Heat Pump System Scoping Study: The Children’s Village Community

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Heat Pump System Scoping Study:
The Children's Village Community

Final Report

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Abstract

The Children's Village campus in Dobbs Ferry, NY has a mix of residential, academic, administrative, and recreational buildings that use fuel oil as a heating source. This study assesses the feasibility of implementing a community geothermal system to provide a high-efficiency heating and cooling system for the campus to eliminate fuel oil consumption. Connecting multiple buildings into a communal geothermal system is the preferred solution because it reduces the required number of vertical geothermal bores that are needed to meet peak thermal loads in each building. Thermal models of the buildings were developed to simulate the hourly aggregated thermal profile of the campus during a typical meteorological year. The results of the models were used to compare energy usage between the proposed geothermal system and a business-as-usual case that uses the existing fuel oil heating and conventional cooling equipment. After conducting a 25-year life-cycle cost analysis, the geothermal system had a higher cost compared to the business-as-usual case. However, if cost sharing from NYSERDA PON 4614 and rebate incentives from the Con Edison Clean Heat Program are included, the geothermal system becomes the more cost-effective option and has a payback period of approximately 10 years. In addition to the community geothermal system, this study also assessed the impact of other clean energy strategies including solar PV, on-site battery storage, and window upgrades.

Keywords

geothermal, life-cycle cost, community heat pump, feasibility study, energy efficiency

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Acronyms and Abbreviations

°F	Degrees Fahrenheit
AC	air conditioning
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
btu	British Thermal Unit
CO_2	carbon dioxide
COP	coefficient of performance
EER	energy efficiency ratio
ft	feet
GLD	ground loop design
GLHE	Ground Loop Heat Exchanger
HDPE	High Density Polyethylene
hr	hour
HVAC	Heating Ventilation & Air Conditioning
kbtu	one thousand btu
kW	kilowatt
kWh	kilowatt-hour
lbs	pounds
LCCA	Life-Cycle Cost Analysis
$MTCO_2e$	Metric Ton Carbon Dioxide equivalent
MWh	megawatt-hour
NYSERDA	New York State Energy Research and Development Authority
PV	photovoltaic
SHGC	Solar Heat Gain Coefficient
TMY3	Typical Meteorological Year, version 3
VRF	Variable Refrigerant Flow

Executive Summary

The Children's Village is a historic nonprofit organization that works with families to help society's most vulnerable children become educationally proficient and socially responsible members of their communities. The campus in Dobbs Ferry, NY provides a safe community for hundreds of children with extensive recreational, vocational, and educational facilities as well as a dedicated team of staff who live on campus with the children to serve as positive role models.

The Children's Village currently maintains an aging assortment of HVAC equipment that has outlived its useful life and needs replacement. Local natural gas infrastructure does not extend to the campus, which in the past meant fuel oil was the only option for heating the buildings. Current fuel oil consumption for the campus can exceed 250,000 gallons per year, incurring an annual cost around $600,000 to operate, depending on annual oil prices. The proposed solution to eliminate fuel oil usage, reduce annual energy costs, and meet carbon reduction targets would be to implement a community geothermal system at the campus.

After conducting a feasibility study, the mix of residential, academic, administrative, and recreational buildings provides the kind of load diversity that make community geothermal heat pump systems worthwhile. Energy models were created for the buildings on campus to determine their hourly heating and cooling demands. When the thermal profiles were aggregated as would be the case in a community geothermal system, the size of the required ground loop heat exchanger decreased by approximately 15%, which would reduce the upfront construction cost of the system.

The proposed community geothermal system will incorporate a one-pipe ambient loop system for distributing geothermal water around the campus to every building. In an ambient loop system, the heat pumps in each building draw water from and return water to the communal loop. A network of water-to-air heat pumps to be installed in each of the children's cottages will replace the existing fuel oil furnaces and AC condensing units. For the staff housing, new ground source variable refrigerant flow (VRF) heat pumps will service wall mounted fan units to providing heating and cooling without needing ductwork. The larger institutional buildings will receive new ground source Roof Top Units (RTUs) that can replace the existing RTUs and integrate into the existing distribution infrastructure in the buildings.

The thermal source and sink for the community geothermal system will be a decentralized network of six ground loop heat exchangers with a total of 280 vertical bores that are each 500 feet (ft) deep. Four Ground Loop Heat Exchanger's (GLHE) with 200 vertical bores would be located on the northern half of campus near the buildings with the highest energy use and two GLHE's with 80 vertical bores would be on the southern half of campus. The current proposed geothermal system is sized to meet 100% of the peak heating and cooling loads of the aggregated thermal profile.

The upfront cost of the community geothermal system is expected to be $23.3 million in construction and pre-construction costs. The expected cost savings from reduced energy bills and lower maintenance costs would take longer than 25 years to break even compared to a business-as-usual case of continued operation with existing fuel oil and conventional AC equipment. However, if cost sharing methods and energy efficiency rebates such as those offered by NYSERDA PON 4614 and the Con Edison Clean Heat program are considered, the reduction in upfront costs would shift the payback period of the project to approximately 10 years.

