy recovery systems in addition to the building-specific heating and cooling reduction strategies (e.g., high-performing envelop and efficient airside systems with energy recovery), offer a more balanced heating and cooling profile, for a better performing geothermal borefield.

As peak loads and 8,760-hourly load profiles were finalized using the methodology discussed above, the team studied the impact of campus piping HW thermal distribution losses and CHW thermal gains. These impacts were not captured by energy modeling, so identifying these losses is necessary to identify the minimum total CEP energy generation capacity requirements. Section 4.2.1.2.3 of the United States Green Building Council (USGBC) Treatment of District or Campus Thermal Energy in LEED V2 and LEED 2009—Design & Construction states: "Actual efficiency performance data on the DES serving the project building is preferred, based on either ongoing operations (existing DES) or design specifications (new DES or DES with added capacity). If the project team cannot obtain the actual performance data, it is permissible to use the following default average performance values. These values are conservative, intended to represent a DES with relatively low efficiency. A well-designed, maintained, and operating DES will generally offer better performance than the defaults listed here." Prior to the Category B analysis, an operational 5 percent distribution loss for both heating and cooling was included as a rule-of-thumb, following USGBC guidance for distribution losses prior to the availability of actual performance data. These losses are applied operationally, against the 8,760-hourly load. Because the campus HW supply temperature (128ºF) is lower than that established in ASHRAE 90.1 (180ºF), the recommended 10 percent distribution loss percentage for campus heating systems as established by USGBC was reduced to 5 percent. The distribution temperature is not specified in the USGBC Campus Thermal Energy document, so designers are pointed to the ASHRAE 90.1 HW temperature of 180ºF. USGBC defers to ASHRAE as the reference standard for calculating distribution piping thermal losses when the actual performance and temperature is unknown. The 128ºF campus HW supply temperature is driven by the required temperature for DHW serving the residences.

The temperature delta (dT) of 42°F to 58°F and of 128°F to 98°F for CHW and HW, respectively, represents the change in temperature from supply to return at all buildings, not from the thermal distribution piping losses. The calculated thermal losses are across the length of the pipes, between the supply temperature and the ground, and the calculation methodology is explained below.

The 10 percent distribution loss recommended by USGBC for HW campus distribution systems is an assumption made about the number of Btus lost when piping 180ºF HW through the ground, which is typically about 50ºF. This results in a temperature differential of 130ºF (180ºF to 50ºF). The 10 percent distribution loss represents 10 percent of the Btus sent out of the plant in the campus distribution HW system being lost to heating the ground around the pipes. The Watchtower HPR campus hot water distribution system instead sends 128ºF hot water out of the plant, in piping buried in ~50ºF ground, resulting in a temperature differential of 78ºF (128ºF to 50ºF). Because the temperature differential of the Watchtower campus hot water distribution loop is about 50 percent of the USGBC/ASHRAE-assumed value (78ºF versus 130ºF), the subcontractor (BR+A) assumed a 5 percent distribution loss as the conservative HW distribution loss based on USGBC guidance. The amount of heat loss from the distribution piping is dictated by the heat transfer equation for a pipe:

Equation 1. $$Q = \frac{T_i - T_g}{R}$$

Where:

- Q is heat loss,
- T_i is the temperature of the working fluid,
- T_g is the temperature of the ground, and
- R is the thermal resistivity of the pipe system.

As the design progressed further and the distribution piping was specified, more accurate distribution losses were accounted for, following the guidance laid out in section 4.2.1.2.3. USGBC recommends that once the actual performance is known, the losses are calculated using manufacturer-provided numbers and operating temperatures. Using heat loss and gain curves for underground piping for a 2 inch-insulated pipe provided by the underground hydraulic piping vendor, distribution losses were calculated for the hot water and chilled water loops on the campus.

Figure 3. Heat Loss for 2 Inches of Polyurethane Foam

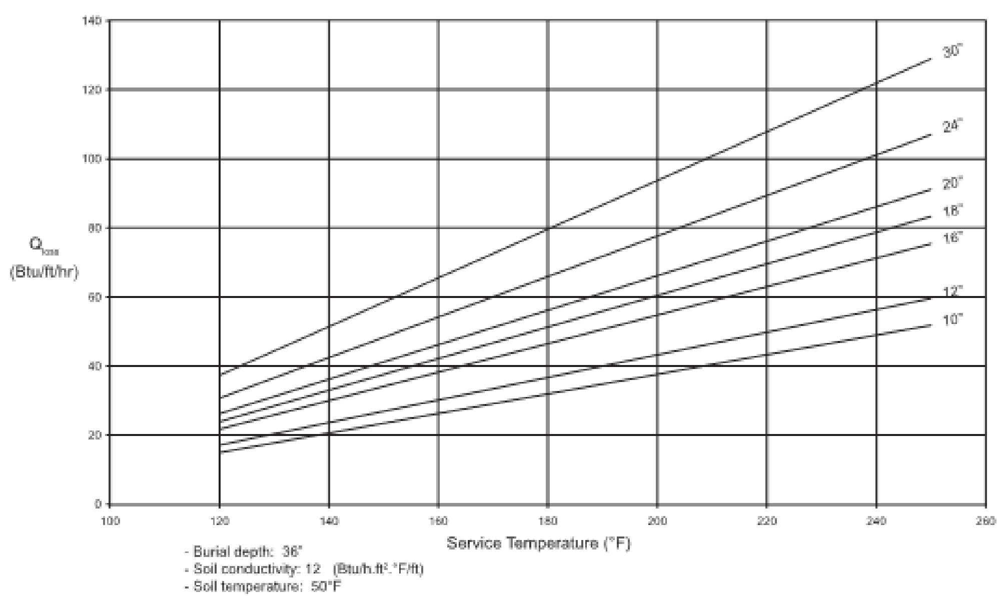


Figure 4. Heat Loss for 2 Inches of Polyurethane Foam

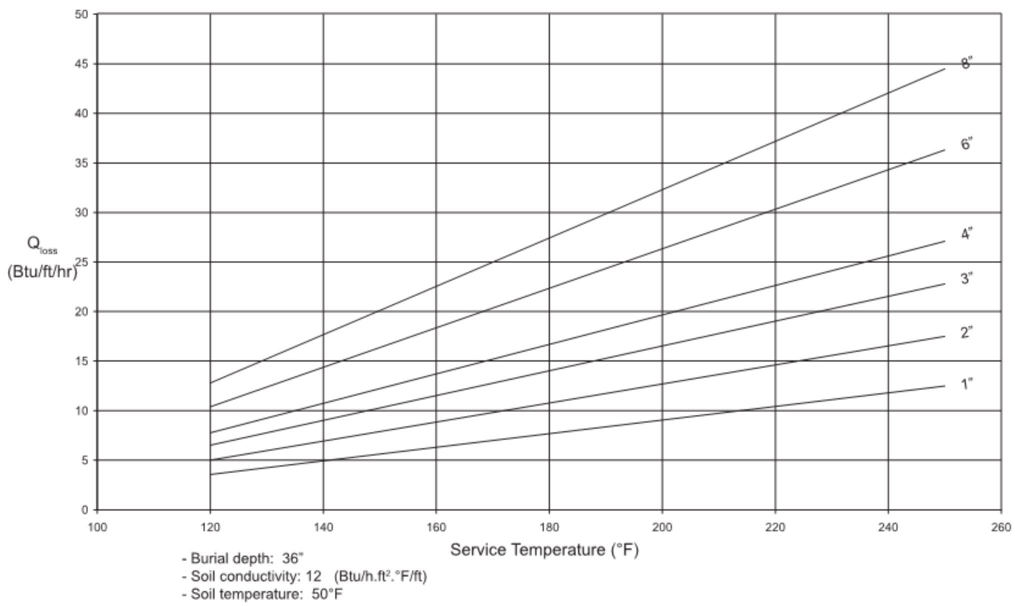
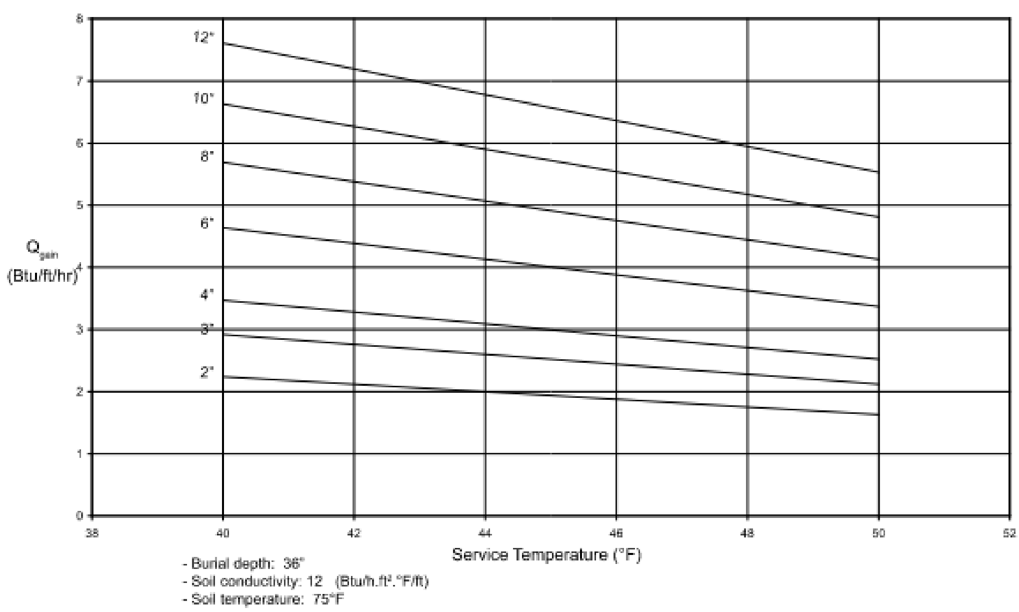


Figure 5. Heat Gain for 2 Inches of Polyurethane Foam



The results of these calculations can be seen tallied below in Table 3 and in Table 4. HW heat losses at soil temperatures of 50ºF and 35ºF were calculated. While the hydraulic pipes will be buried below the frost level, the 35ºF temperature distribution loss was included for worst case losses. The supply temperature of 128ºF with a ground temperature of 35ºF was used for heat loss calculations to yield the most conservative heat loss figure. For the CHW heat gain calculations, a ground temperature of 65ºF was used for worst case calculations. This is the highest temperature the ground is expected to reach based on regional typical meteorological year third collection (TMY3) data and weather models, shown below in Figure 6. The supply temperature of 42ºF was used for both supply and return to yield the most conservative heat gain values.

Figure 6. TMY3 Distribution Piping Ground Temperature

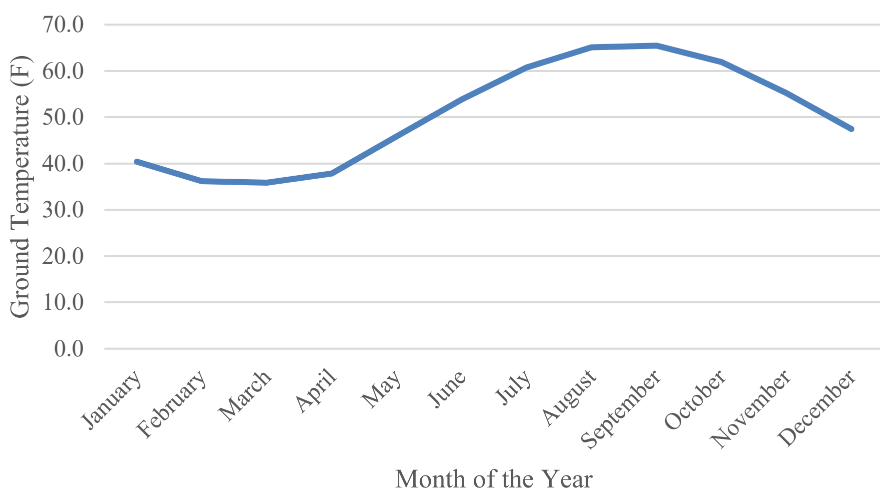


Table 3. Hot Water Loss Calculation Results

Pipe Diameter (inches)	Heat Loss (Btu/ft/hr)	Pipe Length (feet)	Heat Loss at 50°F Ground Temperature (Btu/hr)	Heat Loss at 35°F Ground Temperature* (Btu/hr)
30	40.50	-	-	-
24	33.50	-	-	-
20	28.75	-	-	-
18	26.00	-	-	-
16	23.75	-	-	-
12	18.75	3,556	66,675	80,010
10	16.25	1,904	30,940	37,128
8	14.00	3,444	48,216	57,859
6	11.25	5,516	62,055	74,466
4	8.50	-	-	-
3	7.25	980	7,105	8,526
2.5	6.29	28	176	211
2	5.50	2,996	16,478	19,774
1.5	4.87	1,344	6,544	7,852
1	4.00	-	-	-
TOTAL	**-**	**16,212**	**171,514**	**205,817**

*Heat loss at 35°F ground temperature was calculated by extrapolating from the 50°F ground temperature results.

Table 4. Chilled Water Heat Gain Calculation Results

Pipe Diameter (inches)	Heat Gain (Btu/ft/hr)	Pipe Length (feet)	Heat Gain at 75°F Ground Temperature (Btu/hr)	Heat Gain at 65°F Ground Temperature* (Btu/hr)
30	-	-	-	-
24	-	-	-	-
20	-	-	-	-
18	-	-	-	-
16	-	-	-	-
12	7.25	943	6,837	4,765
10	6.30	1,508	9,500	6,621
8	5.40	1,639	8,851	6,169
6	4.45	3,257	14,494	10,102
4	3.25	6,624	21,528	15,004
3	2.80	1,144	3,203	2,233
2.5	2.70	146	394	275
2	2.10	-	-	-
1.5	2.10	-	-	-
1	-	-	-	-
TOTAL	**-**	**14,318**	**57,970**	**40,403**

*Heat gain at 65°F ground temperature was calculated by extrapolating from the 75°F ground temperature results.

The piping supplier used a soil conductivity of 12 Btu/hr.ft.ºF, although the initial bore test showed a soil conductivity of 1.37 Btu/hr.ft.ºF. The distribution losses were calculated using the 12 Btu/hr.ft.ºF soil conductivity. This number was used for three reasons: (1) The distribution piping is throughout the campus whereas the test bore is the measurement of the ground conductivity at a specific point below the AV studio where there is a rock formation, (2) the soil conductivity from the test bore is for soil at 499 feet deep while the distribution piping will be a few feet below ground, just below the frost line, and (3) it is more conservative than the test bore results.

The distribution piping will supply hot water at 128ºF and chilled water at 42ºF. The loop will return hot water at 98ºF and chilled water at 58ºF. The calculations above show a total distribution heat loss of 7 percent for the hot water distribution piping and heat gain of 0.5 percent for the chilled water distribution, resulting in a total weighted average loss of 3 percent. This is less than the 5 percent carried previously. However, this is expected per section 4.2.1.2.3, which encourages low-efficiency numbers for conservative calculations until the design is better understood.

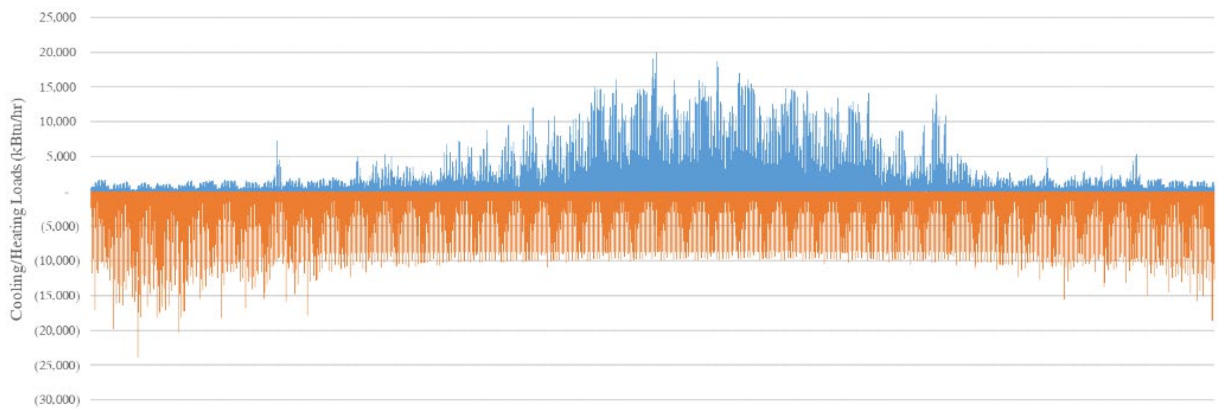
After the distribution losses were determined, they were applied to the peak campus heating and ck lossesooling loads to identify the minimum total required heating and cooling CEP energy generation.

Table 5. Total Annual Heating and Cooling Energy Consumption Summary

	Unit	Annual HW Demand on CEP	Annual CHW Demand on CEP	Annual DHW Demand on CEP
CEP	MMBtu/yr	(45)	31	-
AV	MMBtu/yr	(1,007)	4,784	(1,021)
Offices	MMBtu/yr	(1,014)	4,271	(210)
Fitness Center	MMBtu/yr	(2,904)	4,285	-
Events Center	MMBtu/yr	(1,358)	2,285	-
Residences (10)	MMBtu/yr	(1,698)	7,593	(8,295)
Visitor Center	MMBtu/yr	(1,111)	3,840	-
Links	MMBtu/yr	(734)	-	-
Distribution Losses	MMBtu/yr	(759)	131	(732)
Total:	MMBtu/yr	(10,630)	27,220	(10,258)

Table 5 shows a summary of the total annual heating and cooling energy consumption for each building connected to the CEP. The peak coincidental loads were calculated to be 22,600 kBtu/hr for heating and 1,660 tons for cooling**.** Figure 7 shows the required heating and cooling thermal energy delivered from the central plant, including heating and cooling provided to each building, distribution system heat losses/gains, and campuswide heat recovery strategies as an 8,760 hourly load profile. Heat gain from pumping is unaccounted for in the analysis.

Figure 7. Campus Load Profile at Plant Level Outlet



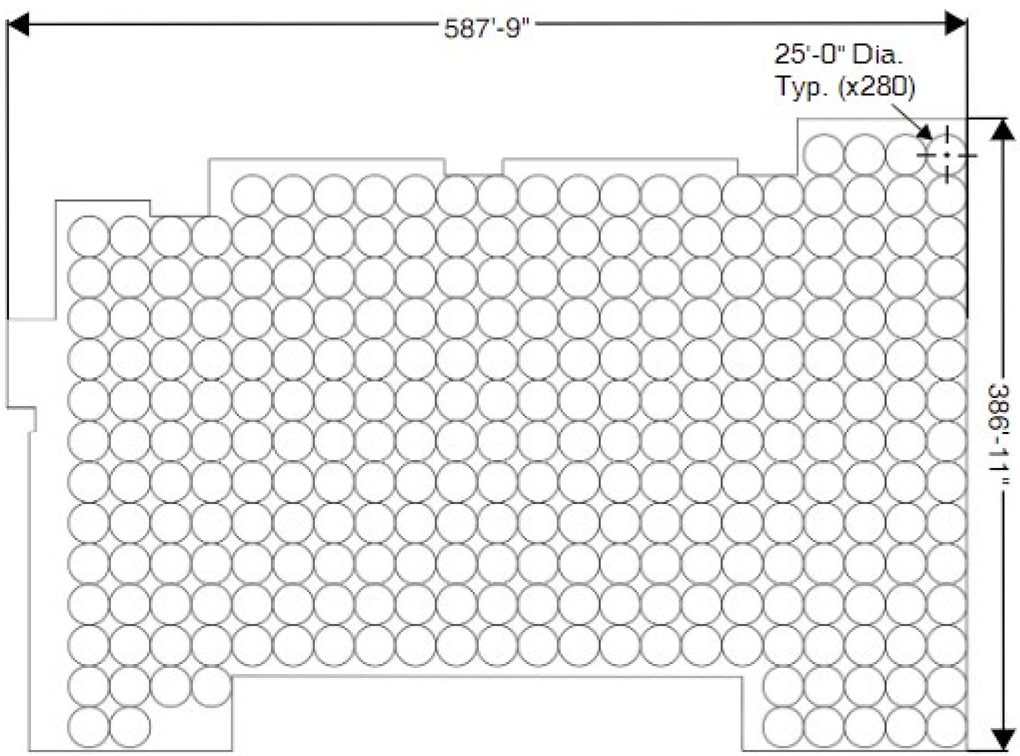
The annual and peak coincidental heating and cooling loads directly informed the design of the campus heating and cooling system and equipment selection and sizing, as discussed in section 3; the loads provided a minimum threshold for CEP energy generation capacity.

3 Discussion of Technologies Utilized

3.1 Thermal Source/Sink

A GSHE is the type of thermal source/sink used in the HPR campus. The GSHE design is 280 bores, each 800 feet deep, with concentric Rygan ground source heat exchangers. The contractor requires that the geothermal field lays completely within the footprint of the AV studio. Figure 8 below shows the 280 bores located within the bounds of the AV studio, at 25 feet on-center.

Figure 8. Ground Source Heat Exchanger Design



The geothermal bore holes were designed to be spaced at 25 feet on-center to optimize for both borefield recovery and the total footprint. At 25 feet on-center, all bore holes can fit within the footprint of the AV studio, as shown in Figure 8, while also being spaced sufficiently far apart to maximize field recovery. The subcontractor (BR+A) worked with the geo-consultant (Aztech Geothermal) to find the optimum spacing, prior to the Category B study, settling on 25 feet on-center.

As explained in task 2, milestone 2/3, a 20 percent propylene glycol-water mixture was selected as the GSHE working fluid, which allows for exposure of the working fluid to temperatures below 32°F during late winter.

As mentioned previously, the size of the geothermal borefield was optimized to satisfy100 percent of the campus heating and cooling peak and annual loads, when operating with the ground source heat pumps discussed in section 3.2.

3.1.1 Ground Source Heat Exchanger Selection

When selecting the heat exchanger, different designs were considered. Ultimately, prior to the PON 4614 Category B effort, a Rygan system was chosen. However, it is important to understand how these heat exchangers compare to other types of heat exchangers on the market. To discuss the benefits of the Rygan system, we compared the concentric heat exchanger to a Standing Column Well (SCW) and to a Poly U-bend.

An SCW is an open system heat exchanger with high-thermal performance. However, this option was not pursued because the Watchtower geothermal site is pure rock, which is incompatible with the SCW's performance requirement of non-mineral laden water.

Poly U-bends were the next option considered. This closed system is comparatively low-cost. A closed system was preferred, in order limit maintenance costs and concerns associated with an open system. However, these ground loop heat exchangers have low thermal performance, and therefore require more bore holes to meet the thermal capacity of a concentric design.

Ultimately, the Rygan concentric heat exchanger was selected because it increases the efficiency of the ground loop heat exchanger system compared to a typical U-bend configuration, while also being a closed system, unlike an SCW. The Rygan option is a composite-based High Performance Geo Xchange (HPGX) concentric heat exchanger. The Rygan heat exchanger has better strength and protection than the U-bend, allowing for deeper bore holes, which was important for this project due to the limited footprint. Rygan systems also better maintain the source supply water temperatures due to its low thermal resistance, which improves heat transfer. The concentric heat exchanger design into the bore annulus increases the surface area and performance of each bore. The Rygan concentric heat exchanger is detailed in appendix C.

The subcontractor (BR+A) has had experience designing a geothermal field with the Rygan heat exchanger in a Boston-based project, the Boston University Data Sciences Building. This Rygan heat exchanger system was designed with 31 bore holes, each 1,500 feet deep, and became operational in December of 2022. Harnessing institutional knowledge and experience, BR+A designed an effective Rygan heat exchanger geothermal field for the Watchtower project.

3.1.2 Cost Evaluations

Prior to the Category B efforts, a high-level cost analysis of the ground loop heat exchanger options was conducted. The concentric heat exchanger was found to increase material costs and borehole size. However, less boreholes were needed due to the system's higher performance, reducing drilling and construction costs. While cost analysis for the concentric verses U-bend systems was not repeated after the design settled on the 280-bore layout, the same principles apply, and the analysis would find cost savings from the Rygan concentric option.

3.1.3 Installation and Operation

During installation of the GSHE, each loop shall be pressure and flow tested once installed into the annulus. Approximately 15 bores will be connected with heat fusion methods into sub-circuits and pressure tested to 1.5 times the operating pressure. All circuits will be piped in reverse return to ensure self-balancing. Once the system is installed, air and any debris shall be flushed out of all piping sections of the system at a minimum of 3 feet per second. All existing water that was used to install the loops shall be flushed out and clean working fluid shall be used to fill the system. Upon starting up, the system will be checked for flow and balanced to ascertain if any circuits are unbalanced in relation to others. After the system is in operation, the only maintenance on the system will involve mechanical components (e.g., pumps) and periodic working fluid treatment. The operating pressure shall be between 20 and 40 pounds per square inch (psi).