Additional clean energy solutions such as solar photovoltaic (PV) systems could also be implemented on the campus. The feasibility study found that solar arrays located in the central field by the basketball court and the open space by the southeast parking lot could host 678 kilowatts (kW) of solar PV systems. With current PV system costs and the existing rate structure The Children's Village pays for electricity, the systems could recoup its upfront cost in approximately 13 years. Battery storage systems can also be incorporated into the PV system to reduce monthly electricity bills and improve system resiliency. Given the high-demand charges during peak hours of the summer months, a battery storage system could supply electricity to the campus during hours of high-electricity demand and recharge during the night when cost of electricity is cheaper. The peak-shaving benefits are not expected to fully cover the cost of the battery storage system, but the battery could also provide system resiliency as an emergency backup supply to replace the existing diesel generators.

After considering all aspects of the project, it has been determined that a community geothermal system is a feasible solution to provide a heating and cooling to The Children's Village campus which eliminates the need for fuel oil into the future. Further information gathered during the schematic design and design development phases will help refine the analysis, including conducting a geothermal test bore to be used to assess the GLHE performance. Throughout the design process, detailed drawings and site plans will be generated and project viability will regularly be assessed. With more detailed information, the goal would be to convince a third-party design-build-operate-own-maintain (DBOOM) company that the project is worth an upfront investment that The Children's Village could accept. This would alleviate a large portion of the upfront cost to The Children's Village while still implementing a sustainable project to meet the project goals.

1 Characterization of Proposed Community

The Children's Village located in Dobbs Ferry, NY consists of 60 buildings with a diverse mix of administration, medical, recreational, educational, and residential spaces. Most of the buildings were built in the early 1900's, while and the newest building was built in 1998. Many of the buildings have been renovated over time, but still use aging HVAC systems heated by fuel oil. The total square footage of all the buildings on campus is approximately 448,000 square feet (ft^2). The whole property is owned by The Children's Village organization; however, the organization does not own all the buildings on their property. The school building is affiliated with Greenburgh 11 Union Free School District, and the D'Assern staff housing is managed by a third-party property management company. With such a large campus, construction of a community geothermal system can take multiple years and require separate phases of the project. Recent HVAC equipment renovations have been made to some of the larger buildings on campus. A full conversion to a community geothermal system would require the eventual removal of those new pieces of equipment. Since the conversion to geothermal can take place in phases, upgrades can start with the residential cottages and the larger buildings can be connected last, so the newer equipment can get more use.

The layout of the campus is divided into seven zones based on clusters of buildings that can represent the thermal block to be used in the aggregated thermal profile of the community geothermal system. Figure 1 presents the map of The Children's Village campus with labels indicating which builds are included in each of the seven thermal block zones.

Figure 1. Campus Map Showing the Buildings Included in each Modeled Zone

A building area summary by building type and zone is provided in Table 1. More than half the building area is made up from the residential cottages, and residential buildings are the primary building type in most of the zones on campus. Zone 2 has the largest area of floor space and includes most of the non-residential heating and cooling loads on campus.

Table 1. Building Area and Space Usage Associated with Each Zone

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Total	% of Total
Residence	49,611	-	40,654	25,068	42,221	18,064	86,320	**261,938**	58.5%
Admin/Office	17,671	35,704	-	-	-	6,480	-	**59,855**	13.4%
Academic	-	89,597	-	-	-	-	-	**89,597**	20.0%
Recreation	-	24,617	-	-	-	5,000	-	**29,617**	6.6%
Other	3,281	-	2,460	1,350	-	-	-	**7,091**	1.6%
Total	**70,563**	**149,918**	**43,114**	**26,418**	**42,221**	**29,544**	**86,320**	**448,098**	
% of Total	15.7%	33.5%	9.6%	5.9%	9.4%	6.6%	19.3%		

Thermal models were created for the Lanza, Greenburgh, Cordero, Wetmore, and medical buildings. The thermal model is used to estimate the amount of energy the building requires for heating and cooling loads throughout the year. Given the number of residential buildings, one cottage was modeled to determine the thermal requirements of a typical residence. Crest Cottage was used to represent the standard residential building. After an hourly thermal model was developed for Crest Cottage, the thermal loads were scaled up in proportion to the residential floor area in each zone. The resulting thermal block loads for zones 1 through 7 is presented in Table 2.