3.1.4 Geothermal Specifications

Finalized GSHE drawings and specifications will be developed by the Geo-Consultant after the foundation of the AV studio is solidified and after other campus-wide design efforts are completed. The contractor is aware of this timeline and has approved of moving forward without the finalized GSHE drawings and specifications at this time.

3.2 CEP Equipment

The CEP is designed to satisfy the entire campus heating and cooling load using a total of seven heat pumps: four 400-ton water-cooled magnetic bearing centrifugal heat pumps (Trane Agility) and three 50-ton water-cooled screw heat pumps (Trane RTWD).

CEP equipment schedules M-602 and M-603 are reported in appendix D, pages D-1 and D-2, and the agility heat pump, screw heat pump, electric boiler, cooling tower, heat exchanger, and pump selections are included in appendix D, pages D-3 through D-39.

Although appendix D includes detailed schedules for the Trane Agility and RTWD screw heat pumps, Table 6 and 7 summarize the capacity and efficiency of each machine under specific operating conditions.

Table 6. Water Cooled Magnetic Bearing Centrifugal Heat Pump Schedule

Operating Mode	Cooling Capacity (Tons)	Heating Capacity (kBtu/hr)	COP		Evaporator				Condenser			
			Heat	Cool	Source	EWT (ºF)	LWT (ºF)	GPM	Source	EWT (ºF)	LWT (ºF)	GPM
Simultaneous Heat & Cool	350	5,552	4.04	3.05	CHW	56	40	540	HW	114	130	694
Cooling Tower Cooling	370	5,423	6.62	5.42	CHW	56	40	570	CW	82	97	723
Geo Heating 1	270	4,394	3.84	2.83	WF	35	29	1,105	HW	111	124	676
Geo Cooling 1	370	5,253	6.14	5.18	CHW	56	40	570	WF	88	94	1,751

Table 7. Water Cooled Screw Heat Pump Schedule

Operating Mode	Cooling Capacity (Tons)	Heating Capacity (Kbtu/Hr)	COP		Evaporator				Condenser			
			Heat	Cool	Source	EWT (ºF)	LWT (ºF)	GPM	Source	EWT (ºF)	LWT (ºF)	GPM
Simultaneous Heat & Cool	152	2,575	3.42	2.42	CHW	55	40	251	HW	114	130	330
Geo Heating 1	128	2,229	3.20	2.19	WF	35	29	530	HW	114	124	350
Geo Cooling 1	200	2,982	5.16	4.14	CHW	56	40	310	WF	88	94	1,010

A combination of two types of heat pumps was selected to allow for better staging of the CEP capacity at different load conditions. While the centrifugal heat pumps are more efficient and have a larger heating and cooling capacity, they are only able to stage down to 30 percent of their design load due to the nature of the compressor (133-tons for a 400-ton heat pump). It is because of this limitation that three smaller water-cooled screw heat pumps were also included in the design to allow for the plant to handle any heating and cooling loads below the minimum turn-down of the centrifugal heat pumps. Despite having a lower efficiency, screw compressors have a much better turndown than centrifugal compressors and can properly modulate down to 10 percent of the design load when coupled with a variable frequency drive (VFD). Hence, the combination of screw and centrifugal heat pumps increases the flexibility of the plant by allowing a turndown of under 2 percent of the total plant design capacity when using the screw machines, while optimizing efficiency with the centrifugal heat pumps when no significant turndown is required.

In terms of the heat pump sizing, the contractor's strong focus on resiliency had a significant impact on the number of heat pumps and their capacities. As discussed previously, the modeled peak heating load of the campus, including piping losses and building-level diversity, is estimated to be 22.6 MMBtu/hr, without accounting for any water-side energy recovery. The geothermal borefield, with 280 boreholes and with the 20 percent propylene glycol working fluid, is sized to satisfy the full heating load of 22.6 MMBtu/hr. The combination of the Agility centrifugal heat pump and RTWD screw heat pump heating capacities is 24.9 MMBtu/hr (four Trane Agility centrifugal heat pumps at 4,518 kBtu/hr each and three Trane RTWD screw heat pumps at 2,265 kBtu/hr each) at maximum lift temperatures, which occurs when the geothermal borefield propylene glycol solution is being supplied to the heat pumps at 35°F. The reserve capacity under these design conditions without any electric boiler operation is 110 percent of peak design loads; thus, a 10 percent factor of safety was applied during heat pump selection for heating.

The heating capacity of the heat pumps increases with increased borefield working fluid temperatures, allowing for additional resiliency. At a borefield supply temperature of 45°F, considered a typical borefield temperature during the majority of the heating season, the total heating capacity of the plant without any electric boilers increases approximately 10 percent to 27.4 MMBtu/hr (four Trane Agility centrifugal heat pumps at 5,031 kBtu/hr each and three Trane RTWD screw heat pumps at 2,409 kBtu/hr each). The reserve capacity under these conditions without any electric boiler operation is 121 percent. This allows the CEP to operate in geothermal heating mode with only one electric boiler turned on if either one Trane Agility or one Trane RTWD machine were to come offline for servicing. The heat pump schedules and selections are included in appendix D, page D-1 and D-3, respectively.

In addition to the seven heat pumps, the CEP is also equipped with two 810 kW electric resistance boilers, with a total heating capacity of 5,527 kBtu/hr. The electric boiler selection is included in appendix D, pages D-8 through D-10. The electric boilers are not expected to have to be used under normal operating conditions and are only incorporated in the design for additional resiliency. Electric boiler usage could become necessary under two rare conditions:

1. One or more extended winter seasons dominated by severely cold temperatures. This would cause the borefield working fluid temperature to drift below the minimum inlet temperatures that the heat pumps are designed to handle. In this rare situation, electric boiler usage would be recommended to supplement the heating load and reduce the amount of heat being extracted from the ground. This would allow for the borefield to slowly recover and for the borefield supply temperature to slowly begin to drift up until electric boiler operation is no longer needed.
2. One Trane Agility machine comes offline during peak heating, with borefield working fluid temperatures into the heat pumps approaching the design temperature of 35ºF. Under this rare condition, the heat pump capacity would be insufficient and electric boiler heating would be required to provide additional heating capacity.

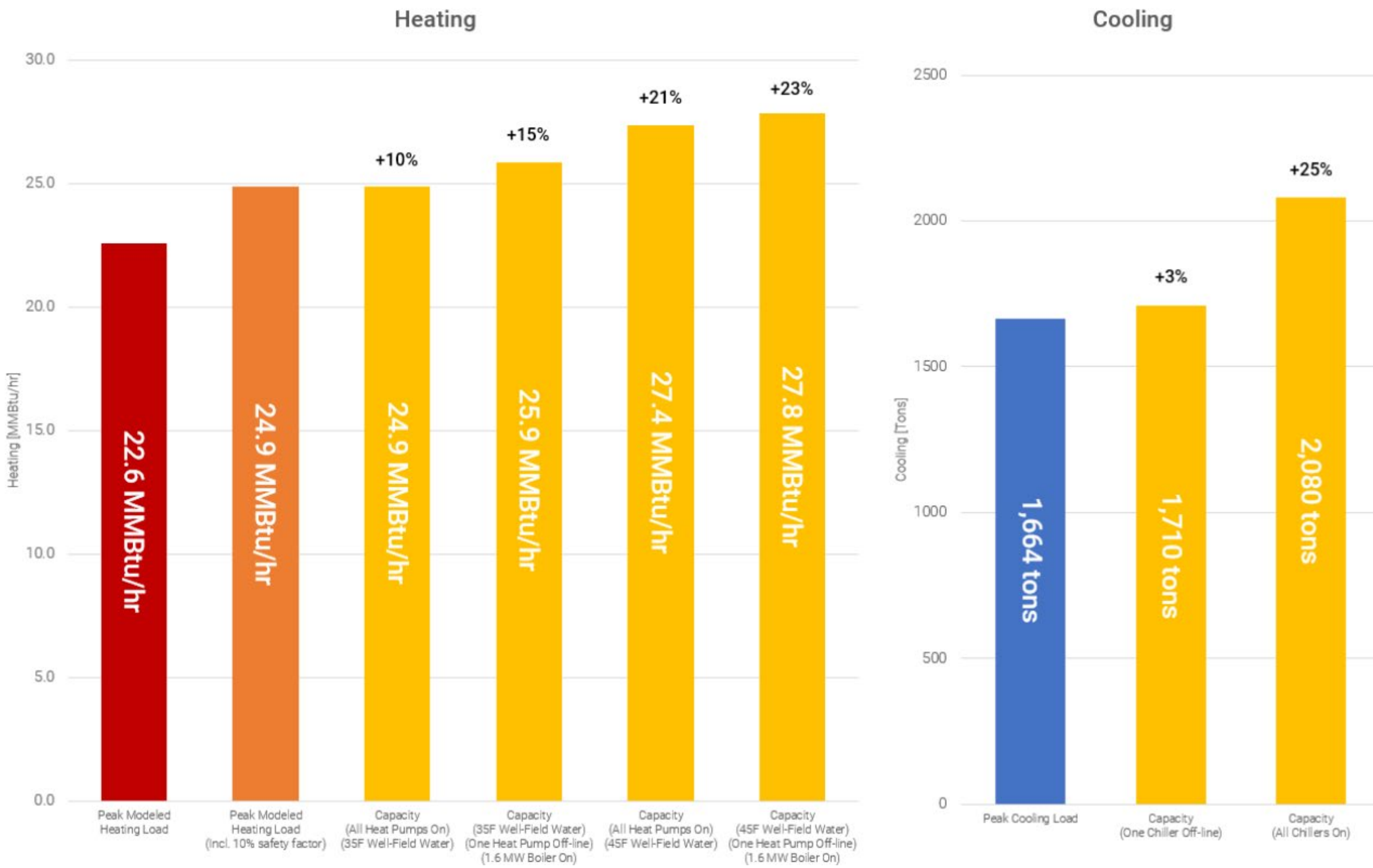
A constraint related to the usage of the electric boilers is the electrical capacity of the CEP due to utility limitations. The total electrical load in the plant is limited to 3.3 MW when accounting for the use of fan-assisted transformers. The peak modeled electrical consumption of the CEP under peak heating conditions is currently expected to be around 2.0 MW including heat pumps and pumps. With one Trane Agility machine offline, the total peak electrical load is expected to be 1.7 MW, which would allow for the full use of the two 810 kW boilers (3.3 MW total electrical load) while remaining within the limits of the maximum allowable electrical load. Under these conditions, assuming that one Trane Agility is offline while the heat pump inlet temperature is 35ºF (minimum design temperature), the total heating capacity of the plant including the two electric boilers would be 25.9 MMBtu/hr. The reserve capacity under these extreme conditions including both electric boilers would be 115 percent.

The peak modeled cooling load of the campus, including piping gains and building-level diversity, is estimated to be 1,664 tons without accounting for any water-side energy recovery. The geothermal borefield with 280 boreholes filled with 20 percent propylene glycol is sized to satisfy the full cooling load of 1,664 tons. The total combined Agility and RTWD heat pump cooling capacity is 2,098 tons, four Trane Agility centrifugal heat pumps at 400-tons each and three Trane RTWD screw heat pumps at 250-ton (nominal), 166-tons (derated) each at cooling design temperatures. The reserve capacity under these design conditions is 125 percent of the peak design load. This allows for N+1 operation in case one Trane Agility (or RTWD) machine goes offline for servicing. Under these conditions (one Trane Agility machine offline), the total cooling capacity of the plant is 1,698 tons, a reserve capacity of 102 percent compared to the peak modeled cooling load.

The CEP is also equipped with two cooling towers sized for a total cooling load of 800 tons. The cooling towers are not expected to operate under normal cooling conditions and are only incorporated in the design for additional resiliency. Cooling tower usage could become necessary under the rare condition in which, during a long summer dominated by extremely high temperatures, the borefield water temperature drifts high, passing the recommended design temperature of 88°F. Under these conditions, the cooling towers could be used to reject heat into the atmosphere instead of rejecting it into the ground. Cooling tower usage under this scenario would only be required temporarily to allow for the borefield to slowly recover thermally and for the borefield water supply temperature to slowly begin to drift down. The cooling tower schedule and selection is included in appendix D, page D-1 and D-11, respectively.

The reserve heating and cooling capacity is illustrated in Figure 9 below, compared against the peak heating and cooling loads.

Figure 9. Reserve Heating and Cooling Capacity Compared against Peak Heating and Cooling Loads



M-601 in appendix G, page G-1, shows a detailed flow diagram demonstrating a schematic of the CEP arrangement. All four centrifugal heat pumps and all three screw heat pumps are piped in parallel to each other such that they can all handle the full lift conditions on both the hot water and chilled water side. On the HW side, the electric boiler is piped in series following all seven heat pumps to supply any additional heating needed in emergency situations when the heat pump capacity is not enough to satisfy the full heating load.

All four centrifugal heat pumps are piped to the chilled water and borefield on the evaporator side, and to the hot water, borefield, and cooling towers on the condenser side. All three screw heat pumps are piped to the chilled water and borefield on the evaporator side, and to the hot water and borefield on the condenser side. Valves are used at all pipe connections to select the appropriate source of heating and cooling. This allows for all heat pumps to be able to operate in simultaneous heating and cooling, geothermal heating, and geothermal cooling modes. Additionally, the larger centrifugal heat pumps are also able to generate cooling using the cooling towers as their source of heat rejection. The smaller screw heat pumps are not connected to the cooling towers, since the cooling towers might only need to operate during peak cooling load conditions. However, cooling towers are not currently projected to operate under standard conditions. The cooling load in situations in which the cooling towers are needed is expected to be large enough to not require the smaller screw heat pumps for staging, so the smaller heat pumps are not connected to the cooling towers.

In terms of pumping, the plant operates on a primary/secondary pumping arrangement, with smaller primary pumps at each piece of equipment to regulate the flow through each heat pump, and larger secondary pumps moving the water throughout the central plant, the borefield, and the rest of the campus. M-603, included in appendix D, page D-2, includes a schedule of all pumps present in the current plant design and their respective flows, pressure heads, and motor horse powers. Pump selections are included in appendix D, pages D-16 through D-39.

All CEP and campus secondary HW and CHW distribution pumping arrangements are sized to satisfy 120 percent of the total peak flow (three pumps in each arrangement, each sized to satisfy 40 percent of the peak flow). This allows for one of the pumps in each of the pumping arrangements to fail while maintaining peak flow by ramping up the flow in the two remaining pumps. The secondary pumps in the borefield loop are sized to 150 percent of peak flow in the geo heating condition (three pumps, each sized to satisfy 50 percent of the peak geo heating flow) and are sized to 100 percent of peak flow in the geo cooling condition (same three pumps, each sized to satisfy 33 percent of the peak geo cooling flow).

If a pump fails during peak geo heating, the total peak flow through the geothermal borefield would be handled by the two remaining pumps. If a pump fails during peak geo cooling, the two remaining pumps would ramp up and any remainder of the cooling load would be satisfied by the cooling towers. All CEP primary pumps at the individual heat pumps are sized to 100 percent of the peak heat pump flow. The cooling tower secondary pumps are sized to 100 percent of the peak cooling tower flow (two pumps, each sized to 100 percent of the peak flow of each cooling tower). The modeled peak heating and cooling loads were used to determine the heat pump sizing and reserve capacity under different conditions.

Heat exchangers are required in two different locations in the CEP. One set of heat exchangers (HX-1,2) separates the cooling tower water (an open system) from the propylene glycol solution present on the condenser side of the larger centrifugal heat pumps (a closed system). A second set of heat exchangers separates the propylene glycol solution from the CHW (HX-3,4) and HW (HX-5,6) loops (pure water) that are used to distribute heating and cooling to the rest of the campus. Since 20 percent propylene glycol is required for use in the borefield, per the selected geothermal option, propylene glycol is required throughout the CEP due to the existing piping arrangement. The borefield piping is connected to the same condenser and evaporator barrels as the CEP CHW and HW loops, forcing the CHW and HW pipes within the CEP to also use the propylene glycol solution. However, using propylene glycol to distribute heating and cooling throughout the entire campus would not only be an expensive solution, but would also require all buildings to be redesigned to adjust for the change. Additionally, it would increase the total required pumping power of the campus. Thus, it was decided to keep water as the distribution fluid and separate it from the propylene glycol solution at the central plant using heat exchangers. M-603, included in appendix D, page D-2, shows a schedule of all heat exchangers, their capacities, and their operational temperatures. Heat exchanger selections are included in appendix D, pages D-12 through D-15.

3.3 Heat Recovery and Thermal Storage Systems

The following heat recovery systems are discussed in this section:

- Centralized heating and cooling generation.
- Heat recovery heat pumps in the CEP.
- De-coupled systems in all buildings to optimize heating and cooling loads.
- Air-side energy recovery in all buildings.

- Events facility cooler and freezer compressor heat rejection.
- Events facility commercial kitchen exhaust heat recovery system.
- Events facility commercial kitchen drain passive heat recovery and residences, possible fitness center, DHW shower drain passive heat recovery.

A thermal energy strategy that is fundamental to the HPR campus' approach is centralized heating and cooling generation in the CEP. This allows the campus to optimize energy recovery throughout the sixteen different buildings by transferring thermal energy from one building to another via centrally located, high-efficiency heat pumps.

Seven heat recovery heat pumps serve as the backbone of the centralized heating and cooling generation in the CEP. As shown previously in Figure 1, a considerable amount of the annual heating and cooling demand is met by simultaneous heat pump heating and cooling. In simultaneous heating and cooling, energy is transferred from the CHW return to the HW return, acting as a heat recovery system by simultaneously heating the HW and cooling the CHW. As shown in Figure 1, simultaneous heating and cooling does not completely satisfy the heating and cooling loads, but it satisfies a considerable amount of the load, and the remainder is provided by electrical energy. This significantly reduces the electrical energy consumed by the heat pumps.

To allow for more simultaneous heating and cooling, DHW demand will also be served by the campus HW loop, except for the events facility and fitness center, which need higher service water temperatures and will be served by a $C0_2$ air source heat pump water heater. DHW production is included in the HW loop to increase the amount of available heat recovery during the summer and shoulder seasons. Simultaneous heating and cooling is limited by the aggregate, non-dominant load on campus.

The residences, events facility, AV studio, and offices all have a DOAS, or dedicated outdoor air system, coupled with a fan coil units or chilled beams to achieve reduced heating and cooling loads by decoupling space conditioning from ventilation. This minimizes the amount of outdoor air that needs to be conditioned to satisfy the building heating and cooling loads.

Air-side energy recovery methods are utilized in all buildings. In the offices, dual energy recovery wheels are used, which take advantage of a classical single energy recovery wheel, but a second wheel also allows for humidity control during the summer. The wheel is placed downstream of the cooling coil. In addition to allowing for humidity control, this energy recovery method achieves 70 percent to 75 percent energy savings.

In all other campus buildings, energy recovery ventilators (ERVs) are utilized. ERVs provide energy savings, humidity control, and improved indoor air quality. ERVs typically recover about 70 percent of energy exhausted from buildings and can reduce HVAC loads by as much as 25 percent.

Coolers and freezers that support the events center kitchen and commissary operations offer consistent, 24/7 heat recovery opportunities. A compressor rack refrigeration skid will be required to maintain the appropriate temperature within each cooler and freezer. Instead of allowing the heat removed from the coolers and freezers (and its associated compressor motor heat) to be rejected to the atmosphere, a water-cooled condenser will be utilized to transfer this heat into the campus HW loop.

A significant amount of heat is generated in a commercial kitchen that can be recycled for use elsewhere on the campus. A significant portion of this heat can be captured from the kitchen hood exhaust. An exhaust air handling unit (AHU) will be used to extract this heat from the exhaust air stream. The AHU will consist of an exhaust fan, energy recovery coil, specialized air filtration and treatment, and a water source heat pump utilized to mechanically transfer this heat to the campus HW loop.

Large quantities of hot drain water are expected in the events enter commercial kitchen drains and in the residences shower drains. Passive heat recovery in these areas will transfer thermal energy to the DHW building loop. Passive heat recovery is being considered for use in the fitness center shower drains.

These energy recovery systems in addition to the building-specific heating and cooling reduction strategies (e.g., high-performing envelop) offer a more balanced heating and cooling profile, for reduced overall load on the CEP and a better performing ground source heat exchanger and heat pump system.

As discussed previously in section 2.1, thermal storage was not a viable design option for the campus. A study was conducted that found that the cost of introducing buffer tanks was comparable to the cost of the equivalent expansion of the geothermal borefield. It was considered that a thermal buffer tank located at each of the residences would help curtail the DHW demand. However, the residences do not have space in their mechanical rooms for buffer tanks. Further, it was determined that burying buffer tanks would not be a viable solution and locating buffer tanks in other buildings is ineffective because the primary load is located at the residences. Ultimately, option 6 from task 2, does not rely on thermal storage. The geothermal borefield, coupled with the central plant equipment, can satisfy 100 percent of the campus' heating and cooling peak and annual load.

3.4 Thermal Resiliency and Reliability

A resilient and reliable campus energy system is paramount to the comfort and safety of the Watchtower Headquarters Project Ramapo (HPR) campus residents and visitors. Thus, resiliency was a priority for the contractor. To ensure robust campus resiliency while also considering the electrical load letter limit, a high-level design constraint was that the geothermal borefield must be sized to handle peak campus heating and cooling loads without assistance from the backup electric boilers nor cooling towers.

Resiliency provided by the sizing of the heat pumps and pumps and by including the electric boilers and cooling towers in the CEP design was discussed previously in section 3.2. The reserve capacity provided by the borefield, heat pumps, electric boilers, and cooling towers was also illustrated previously in Figure 9.

The backup electric boilers are only included in the plant in case a heat pump goes offline during peak heating conditions, which is unexpected during normal operation. The plant can fully handle peak heating loads with simultaneous heating and cooling and with the ground source heat pump. The electric boiler is not expected to be used in a typical heating season. If for some reason the electric boiler must be turned on to supplement heating, it would be powered by the electric grid, solar PV, or utility-scale batteries on-site.

The normal operation of the campus, as modeled by the subcontractor (BR+A), does not predict that the system will ever need to operate in water cooled chiller mode, rejecting to the cooling towers. In the unanticipated and rare case that the cooling towers must be used, the operation would be powered by the electric grid, solar PV, or utility-scale batteries on-site.

There are LNG tanks on campus that are exclusively for emergency natural gas generators. In the case of a utility-wide power outage, the campus is equipped with solar PV paired with a 10 MWh utility-scale battery to support islanded operation of the central plant and campus operations. Only when the power outage extends beyond the capacity of the PV and storage capacity of the utility-scale batteries will the NG generators be needed to support campus operation.

To improve resiliency, the campus electrification is diversified, as mentioned in section 1.1. The campus HVAC electrified system is powered by three sources: (1) Orange and Rockland Electricity Utility, (2) 3,275 kW total, approximately 4,500 MWh/year PV arrays, located on the events facility and AV studio, and (3) a 2.5 MW x 10 MW-hour industrial EOS Zynth Aqueous Zinc battery system.

To support the electrified system, the campus is equipped with a grid-connected microgrid to optimize campus energy consumption and increase resiliency by reducing dependency on the grid. During normal operation, the microgrid operates connected to the utility grid and acts as a sophisticated controller, monitoring and balancing the use of the PV, battery, utility power, and generators. In case of a utility grid-wide power outage, the microgrid can operate independently, powered by the PV installations, battery system, and emergency generators.

3.5 Controls Optimization Strategies and Use of Heat Recovery to Achieve Desired Results

As discussed previously, the CEP consists of four centrifugal heat pumps (400 nominal tons each) and three screw heat pumps (250 nominal tons each) that satisfy the campus cooling and heating demands. All heat pumps are connected to and hydraulically decoupled from the campus system HW and CHW loops, isolated by heat exchangers. This allows for the CEP to use a 20 percent propylene glycol solution as the working fluid, while using water on the campus sides of the heat exchangers for HW and CHW distribution to the buildings. This decoupled arrangement also allows for the use of different campus- and CEP-side HW and CHW supply and return temperatures and temperature deltas, if necessary. The campus CHW system has been designed for controls to maintain the supply temperature at 42ºF and the return temperature at 58ºF and the campus HW system has been designed for controls to maintain the supply temperature at 128ºF and the return temperature at 98ºF. The CEP CHW system has been designed for controls to maintain the supply temperature at 40ºF and the return temperature at 56ºF and the campus HW system has been designed for controls to maintain the supply temperature at 130ºF and the return temperature of at 100ºF. Refer to equipment schedules M-602 and M-603 in appendix D, pages D-1 and D-2, for the specific design temperatures for each operating mode.