Table 2. Results of Thermal Loads in Each Zone: Peak and Annual Heating and Cooling

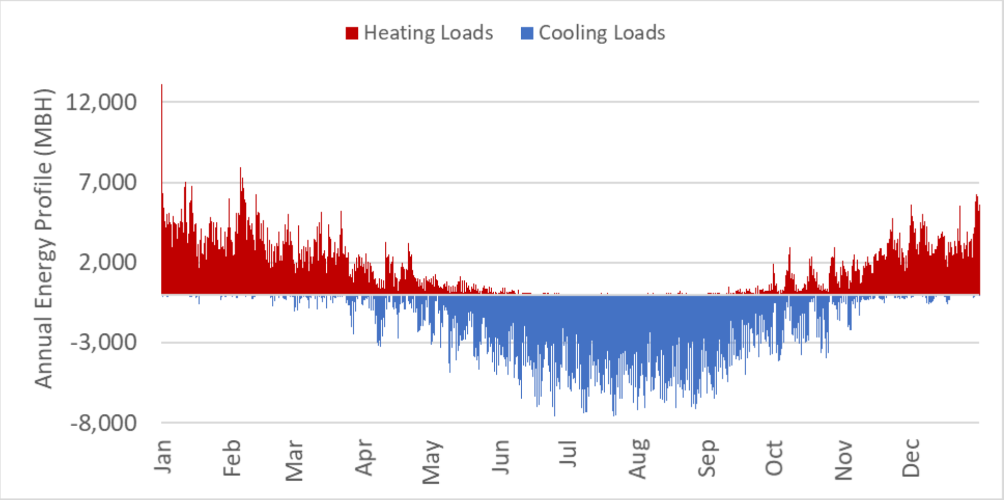
	Sum of Zones 1-7	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Peak Heating (kbtu/hr)	15,025	2,657	2,129	1,961	1,202	2,176	974	3,926
Annual Heating (kbtu)	10,110,251	2,149,097	1,897,672	1,048,692	642,583	1,163,718	1,090,324	2,118,165
Peak Cooling (kbtu/hr)	9,030	1,402	3,710	705	432	782	588	1,411
Annual Cooling (kbtu)	10,940,622	1,783,171	3,584,438	1,057,954	648,259	1,173,997	574,638	2,118,165

In an integrated community geothermal system, the combined thermal loads of all seven zones would be aggregated into one full-campus thermal profile. This reduces the necessary annual peak heating and cooling experience by the community system because the buildings in each zone won't experience their peak loads at the same time. Table 3 shows how aggregating the thermal loads of the campus into one community geothermal system reduces the peak heating and cooling loads by approximately 15%.

Table 3. Peak Load Reduction Resulting from Aggregating Campus-Wide Thermal Profile

	Sum of Zones 1-7	Aggregated Campus Profile	System Reduction
Peak Heating (kbtu/hr)	15,025	13,110	1,915
Peak Cooling (kbtu/hr)	9,030	7,579	1,451

Figure 2. Hourly Thermal Model of Aggregated Campus Profile



Currently, the primary party involved in the community geothermal discussion is The Children's Village. In the future, additional parties will be involved in the discussion of improvements to the D'Assern staff housing buildings and Greenburgh school. On a campus level, the full buildout of the community geothermal system would cost approximately $23.3 million dollars. The upfront cost accounts for approximately $2.2 million in pre-construction costs for developing site plans and developing architectural and engineering design plans. The remaining $21.1 million in construction costs would go toward construction of the one-pipe ambient loop that will circulate water around the campus, construction of 280 vertical bores in the geothermal heat exchangers, and the geothermal heat pump equipment that will be installed in each building. While this is a high upfront cost, there are also financial incentives available to reduce the initial price. Available incentives through the New York State Energy Research and Development Authority (NYSERDA) and the Con Edison Clean Heat Program could provide up to $8.9 million as cost share and rebates to lessen the financial burden. With these incentives, the total payback period of the project would be approximately 10 years due to eliminating fuel oil consumption and reducing annual maintenance costs.

The Children's Village is well suited for a community geothermal system given the availability of open spaces which can locate ground loop heat exchangers (GHLE's) around the campus. The road that encircles the campus provides a convenient path for the ambient loop to reach the most buildings, and the cross streets can accommodate valves that can segment the ambient loop into smaller zones as well. This would provide the opportunity to build out the community geothermal system in phases over multiple years. One constraint of the site is the existing water and sewer infrastructure. The existing piping on campus also follows the roads on campus, so during the construction of the ambient loop care must be taken to not disturb that infrastructure.

1.1 Discussion of Technologies Assessed

The proposed community geothermal solution for The Children's Village will be a decentralized system with borefields spread in multiple locations around the campus. A one-pipe ambient loop with three pump stations will circulate water around the campus to connect the borefields and the buildings. The geothermal heat pumps in each building will tie into the ambient loop with supply and return piping to leverage the system as a thermal resource.

New water-to-air geothermal heat pumps will replace the existing oil furnaces and air conditioning systems in the children's cottages and the smaller buildings such as the chapel, daycare, and the Quartermaster's office. The heat pumps will connect to the existing ductwork in each building to provide the heating and cooling. The smaller buildings and most cottages will receive two 4-ton heat pumps to meet the buildings' thermal capacity requirements. The cluster of smaller Clearview cottages are expected to only need one 4-ton heat pump. A total of 72 water-to-air heat pumps are needed for the children's cottages and smaller buildings.

The D'Assern cottage buildings don't have the ductwork to use water-to-air heat pumps, so new geothermal variable refrigerant flow (VRF) heat pumps will be installed instead. The VRF heat pumps will circulate refrigerant throughout the buildings. In each room, a fan will blow air over the refrigerant to provide hot or chilled air without the need for ductwork. Of the 14 D'Assern Cottages, five are approximately 4,000 square feet (ft^2) and nine are approximately 7,200 ft^2. It is estimated that three VRF heat pumps are needed to support the smaller cottages, and four heat pumps are needed for the larger cottages. A total of 51 geothermal VRF heat pumps are required to service all 14 D'Assern cottages. The institutional buildings will be serviced by larger 15-ton water-to-air geothermal roof top unit (RTU) heat pumps which will replace the existing RTUs and can connect to the existing HVAC systems in each of the buildings.

The campus has a mix of buildings and open fields with enough available land to accommodate 825 geothermal bores at 20-foot center-to-center spacing from one bore to another. The layout of the ground loop heat exchangers (GLHEs) is well distributed around campus with higher bore capacity under the baseball fields near the larger buildings. The available land for GHLEs on campus is shown in Figure 3. Given the availability of large open areas on the campus, a community geothermal system could rely entirely on GLHEs as a thermal resource.

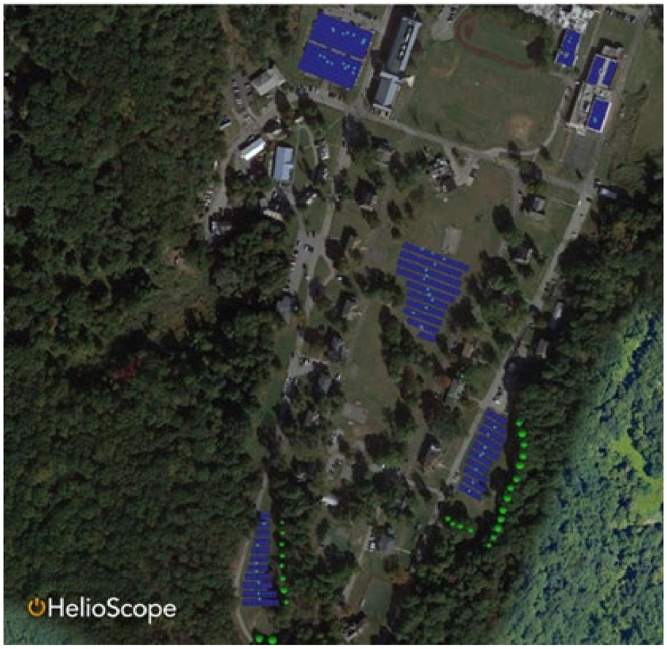
Figure 3. Available Space for Borefields at The Children's Village Campus

The proposed geothermal system is sized based on the campus thermal profile, which has higher demands for peak heating than for peak cooling. The peak heating is primarily a result of heating the residential cottages and staff housing. Fossil fuels are not an option to provide supplemental heating because there is no natural gas service available on site, and the new geothermal equipment will replace the existing fuel oil heating equipment. Electricity can provide the supplemental heating through heating coils that are built into the installed water-to-air geothermal heat pumps. It is difficult in the feasibility study phase to determine if supplemental heating would be economical to implement in a general way to reduce upfront capital expenditure costs. Supplemental heating coils use electric resistance, which is a less efficient heating method with a Coefficient of Performance (COP) of 1.0 compared to the geothermal heat pumps which have COPs ranging from 3.6 to 4.8. It is possible that supplemental heating coils may be economical for some cottages which have a peak heating demand that slightly exceeds what one 4-ton heat pump can provide. In those cases, the extra cost associated with higher electricity usage to operate the heating coil in one 4-ton heat pump could offset the upfront cost of installing a second heat pump unit. The economics would need to be determined on a case-by-case basis in the design phase. It is unclear if enough supplemental heating could be implemented to reduce the number of vertical bores in any of the GLHEs. With the current information, the best solution for The Children's Village would be to meet 100% of the campus peak loads with a geothermal system.

In addition to the proposed geothermal system, further clean energy strategies can be implemented on The Children's Village campus to provide sources of renewable energy, reduce energy costs, and add resiliency to the campus energy system.

The Children's Village has had past discussions with a solar contractor to provide solar generation to the campus. The contractor provided a plan to host multiple PV arrays with a 1,754-kilowatt (kW) nameplate capacity on the campus and provide lease payments and the right to purchase electricity from the panels at a discounted rate compared to grid-supplied electricity. In exchange, the contractor would sell 70% of the generated electricity to the surrounding area with the remaining 30% going to the campus. The satellite view in Figure 4 shows the locations on campus the contractor planned to locate panels. Those discussions have not progressed since this proposal.

Figure 4. Early Proposal for where Solar PV Systems Could Be Installed on Campus



The system presented by the solar contractor incorporates a mix of ground mounted, car port, and rooftop solar PV systems. If The Children's Village chooses to implement solar exclusively for their own use, the system size could be reduced. From the available locations suggested by the solar contractor, the most economical solar arrays to implement would be the ground mounted systems in the center field by the basketball court and the field by the southeast parking lot. With an estimated system construction cost of $2.5/Watt (W) capacity The Children's Village could choose how much solar they would like to implement. Table 4 presents three options for potential amounts of solar generation.