The primary operation of the heat pumps is to satisfy the heating and cooling demand simultaneously by cooling the CHW and transferring this condenser heat into the HW loop. If the heat pumps receive controller feedback signaling additional cooling or heating demand, they will satisfy the supplemental load via the geothermal borefield. During late summer and/or peak cooling times, a portion of heat rejected from the CHW loop can be diverted to the cooling towers to avoid over-heating the borefield. The centrifugal heat pumps can use the campus HW loop, the borefield, or cooling towers for heat rejection and can use the CHW loop or borefield for heat recovery. Similarly, the screw heat pumps can use the HW loop or borefield for heat rejection and can use the CHW loop or borefield for heat recovery. The screw heat pumps cannot use the cooling towers for heat rejection, since they are not connected to the cooling towers. The capacity of one centrifugal heat pump is equivalent to the capacity of one cooling tower. These operating modes are reflected in the heat pump schedules in M-602 in appendix D, page D-1 (i.e., cooling tower cooling, simultaneous heating and cooling, geo cooling, and geo heating for the centrifugal heat pumps and simultaneous heating and cooling, heating only, and cooling only for the screw heat pumps). Controls optimization strategies will favor heat recovery via simultaneous heating and cooling and otherwise optimize the operating mode to maximize efficiency and minimize CEP energy consumption.

The cooling tower water is isolated from the CEP propylene glycol loop by a set of heat exchangers. The cooling tower make-up water is fed primarily by a rainwater system which includes tanks and an equipment skid. The skid contains its own local controls for providing rainwater or domestic water as a backup.

Two backup electric boilers are connected downstream of all CEP heat-producing equipment, providing emergency HW supply temperature boosting. Boiler use is unexpected during normal operation, but the need for electric boiler use is possible during unusually cold temperatures in late winter. Each heat pump, heat exchanger group, cooling tower group, electric boiler, and borefield have dedicated primary pumps. The discrete operating modes transition through a series of isolation valves which open and close to the HW and CHW loops, borefield loop, and cooling tower loop, with these transitions automated by controls.

The building automation system (BAS) contractor shall coordinate with the heat pump manufacturer for all flow, temperature, pressure, optimization routines, set points, and operation limits. Programs and sequences indicated or implied herein shall be provided by the subcontractor (BR+A). The BAS contractor shall provide an allowance for an additional 10 percent of input/output points, wiring, engineering, documentation, starting up/checkout, graphics/programming, and any additional required boards or expansion modules to be utilized at the owner’s discretion. All points shall be able to integrate to all trends, totalizations, etc., as applicable. Trending of key parameters shall be required for non-object proof of system compliance of design and operation. Unless otherwise indicated, all set points, limits, and time delays shall be adjustable by the operator using the BAS via menu access at all field panels without the need for hardware or software revisions.

The CEP controls infrastructure shall be designed for redundancy so the failure of a single plant staging controller does not cause a total plant staging failure. The CEP control system shall also provide all routines for heat pumps, cooling towers, primary and secondary pumps, heat exchangers, and electric boilers. The plant control shall be provided to require minimal user intervention and shall operate as a fully automatic plant for year-round operation.

The CEP is connected to emergency generator power in the event of utility power loss. The BAS contractor shall confirm all sequences on normal power, generator power, and transition the starting process so all restarts occur automatically without user intervention. All sequences, set points, dead-bands, timing delays, and adjustable control elements shall be evaluated and optimized during commissioning and monitor-based commissioning. All predictive control and machine learning routines shall be monitored quarterly for three years post occupancy. All operating modes shall be fully tested, initially by either changing set points and/or by simulating loads.

3.6 Control Sequences, Points, Diagrams, and Logic

Documents detailing the design of the community heat pump control sequences, points, diagrams, and logic are included in appendix E.

4 Results—System Design

4.1 Infrastructure Necessary to Serve Additional Building Space with Centralized System

The 100,000 square feet (SF) increase to the AV studio, which is one of the most energy-dense buildings on campus, increased the overall campus heating and cooling loads. Thus, it was necessary to reevaluate the maximum HW and CHW flows through the campus distribution piping necessary to serve the increased loads, which in turn made it necessary to reevaluate the distribution pipe sizing.

However, other variables also changed as the design progressed, all of which served to reduce campus loads and therefore reduce the required HW and CHW flows. These design changes are listed below:

- Energy models were updated as the design was refined and as building performance was better understood. Preliminary models used conservative assumptions to temporarily fill unfinalized variables to avoid under-sizing systems. As the design progressed, conservative assumptions were replaced with more accurate (and typically less energy intensive) information.
- As discussed in section 2.1, distribution thermal piping losses were reduced after they could be accurately calculated.
- Campus load diversity was applied to the design; assuming no load diversity between buildings was an overly conservative assumption. Thus, the subcontractor (BR+A) and the contractor agreed to incorporate 70 percent load diversity (industry standard) to more accurately represent peak heating and cooling loads.
- The HW dT increased from 25°F to 30°F, which decreased the total HW flow rate by a factor of 5/6, the ratio of the previous dT (25°F) to the current dT (30°F). Decreasing the HW flow rate allowed for the selection of smaller secondary HW pumps (PHW-4,5,6), which allows for better turndown, or regulation of flow at low flow rates.

Following the design changes throughout the Category B effort, the HW and CHW peak campus flows were finalized to 2,110 gallons per minute (GPM) and 2,926 GPM, respectively. Following the update to the campus HW and CHW peak flows, it was necessary to reevaluate the campus piping distribution infrastructure, which was analyzed using hydraulic modeling software, PIPE-FLO v18.1.

To determine the peak flow rates that were input into PIPE-FLO, it was necessary to evaluate the peak building heating and cooling loads. The building loads differ from the campus peak heating and cooling loads of 22.6 MMBtu/hr and 20.0 MMBtu/hr because peak building loads do not consider campus diversity (i.e., following typical patterns of building operations, so not all buildings simultaneously demand peak heating or cooling loads). Using peak building loads ensures that pipe sizes are sufficient to serve the demand of a building or group of buildings if it or they demand peak loads. However, as mentioned before, a 70 percent campus load diversity was ultimately applied.

The campus peak HW load was calculated by summing peak DHW demands for buildings whose DHW is not isolated from the CEP with the HW loads for heating all buildings during peak demand. HW loads for the residences included any heating loads from the links. The campus peak CHW load was calculated by summing peak CHW demands for cooling all buildings during peak demand. The links do not contribute to the cooling peaks, as they are only heated. For cooling, the links have operable windows to provide natural ventilation. After applying safety and a 70 percent diversity factor, the HW and CHW campus load was determined to be 31,651 KBtu/hr and 23,405 KBtu/hr, respectively.

The peak loads for each building, with added safety factors, were used to determine the required flow rate through the hydronic system, dictating the pipe sizing and system pump size. While the campus distribution system is sized for peak campus flow with a 70 percent diversity factor, the actual campus flow and load will be further diversified throughout the year, making the distribution system conservatively sized.

After maximum HW and CHW loads were determined, the values were converted to maximum flow rates in GPM using the equation below:

Equation 2 $$\boldsymbol{Flow\ Rate} = \frac{\boldsymbol{q}}{\mathbf{8.34*1*60*}\boldsymbol{dT}}$$

Where:

- q is the thermal load in Btu/hr, 8.34 is the density of water in pounds per gallon,
- 1 is the specific heat of water in Btu/lb°F,
- 60 has units of minutes per hour, and
- dT is the change in temperature of the loop in °F. There is a 16°F dT for the CHW loop and a dT of 30°F for the DHW and HW loop.

Two separate campus distribution hydraulic models were developed, one for the HW loop and another for the CHW loop. The calculated peak HW and CHW campus flow rates of 2,110 GPM and 2,926 GPM, respectively, were input into PIPE-FLO. Also using the equation above, peak HW and CHW flow rates were calculated for each building, given the peak heating and cooling demand of each building. All buildings besides residence 3 were modeled as a flow demand, matching the peak building HW and CHW flows. Residence 3 was modeled as a fixed pressure drop device, with a dP of 3 psi, because it was calculated to be the most hydraulically remote from the secondary pumps, which are located at the CEP. The buildings are also modeled to have a 3-psi pressure drop. The pressure drop is this low because there are tertiary pumps at each building to bring the loop pressure up to the building's pressure needs. Residence 3, as the most hydraulically remote building, is the location on campus with the lowest supply pressure in the system, and therefore the hydraulic model had to be sized to supply the minimum pressure required at this building.

The PIPE-FLO model considers losses due to the pipe lengths between buildings and due to bends and fittings. Mitered bend head losses were included for both 45º and 90º bends, and tee-connection losses were calculated both for through and bend flow conditions. The PIPE-FLO software calculated the k losses associated with each bend or connection type. The software calculates the flow rate in each pipe, which informed the selection of pipe sizes. Pipe diameters were optimized to flow demands in each run to minimize the pressure drop through the system. Pipe sizes were determined using Table 8 below; flow rates determine the minimum pipe size for each run. All piping is ASME B.36.10M Schedule 40 Steel and the working fluid is 100 percent water.

Table 8. Pipe Selection Guide

Pipe Selection Guide	
Size (Inches)	**Gallons Per Minute (GPM)**
0.5	0-3.2
0.75	3-5
1	5-9
1.25	9-15
1.5	15-25
2	25-40
2.5	40-60
3	60-110
4	110-200
5	200-300
6	300-500
8	500-1000
10	1000-2000
12	2000-3500
14	3500-5500

When sizing the piping system, pipe runs were optimized to have fluid velocity between 4 feet/s and 9 feet/s. Also, head loss per 100 feet of linear length was kept below 4 feet. The system was analyzed with a worn pipe condition, which has higher head losses than new pipe.

The CEP was modeled as both a flow demand and as hydraulic equipment. A pressure boundary was created at the inlet of the pump, with a value of 10 psi, and the heat pump was modeled as a fixed pressure drop device with a dP of 10 psi. The pump is modeled as a centrifugal VFD pump, sized to the maximum flow demand.

The campus HW and CHW distribution schematic is included in appendix F, page F-1. The campus HW and CHW PIPE-FLO hydraulic models are included in appendix F, page F-2 and F-3, respectively.

4.2 Resultant Technical Design and System Configuration

The resultant technical design and system configuration is largely detailed in section 3, Discussion of Technologies Utilized. However, a high-level overview will be provided in this section.

Central heating and cooling generation for the campus is provided by the CEP, which allows for the optimization of energy recovery across the 16 different buildings by transferring thermal energy from one building to another via centrally located, high-efficiency heat pumps. The CEP is designed to satisfy 100 percent of the campus peak and annual heating and cooling loads using four 400-ton water-cooled magnetic bearing centrifugal heat pumps and three 250-ton water-cooled screw heat pumps. These community heat pumps are supported by a concentric Rygan ground source heat exchanger, sized with 280 bores, each 800 feet deep, to satisfy peak heating and cooling demands. 20 percent propylene glycol is used as the GSHE and CEP working fluid, which allows borefield temperatures to drop below 32°F, improving heat capacity during cold winter days. The design of the geothermal borefield is included in section 3.1 and the Rygan concentric heat exchanger is detailed in appendix C.

The CEP flow diagram M-601, which illustrates the configuration of and connections between all major CEP equipment, is included in appendix D, page D-40. CEP equipment schedules M-602 and M-603 are reported in appendix D, pages D-1 and D-2, and the centrifugal heat pump, screw heat pump, electric boiler, cooling tower, heat exchanger, and pump final selections are included in appendix D, pages D-3 through D-39.

Trane centrifugal heat pumps were selected for use due to their high efficiency, high capacity, and ability to handle high-lift conditions. Trane screw heat pumps were paired with the centrifugal heat pumps because they can handle high-lift conditions and during turndown they can modulate down to 10 percent of the design load when coupled with a VFD, improving CEP flexibility by allowing a turndown of under 2 percent of the total CEP design capacity.

Heat exchangers are required in two different locations in the CEP. One set of heat exchangers separates the cooling tower water (an open system) from the propylene glycol solution present on the condenser side of the larger centrifugal heat pumps (a closed system). A second set of heat exchangers separates the propylene glycol solution from the CHW and HW loops (pure water) that are used to distribute heating and cooling to the rest of the campus.

Although use during normal operation is unexpected, electric boilers and cooling towers are incorporated into the design to provide additional resiliency and heating and cooling capacity.

CEP pumps were sized to peak heating and cooling flows, with appropriate factors of safety applied as necessary, as discussed in section 3.2.

As discussed in section 4.1, the campus distribution HW and CHW piping system was resized following the expansion of the AV studio and other design changes. The campus HW and CHW distribution schematic is included in M-601 in appendix F, page F-1.