Table 4. Cost Benefit Analysis of Potential Solar Energy Options

PV Array Location	Nameplate Capacity (kW)	Annual Electricity Generation (kWh)	Carbon Reductions (MTCO2)	Upfront System Cost ($2.50/W)	Annual Electricity Savings	Payback Period (years)
Southeast Field	252	345,760	87.1	$ 630,000	$ 45,466	12.5
Center Field	426	583,470	147.0	$ 1,065,000	$ 73,430	13.25
Combined	678	929,230	234.2	$ 1,695,000	$ 113,160	13.5

PV Array Location	Nameplate Capacity (kW)	Annual Electricity Generation (kWh)	Carbon Reductions ($MTCO_2$)	Upfront System Cost ($2.50/W)	Annual Electricity Savings	Payback Period (years)
Southeast Field	252	345,760	87.1	$ 630,000	$ 45,466	12.5
Center Field	426	583,470	147.0	$ 1,065,000	$ 73,430	13.25
Combined	678	929,230	234.2	$ 1,695,000	$ 113,160	13.5

The carport and rooftop solar arrays would require higher upfront construction costs and the southwest field is likely to have too much shading to be worth pursuing. A preliminary review of campus electricity distribution wires indicates that no added distribution capacity is needed if the 678 kW of solar panel capacity is installed. Also, electricity generated by the solar panels is not expected to exceed the demand of the campus at any time during the year.

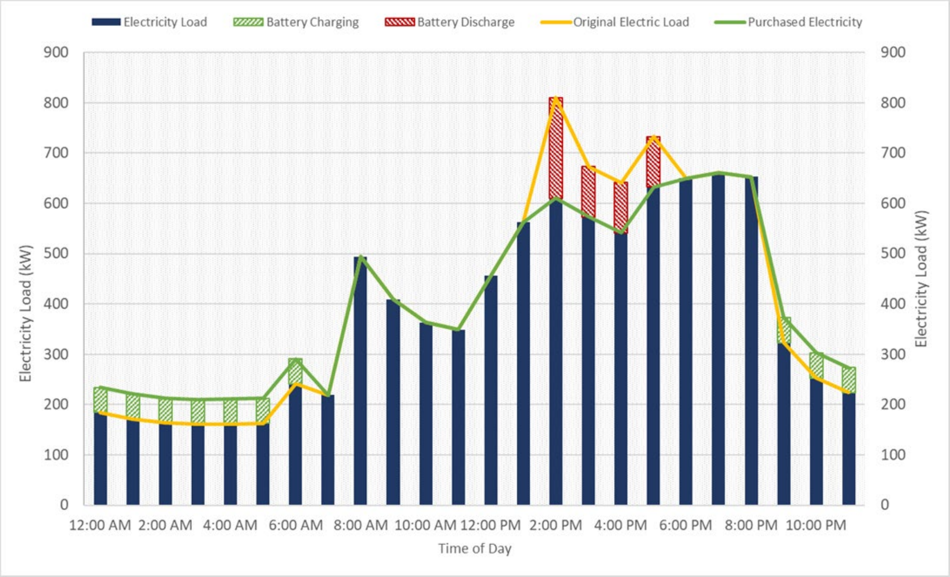
In conjunction with the solar PV systems, an on-site battery storage system can also be incorporated to reduce monthly electricity bills and improve system resiliency. Given the high-demand charges during peak hours of the summer months, a battery storage system could supply electricity to the campus during hours of high-electricity demand and recharge during the night when cost of electricity is cheaper.

Figure 5 shows how a 400-kilowatt-hour (kWh) battery storage system could reduce peak hourly loads during a summer day and transfer that incremental load to the night hours. A battery storage system with a capacity of 400 kWh could reduce the peak usage of site electricity during the summer from 810 kW to 661 kW which can be seen in Figure 5.

The Children's Village falls under the ConEdison General Large SC9 for electricity charges. Using the demand rate charges outlined in the Con Edison SC9 rate schedule, the total demand charges would be reduced by $5,439.52 for a peak reduction from 810 kW to 661 kW. Over the course of the four months that the high-demand rate charges are implemented, this could total over $21,000 in electric demand savings. As commercial battery storage systems become more competitive and readily available, prices will start to reduce. Currently battery storage system costs are in the $350/kWh for a 4-hour lithium-ion battery system (NREL, 2021). This would put a 400-kWh battery system at $140,000. A simple payback for the system would be 6.4 years.

Along with peak shaving reduction benefits, the battery could also provide system resiliency as an emergency backup supply to replace the existing diesel generators.

Figure 5. Benefits of Peak Shaving for Battery Storage During Summer Day



1.2 Discussion of Analytical Methods

Test bores were not drilled during this feasibility study. Two test bores will be installed during the design phase and will provide valuable information on the thermal properties of the geology on site. The information from these tests will be used to produce more accurate modeling of heat exchanger performance so the final system can be correctly sized.

The thermal profiles of the buildings were created using IES, Trace 700, and HAP modeling software. The climate data used in the model is the TMY3 weather data file at New York-LaGuardia Airport 725030. ASHRAE defines the climate zone of the campus as climate zone 4A. Temperature setpoints are modeled to be 74°F during the cooling season and 70°F in the heating season.

For institutional building spaces like Wetmore building, the modeled occupant counts are provided for each space type based on occupant density default values defined in ASHRAE 62.1-2016 Table 6.2.2.1. ASHRAE defines a default occupant density in units of people per 1,000 ft^2 for all possible space types (ASHRAE Standard 62.1-2016 2016). In the residential cottages, each cottage is modeled to have an occupancy of 15 residents as is generally the case for most of the residences.

Building envelopes are modeled based on as-built U-Values when the information is listed in the drawings. When U-values are not provided, reasonable values were used instead. For the cottages, the energy modeling software default values were applied to represent a building classified as older construction. In other cases, such as for Wetmore and Medical buildings, U-values and SHGC were estimated to follow older ASHRAE requirements.

Energy models for Greenburgh, Lanza, Cordero, Wetmore, Medical, and Crest cottage were created using these methods to produce 8760 annual thermal profiles for heating and cooling. When a zone has several residential buildings, Crest Cottage serves as a representative residential building. Thermal profiles of the zone are then scaled by area to account. Crest Cottage was chosen to represent residential usage because it was the largest cottage building for which detailed construction drawings were available.

Heat generated by equipment operation affects the modeled cooling and heating loads experienced by the geothermal heat exchangers. This translates to the peak heating and cooling capacity that must be serviced by the geothermal system. The process of sizing the geothermal system was done in Ground Loop Design software (GLD). In GLD, modelers provided building energy loads, ground thermal properties, borehole lengths, and various other inputs. When designing a geothermal system, the GLD software allows the user to input the known variables of the site geological conditions; the software will then calculate the required heat exchanger length. The GLD software accounts for the heat generated by equipment and includes those calculations when sizing the required length of piping in the heat exchangers.

1.3 Results—System Design

For The Children's Village, the peak heating and cooling loads were taken from the thermal profiles of the multiple zones around the campus. With the given peak loads, GLD calculated the required borehole length necessary to satisfy the peaks in each zone. The borehole count was calculated using 500 feet deep bores. Using this method of adding each zone individually, the calculated number of vertical bores necessary would be 325 as shown in Table 5.

Table 5. Sizing of Geothermal System for Individual Zones

	Sum of Zones 1-7	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Peak Heating (kbtu/hr)	**15,025**	2,657	2,129	1,961	1,202	2,176	974	3,926
Peak Cooling (kbtu/hr)	**9,030**	1,402	3,710	705	432	782	588	1,411
Total Geothermal Borehole Length (ft)	**162,175**	24,950	54,890	14,970	8,982	16,467	11,976	29,940
Number of 500 ft vertical bores	**325**	50	110	30	18	33	24	60

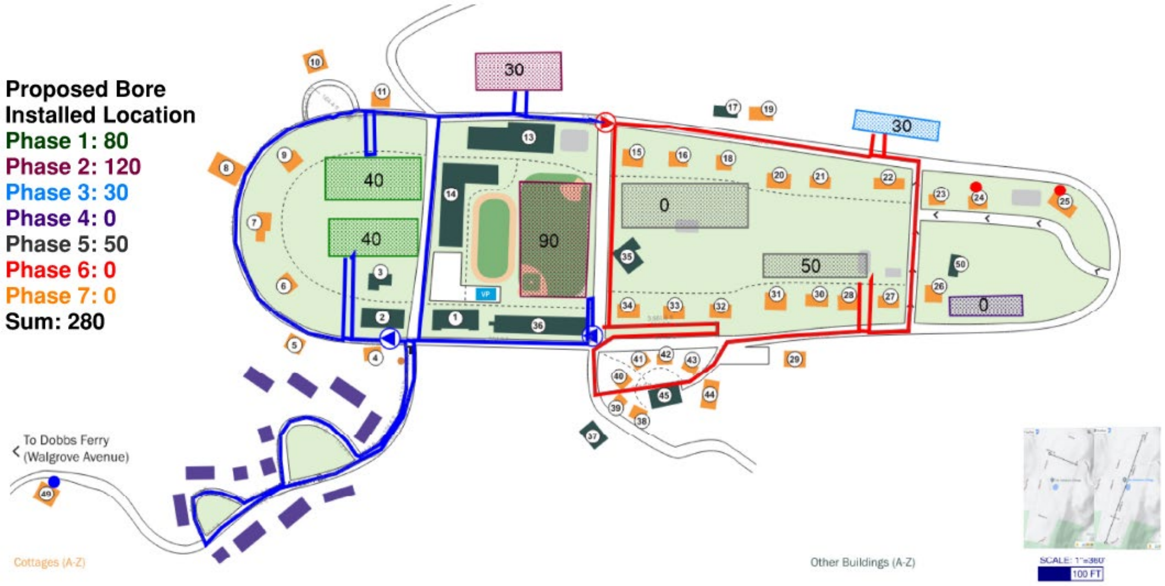
However, by combining all seven zones into one aggregated thermal profile, the geothermal system can service the same loads using fewer vertical boreholes. Because zones won't experience their peak loads at the same time, peak heating and cooling for the aggregated campus profile will be lower than simply adding the peaks of each individual zone. Table 6 shows how aggregating the thermal loads of the campus into one community geothermal system reduces the peak heating and cooling loads by approximately 15% and reduces the necessary number of geothermal bores from 325 down to 280.