4.3 Design and Control Strategies to Minimize Energy Use and Potential Need for Emergency Fossil Fuel-Based Heating

By designing energy efficient buildings with high-performing envelopes, ventilation energy recovery, reduced lighting power densities, and other heat recovery strategies, the campus is designed to have reduced peaks from a typical ASHRAE 90.1-2016 baseline. This reduction in peaks, when paired with simultaneous heating and cooling, significantly reduces campus heating and cooling peaks that need to be met by the geothermal heat pump system. This reduction in heating and cooling peaks allows for a reduced number of bore holes, reducing the upfront cost of drilling geothermal bores. Through this synergy of strategies, the campus is 100 percent free of fossil fuel for non-emergency operation.

Heat pump simultaneous heating and cooling significantly reduces energy use. Rather than demanding electrical energy to produce heating or cooling, in simultaneous heating and cooling, energy is transferred from the CHW return to the HW return, acting has a heat recovery system by simultaneously heating the HW and cooling the CHW. Thus, this significantly reduces the electrical energy consumed by the heat pumps. Controls optimization strategies will favor heat recovery via simultaneous heating and cooling, given its relatively low-energy intensity. Further, the energy intensities of the other operating modes and equipment operation (geo heating, geo cooling, cooling tower rejection, electric boiler usage) will be programmed into the controls, which then can prioritize energy minimization in its automated selection of the operating mode.

The microgrid also serves to minimize energy use by sourcing energy from the PV array and industrial Zynth Aqueous Zinc battery system. Controls governing the microgrid consider factors such as battery capacity to inform intelligent, automated decisions about how much electrical energy to consume from the PV and battery systems to minimize electrical energy use, while considering other factors such as reserving battery capacity for resiliency.

As stated above, the design is 100 percent free of fossil fuel for non-emergency operation. As a first line of defense, emergency heating is provided by electric boilers. If a utility-level power outage occurs, the electric boilers will continue to be powered by the PV arrays and industrial battery system, controlled by the microgrid. Only if these energy sources are depleted will the controls logic automatically initiate the use of the NG generators to provide electricity to the CEP and campus.

4.3.1 Key Testing Criteria for Commissioning

A Certified Commissioning Professional (CCP) from BR+A will provide Commissioning Services for the project. DM Engineers will provide Enhanced Commissioning, per LEED v.4 Option 1, Path 1, and Monitoring-Based Commissioning, per LEED v.4 Option 1, Path 2. All 10 residences will be Energy Star Rated and ReVireo will be providing NYSERDA HERS rater services on the project. These efforts will help optimize community-based performance, COPs, and machine learning techniques. Key systems to be commissioned include the geothermal heating and cooling system, CHW system, HW system, and electrical components. Commissioning criteria will be finalized in the Commissioning Plan, which will be prepared and followed during the construction implementation phase.

4.4 Construction Specifications

CEP mechanical and electrical specifications related to the PON 4614 Category B effort are included in appendix G, starting on page G-1 and G-92, respectively.

4.4.1 Design Drawings

CEP mechanical and electrical design documents related to the PON 4614 Category B effort are included in appendix H, starting on page H-1 and H-13, respectively.

4.4.2 Make, Model, and Size of Major Equipment

The make, model, and size of major equipment (i.e., centrifugal heat pump, screw heat pump, electric boiler, cooling tower, heat exchangers, pumps) can be found in the selections included in appendix D, pages D-3 through D-39.

4.4.3 CEP Equipment and Geothermal System Costs

As previously cited in section 1.3, appendix A, page A-3, reports the CEP and geothermal system first costs. The CEP is estimated to cost $38,601,648, with the geothermal borefield contributing $8,480,000 toward the total cost.

One aspect of the geothermal cost that is being reviewed relates to the permit. The community heat pump design for the campus is a geothermal borefield of 280 bores, each 800 feet deep. Under the current New York State Department of Environmental Conservation (DEC) code, this system will require a mining permit and financial security payment since the bores are deeper than 500 feet. The mining permit is an important measure to ensure minimal intrusion to sensitive resources from continuous disturbances, like leeching of materials; however, the proposed geothermal borefield does not fall into this risk category. Further, these regulations apply on a per-bore basis, thus adding permitting cost and regulatory time burden to geothermal borefield projects. The project consultants (particularly John Ciovacco, Aztech Geothermal) are working with the DEC to provide an exception wherein closed loop geothermal systems that bore deeper than 500 feet can avoid a mining permit. This would set a precedent wherein the community heat pump project would not be limited to 500 feet and would make the installation of these types of systems financially attainable for more applicants in the future by removing the $250,000 cost of said permit and financial security payment.

4.4.4 Array of Ground Boreholes Design

The design of the borefield array was previously addressed in section 3.1; this topic will not be addressed again here.

5 Results—Business/Ownership Model

The occupants of the project site will be members of the Religious Order of Jehovah's Witnesses—all of whom are adults without young children—who live under a vow of obedience and poverty. Some members will live on-site and other adult religious volunteers will be assisting on a short-term basis. The proposed live/work facility is integral to the religious missionary and global educational work of Jehovah's Witnesses. Accommodations for the resident staff, totaling approximately 1,200 adults, include 645 residential units in 10 buildings.

The Watchtower Bible and Tract Society of New York has established in-house design services through the formation of a five-member project committee. This group manages the efforts at the project site through to completion in 2027. Ownership and maintenance of all buildings and systems on the completed campus will continue with the Watchtower Bible and Tract Society of New York, Inc. Members of the religious order, including skilled technicians and maintenance staff, will maintain the community heat pump system, including the thermal production equipment, distribution piping, and other assets appurtenant to the system.

The applicant does not intend to have ownership by a utility or by a public entity. The applicant will fully own the buildings and systems.

6 Lessons Learned

6.1 Opportunities to Improve Project Value for Stakeholders

The contractor and subcontractors believe that substantial value was added to the project thanks to the NYSERDA Community Heat Pump Category B program. The expansion of the AV studio, which initially triggered the redesign of the geothermal system, led to a study which resulted in an updated geothermal design. The final design does not only cover the heating and cooling needs of the additional space, but also adds resiliency to all the other buildings connected to the system. Despite the success of the program, there are a few opportunities for improvement. One key consideration would be to enroll in the program at the beginning of the design of the geothermal system, rather than during a redesign phase. Both the contractor and the subcontractors became aware of and applied for the Community Heat Pump program during the redesign of the system, rather than during early design stages. Despite the flexibility to change aspects of the design and optimize it to meet the needs of the redesign, there were a number of constraints that could have been avoided had the program been engaged earlier. Given the experience gained during this Category B effort, a future opportunity to improve the project value for all stakeholders involved would be to engage in the Community Heat Pump project at the onset of system design to avoid additional constraints.

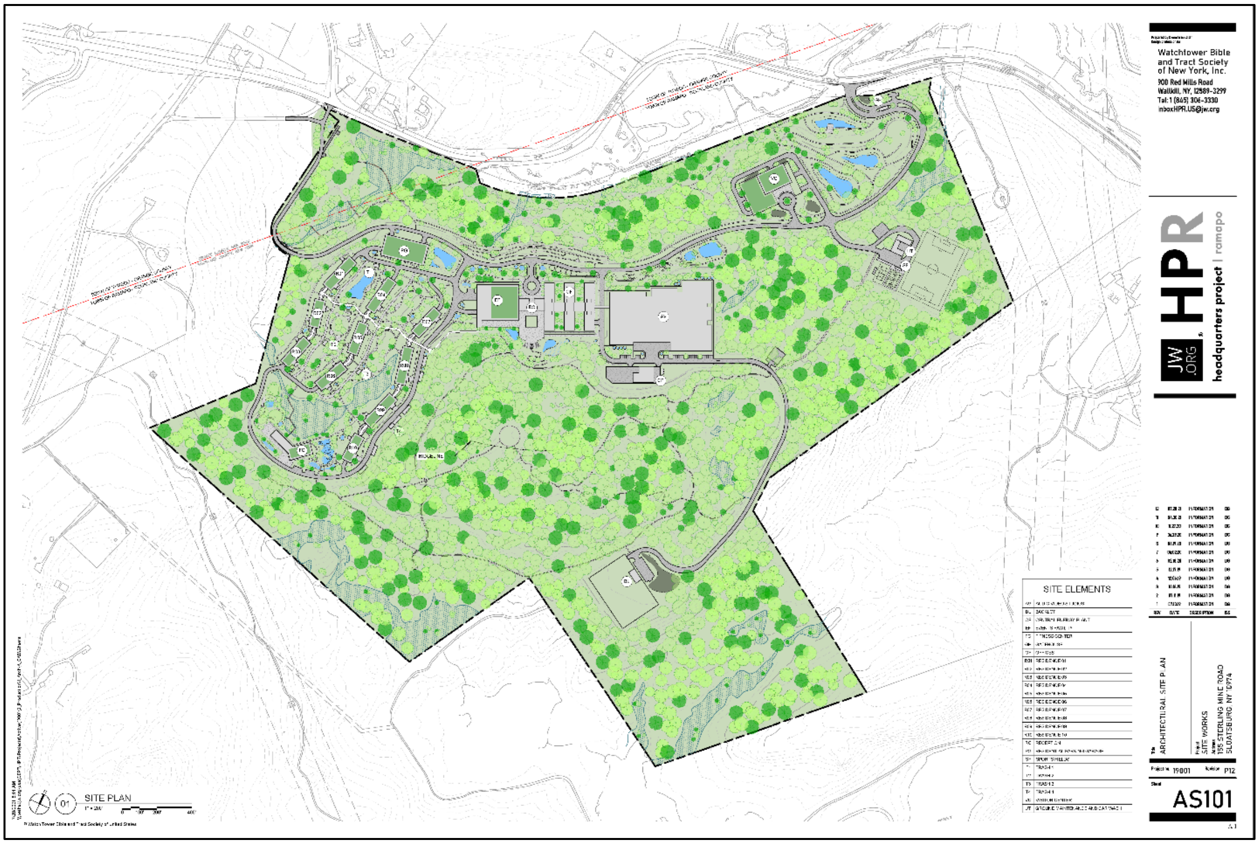
In terms of the final design, another opportunity to improve the project value for stakeholders would have been to consider earlier the use of thermal storage and/or buffer tanks to manage peak heating loads. Considering the campus heating load profile is driven by large DHW peaks, HW storage and buffer tanks were considered as part of the design. It was ultimately decided that, due to building space constraints, the benefit of the buffer tanks was not substantial enough to cover the cost of building redesign to accommodate them. Had the project engaged in the Community Heat Pump program earlier in the design process, thermal storage tanks could have been incorporated.

Another opportunity to improve the project value for stakeholders would have been to consider earlier the constraints related to the use of 20 percent propylene glycol as the CEP working fluid and the resultant higher lift conditions experienced by the heat pumps. Despite the fact the subcontractor (BR+A) was able to resolve this challenge and find an appropriate selection of heat pumps to meet the increased lift, while focusing on efficiency, this was a significant challenge considering the availability of equipment in today's market. BR+A had to closely coordinate with equipment manufacturers to ensure that the selected heat pumps were able to meet the chosen design conditions. Even though this did not affect the final design, it was time consuming on BR+A's behalf.

6.2 Improvements to Recruitment and Selection of Additional Teammates to Conduct Subsequent Work

The contractor assembled a team of highly qualified subcontractors who were able to carry out a successful project which resulted in an effective design that met the contractor's needs, while abiding to their constraints. Looking forward, the team could benefit from a geothermal drilling expert who could help guide decisions related to the drilling and installation of the chosen geothermal system. While current members of the team were experts in geothermal system design, a drilling expert would be advantageous in providing insight during the installation process. The team could also benefit from a commissioning agent who could help ensure the geothermal system was installed and operating correctly once fully operational. The contractor now has an enhanced commissioning agent who will provide commissioning services for the borefield, CEP, and the rest of the buildings on campus. However, the commissioning authority may benefit from communication with dedicated geothermal experts to augment the existing commissioning team.