Table 6. Reduction in System Size due to Aggregating Thermal Loads

	Sum of Zones 1-7	Aggregated Campus Profile	System Reduction
Peak Heating (kbtu/hr)	**15,025**	13,110	1,915
Peak Cooling (kbtu/hr)	**9,030**	7,579	1,451
Total Geothermal Borehole Length (ft)	**162,175**	139,720	22,455
Number of 500 ft vertical bores	**325**	280	45

The proposed community geothermal system will incorporate a one-pipe ambient loop system for distributing geothermal water around the campus to every building. In an ambient loop system, the heat pumps in each building will draw water from and return water to the communal loop. This alters the temperature of the water in the ambient loop as the water travels to subsequent buildings. For example, in the cooling season the heat pumps will release energy into the source water as a thermal sink. This causes the temperature in the ambient loop to increase from one building to the next resulting in slightly lower efficiencies from heat pumps that have warmer supply water temperatures. The inverse is true during the heating season when heat pumps will draw energy from the ambient loop resulting in lower water temperatures for subsequent heat pumps reducing their heating efficiencies. The temperature drift in the ambient loop is rebalanced each time the loop is connected to a GLHE. At the GLHE, energy is transferred between the ambient loop and the ground to ensure the water in the loop is at a temperature the heat pumps will operate at optimal efficiency. Therefore, in the ambient loop system, it is important to distribute GLHEs around the campus to ensure there are enough locations to rebalance the temperatures. Figure 6 shows the proposed one-pipe ambient loop system for The Children's Village and the distribution of GLHEs around the campus.

Figure 6. Conceptual Design of Proposed Ambient Loop and Geothermal Borefield Distribution



One benefit of the proposed decentralized design is that the ambient loop includes internal connections that produce smaller circuits inside the larger community loop. This provides the benefit of extending the system construction into phases that, once complete, can provide benefits to some buildings before the full system is complete. Additionally, splitting the project into phases provides the flexibility to house the children away from the construction areas, which will be taking place over multiple years. Smaller circuits inside the communal loop also add resiliency to the system by providing the option to section off portions of the system to maintain service in some buildings, while repairs are being made in another area.

The existing subsurface infrastructure includes the water and sewage piping that circulates around the campus. The existing pipes follow the roads of the campus to reach every building. There is no natural gas piping on the campus. Electrical distribution is arranged in overhead wires around the site. The campus sits at the top of a hill above the surrounding area. The ground has a soil layer consisting of sand and mud that is approximately 10 feet deep. Below the soil is solid bedrock known as the Manhattan Formation. There is no groundwater at the site. The proposed one-pipe ambient loop will also follow alongside the roads. Alteration to the roads and sidewalks will be kept to a minimum and is expected to only be necessary when crossing streets in a few key locations. It is expected that subsurface conditions and existing infrastructure will not create any hurdles that cannot be overcome.

1.4 Results—Business Model

As the owner of the property, The Children's Village would be the lead point of contact for discussions between the design and construction team and the clients. Other clients in future discussions include Greenburgh 11 School District, which manages the Greenburgh school building, and H&S Property Management Inc., which manages the D'Assern staff housing buildings.

The ideal ownership model is one in which a third-party company could provide a mechanism to reduce the upfront costs for which The Children's Village and other clients would be responsible. Contract structures could include Design-Build-Own-Operate-Maintain (DBOOM), Energy-as-a-Service (EaaS), Energy Savings Performance Contracts (ESPC), etc. Under this type of a business model, the third-party company would assess the upfront costs of design and construction and the long-term costs of operating and maintaining the system. Before deciding the ideal structure for third-party engagement, it is important to understand that The Children's Village has different variables to assess if a third-party company is engaged. Some of those potential variables that will require assessment are the extent to which risks are transferred to a third party, the length of the risk transfer commitment, the potential desire to receive up-front capital for deployment toward other initiatives and programs, the speed to savings achieved and incentivization mechanisms. All these factors need to be weighed carefully if a third party is engaged in delivering this system. As a for-profit company, the third party would also be able to leverage tax incentives such as the 10% geothermal investment tax credit and accelerated depreciation schedules that a nonprofit could not take advantage of, such as The Children's Village.

After a review of the cost estimates for the proposed geothermal, it was determined that if a third party were to charge The Children's Village and other clients an annual fee of approximately $2 million for the cost for DBOOM services, the annual cost of DBOOM services and geothermal electricity usage would be equal to the business-as-usual case of operating, maintaining, and regularly replacing the existing equipment. The $2 million-dollar annual fee would provide the third party a weighted average cost of capital (WACC) of 6.8% which may be high enough for them to justify providing upfront funds for this project.