Appendix A. Campus Site Plan, Construction Schedule, and CEP Cost Estimate



(Click on image to access the schematic drawing)

Appendix B. Energy Modeling Assumptions

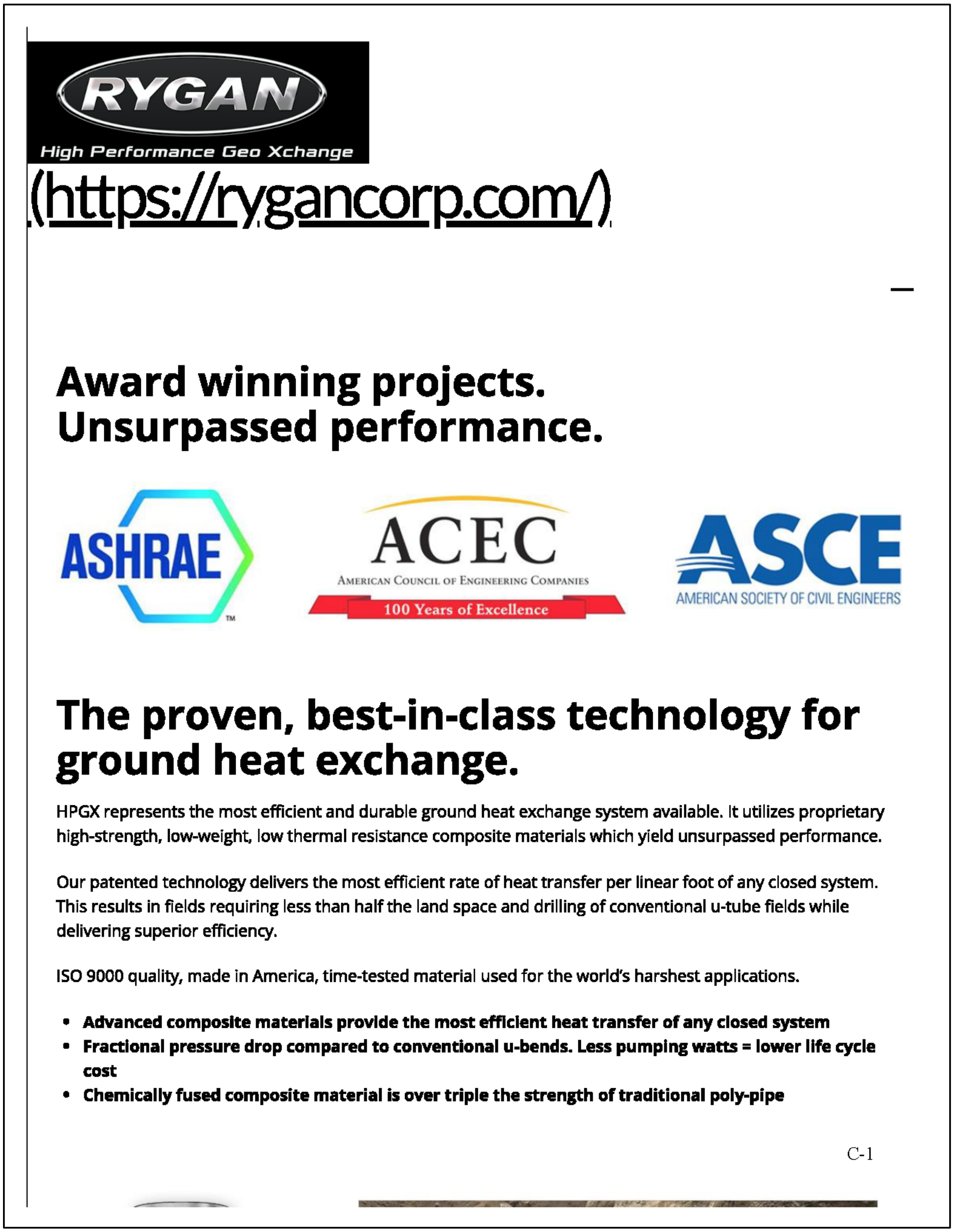
CENTRAL PLANT:

MECHANICAL	
Component	Details
SIMULTANEIOUS HEATING/COOLING	Up to four (4) Trane Agility water-cooled chillers and three (3) Trane Screw water-cooled chillers operate in simultaneous heating and cooling by rejecting condenser water heat from the chilled water loop into the hot water loop to minimize heating energy and maximize energy recovery.
GROUND SOURCE HEATING	All seven (7) water-cooled chillers are also equipped to recover heat from a 280-borehole geothermal wellfield located beneath A/V Studio in a high efficiency heating mode.
GROUND SOURCE COOLING	All seven (7) water-cooled chillers can reject heat into the ground to efficiently supplement cooling loads without increasing equipment quantity.
COMMERCIAL KITCHEN COOLER/FREEZER HEAT RECOVERY	Campus CHW (Chilled Water) will be used for heat rejection, recovering waste heat from commercial freezers and coolers.

B-1

(Click on image to access the schematic drawing)

Appendix C. Ground Source Heat Exchanger Design



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Unsurpassed performance.

The proven, best-in-class technology for ground heat exchange.

HPGX represents the most efficient and durable ground heat exchange system available. It utilizes proprietary high-strength, low-weight, low thermal resistance composite materials which yield unsurpassed performance.

Our patented technology delivers the most efficient rate of heat transfer per linear foot of any closed system. This results in fields requiring less than half the land space and drilling of conventional u-tube fields while delivering superior efficiency.

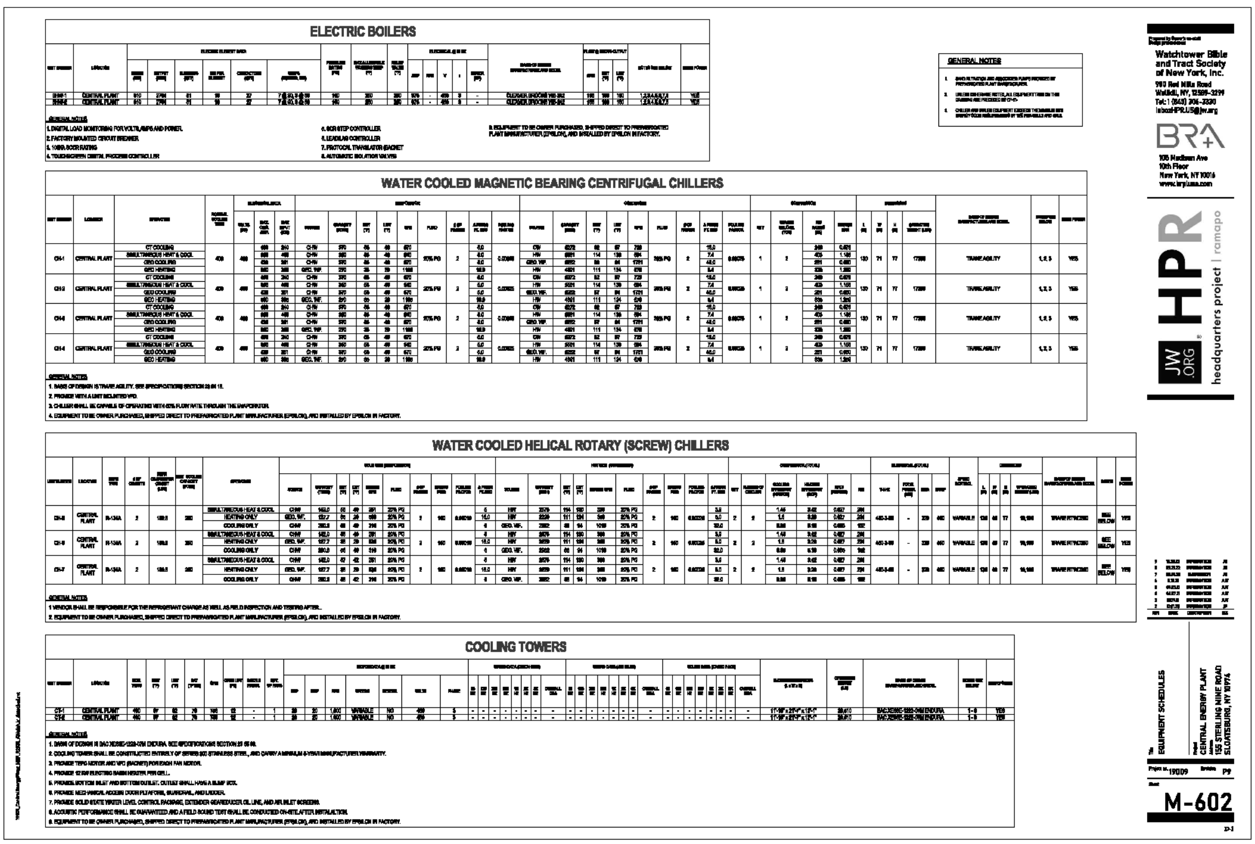
ISO 9000 quality, made in America, time-tested material used for the world's harshest applications.

- **Advanced composite materials provide the most efficient heat transfer of any closed system**
- **Fractional pressure drop compared to conventional u-bends. Less pumping watts = lower life cycle cost**
- **Chemically fused composite material is over triple the strength of traditional poly-pipe**

C-1

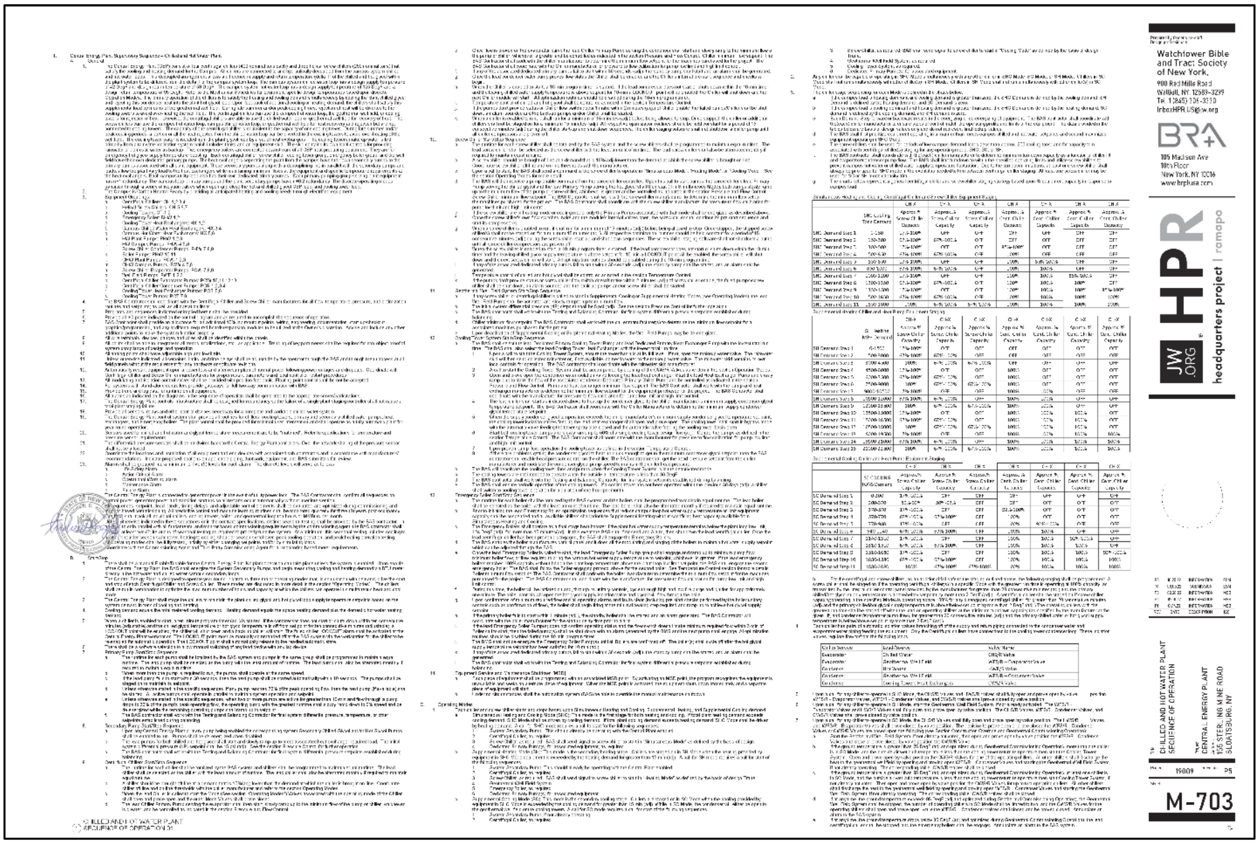
(Click on image to access the schematic drawing)

Appendix D. Central Energy Plant (CEP) Equipment Selection



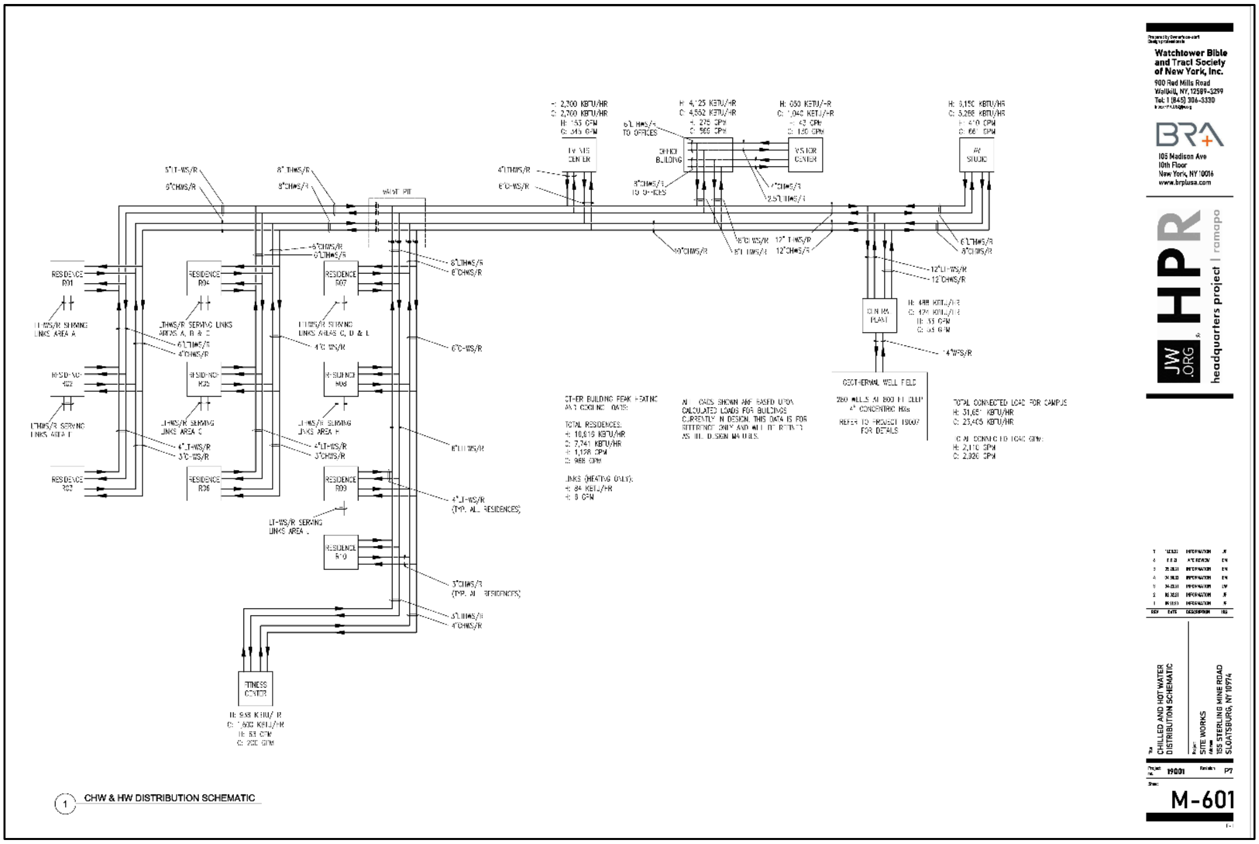
(Click on image to access the schematic drawing)

Appendix E. Community Heat Pump Control Sequences, Points, Diagrams, and Logic



(Click on image to access the schematic drawing)

Appendix F. Central Energy Plant Flow Diagram and Borefield Hydraulic Models



(Click on image to access the schematic drawing)

Appendix G. CEP Mechanical, Electrical, and Plumbing Specifications

SECTION 23 05 00

BASIC MECHANICAL MATERIALS AND METHODS

PART 1 – GENERAL

1.01 **PROVISIONS INCLUDED**

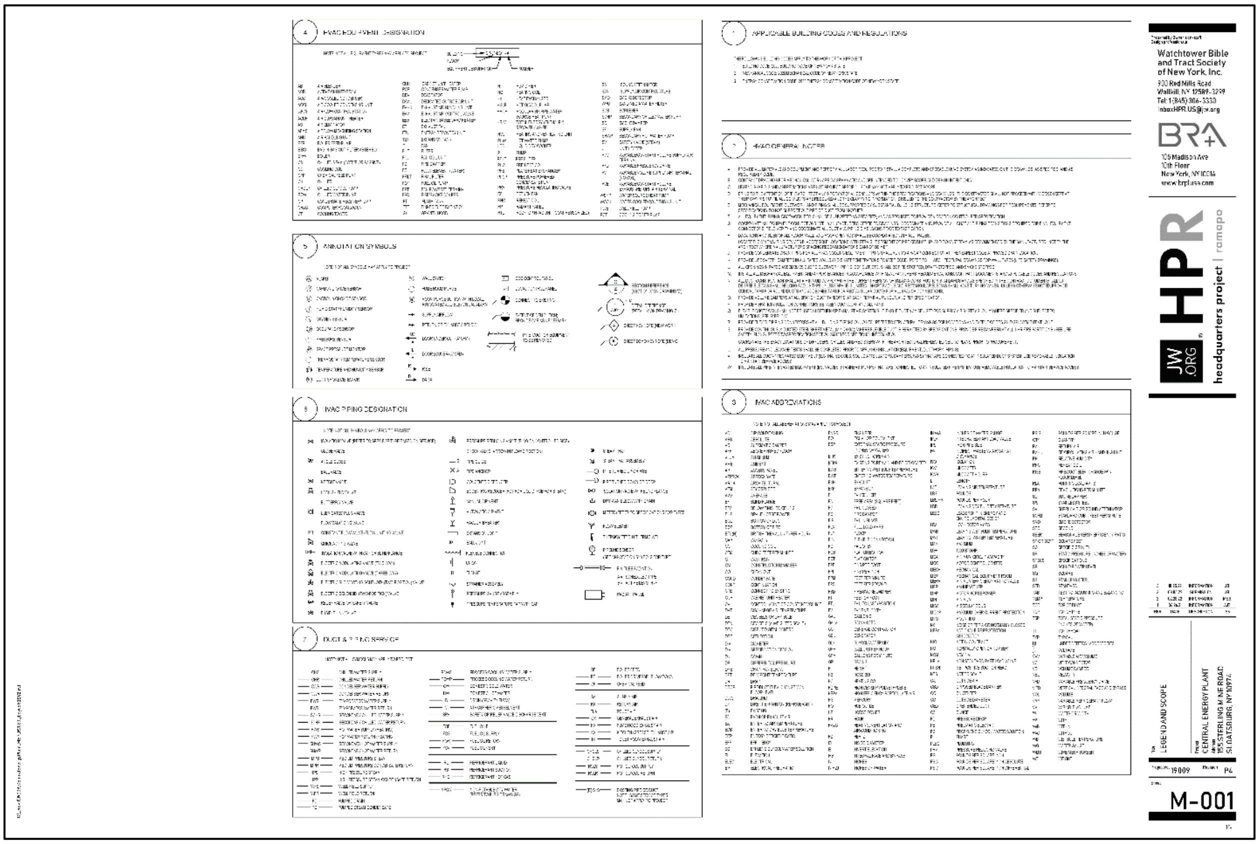
A. Include General Conditions.
B. Supplementary General Conditions
C. Division 0 “Procurement and contracting Requirements”.
D. Division 01 “General Requirements”.
E. Division 02 “Existing Conditions”.
F. See Division 21 for Fire Protection
G. See Division 22 for Plumbing.
H. See Divisions 26, 27 and 28 for Electrical.
I. Section 019113 Commissioning and requirements which may affect the work of this Section.
J. Examine all other Sections of the specifications for requirements which affect work under this Section whether or not such work is specifically mentioned in this Section.
K. Coordinate work with that of all other Trades affecting, or affected by work of this Section. Cooperate with such Trades to ensure the steady progress of all work under the Contract.

1.02 **DEFINITIONS**

A. Words in the singular shall also mean and include the plural, wherever the context so indicates and words in the plural shall mean the singular, wherever the context so indicates.
B. Wherever the terms "shown on drawings" are used in the specifications, they shall mean "noted", "indicated", "scheduled", "detailed", or any other diagrammatic or written reference made on the drawings.
C. Wherever the term "provide" is used in the specifications it will mean "furnish" and "install", "connect", "apply", "erect", "construct", or similar terms, unless otherwise indicated in the specifications.
D. Wherever the term "material" is used in the specifications it will mean any product", "equipment", "device", "assembly", or "item" required under the Contract, as indicated by trade or brand name, manufacturer's name, standard specification reference or other description.
E. The terms "approved", or "approval" shall mean the written approval of the Architect.
F. The term "specification" shall mean all information contained in the bound or unbound volume, including all "Contract Documents" defined therein, except for the drawings.
G. The terms "directed", "required", "permitted", "ordered", "designated", "prescribed" and similar words shall mean the direction, requirement, permission, order, designation or prescription of the Architect. The terms "approved", "acceptable", "satisfactory" and similar words shall mean approved by, acceptable or satisfactory to the Architect. The terms "necessary", "reasonable", "proper", "correct" and similar words shall mean necessary, reasonable, proper or correct in the judgment of the Architect.
H. "Piping" includes in addition to pipe or mains, all fittings, flanges, unions, valves, strainers, drains, hangers and other accessories relative to such piping.
I. "Concealed" means hidden from sight in chases, furred spaces, shafts, hung ceilings, embedded in construction or in crawl spaces.
J. "Exposed" means not installed underground or "concealed" as defined above.
K. "Invert Elevation" means the elevation of the inside bottom of the pipe.

(Click on image to access the schematic drawing)

Appendix H. CEP Mechanical, Electrical, and Plumbing Design Documents



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Appendix I. Exhibit F

NYSERDA Solicitation: Program Opportunity Notice (PON) 4614 Community Heat Pump Systems ATTACHMENT B.2	Category B: Site-specific design study	Report Stage (Final Report for Category B Instructions part 2)

Instructions

Completion of this data spreadsheet is required as part of the **Category B Site-Specific Design Study final report**. This report-stage spreadsheet updates the data previously collected by the Applicant, and includes new data collected during the design study.
Green shaded cells indicate data that were submitted at the Solicitation Stage. **If previously reported data were updated during the design study, enter only the updated responses.**
Yellow shaded cells indicate new information compiled or collected during the detailed design study.

If your application is for a different Category (**Category A** - Site-Specific Scoping Study, or **Category C** - Site Specific Implementation Project),
please download and provide information in the relevant Category spreadsheet.

Data to be provided by applicants are grouped into 3 main areas : ***District Characteristics , Systems and Technology, and Business Model.*** There is one worksheet tab for each sub-category.
Please fill in information for all 3 worksheets

District Characteristics worksheet instructions

CA1 Location & Site Area
Provide the requested system location data.

CA2 Building Cluster Scale & Type
Characterize the scale of the proposed system.

CA3 Building Construction/Retrofit
Identify whether buildings to be served are new construction, retrofit or both. Also indicate if building heating/cooling systems will be replaced.

CA4 District System Construction/Retrofit
Identify whether the proposed district energy distribution system will be new construction, retrofit of an existing system, or both. Indicate distribution system type (high- or low- temp hot water, steam)

CA5 Building Address, Type, Size, Conditioned Area, Age
Provide information for each building to be served by the district system including address, conditioned space, new construction, major building renovation, or retrofit of heating/cooling system.
Indicate building age of existing buildings to be served by the system.

CA6 Estimated Building Loads
Provide information regarding building loads.

CA7 If Retrofit - Energy Systems of Existing Buildings
For existing buildings, identify the primary heating and cooling energy sources, annual energy consumption data from utility bills, and type of heating and cooling system.

CA8 If Retrofit - Building Conversion Related Information
For existing buildings, identify whether heat pumps are used and the year the heating and cooling systems were last upgraded or replaced.

CA9 Energy Use from Existing Facilities
Calculate the total energy use for all existing buildings to be served by the system.

CA10 Conditioned Space, Loads and Energy Use
Calculate the total conditioned area for heating and for cooling for all existing buildings to be served by the system.

Systems and Technology worksheet instructions

CA11 Proposed Thermal Capacity from Geothermal Resource
The data requested in this section is thermal capacity supplied from the ground heat exchanger (GHX), not supplied to the buildings.

CA12 Other Thermal Resources Proposed as a (% of Total Thermal Resource)
Identify renewable or waste heat thermal resources that will be used to supplement the heat provided from the GHX.

CA13 Ground Heat Exchanger
Identify the proposed Earth-coupling method(s).

CA14 Heat Pumps
Provide information on proposed heat pumps including COPs, entering water temperatures, refrigerant, and equipment information.

CA15 Pilot Borehole(s)
Provide information regarding test bores or wells that were installed during the scoping study or detailed design study.

CA16 Onsite Electric Generation / Storage
Identify type and capacity of other renewable power sources or energy storage proposed for the project.

CA17 Community Distribution Piping Proposed
Indicate whether the community distribution system will be a 2-pipe (e.g., ambient loop) or 4-pipe (e.g., separate chilled and hot water piping) system.
Provide community distribution system information including pipe size, insulation, and length for 2- and 4-pipe systems.

(Click on image to access the schematic drawing)

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