1.5 Results—Impact

The three primary upfront capital expenditure costs the proposed community geothermal system will incur include installation of the equipment in the buildings, construction of the GLHEs, and construction of the one-pipe ambient loop system.

For equipment costs, new water-to-air geothermal heat pumps will replace the existing oil furnaces and air conditioning units in the children's cottages and the smaller buildings such as the chapel, daycare, and the Quartermaster's office. The heat pumps would connect to the existing ductwork in each building to provide the heating and cooling. The smaller buildings and most cottages will receive two 4-ton heat pumps to meet the buildings' capacity requirements. The cluster of smaller Clearview cottages will only need one 4-ton heat pump. Equipment costs would include the cost of the geothermal heat pumps and circulating pumps plus any added piping, wiring, or ductwork. Labor costs are estimated based on the number of hours needed to remove existing equipment, install the new units, and connect the systems with the rest of the building. For the larger cottages and smaller non-residential buildings, installing two 4-ton heat pumps is estimated to be $19,000 for equipment and $9,000 for labor which comes to a total of $28,000 per building. For the smaller Clearview cottages that will only have one 4-ton heat pump, the cost is half that of the larger cottages for a total of $14,000 per building.

The D'Assern cottage buildings don't have the ductwork to use water-to-air heat pumps, so new geothermal variable refrigerant flow (VRF) heat pumps will be installed instead. The VRF heat pumps will circulate refrigerant throughout the buildings. In each room, a wall mounted unit will receive the refrigerant and blow hot or chilled air without the need for ductwork. Of the 14 D'Assern Cottages, five are approximately 4,000 ft^2 and nine are approximately 7,200 ft^2. It is estimated that three heat pumps are needed for the smaller cottages, and four heat pumps are needed for the larger cottages. Equipment costs for the larger D'Assern cottages are estimated to be $49,000 and labor costs are estimated to be $30,000 for a total cost of $79,000 per building. Equipment costs for the smaller D'Assern cottages are estimated to be $33,000 and labor costs are estimated to be $23,000 for a total cost of $56,000 per building.

The total cost to replace the existing heating and cooling equipment in the residential cottages and smaller campus buildings is estimated to be $1,999,000.

The larger academic, administrative, and recreational buildings can be serviced by 15-ton water-to-air geothermal RTU heat pumps which will connect to the existing HVAC systems in each of the buildings. Hours of labor and added piping, wiring, and materials for the larger buildings are more difficult to estimate than the cottages or smaller buildings. For that reason, the estimated cost of the larger buildings is estimated based on a dollars per square foot estimate. The costs to replace the heating and cooling systems in the larger buildings with geothermal RTUs is estimated to be $5,571,370 under a $35/ft^2 cost estimate.

The largest costs associated with the proposed one-pipe geothermal system are the cost of drilling the vertical bores, connecting the network of piping in each GLHE, and connecting each building to the ambient loop. Each vertical geothermal bore will reach a depth of 500 feet. The estimated cost to drill the borehole, install a U-Bend and grout the borehole is $35 per linear foot. Therefore, the cost of this process for each 500 foot borehole is approximately $17,500. After the U-Bends have been installed, they are connected through lateral piping in circuits which are then connected to the vault. The lateral piping connecting the circuits is expected to cost approximately $20 per linear foot. The cost of connecting each building to the ambient loop is estimated to be between $50 and $60 per linear foot. Additional costs include construction of the vaults at each GLHE, flushing out the circuits of debris, and restoring the greenspaces. Table 7 summarizes the total estimated cost of constructing the GLHEs in each zone and connecting the buildings in each zone to the ambient loop. The total cost of this construction throughout the campus is estimated to be $7.4 million.

Table 7. Tally of Borefield Construction Costs by Zone

Borefield Construction & Building Connection to Ambient Loop Cost	
Zone 1	$ 1,777,000
Zone 2	$ 2,650,000
Zone 3	$ 815,000
Zone 4	$ 403,000
Zone 5	$ 1,305,000
Zone 6	$ 170,000
Zone 7	$ 280,000

The next cost to consider is the cost of installing the ambient loop around the campus. After measuring the distances in the proposed system, the total length of necessary piping was determined to be approximately 12,150 feet. The ambient loop will use a 10-inch, high-density polyethylene (HDPE) pipe. The material cost of the pipe is estimated to be approximately $130 per linear foot for an estimated cost of $1,579,630. The next largest cost incurred by the ambient loop construction is from the excavation process which is necessary to bury the ambient loop around the campus. After volume calculations were done, it was determined that approximately 17,500 cubic yards of material must be excavated and stored. Once the ambient loop is installed, the material that was excavated will be used to back fill the volume that was removed. Because the ambient loop will take up volume that used to contain soil, only 11,500 cubic yards of material will be used as back fill. The remaining 6,000 cubic yards of material removed would need to be hauled offsite for disposal. The cost of the excavation, backfill, and hauling process is estimated to be $1,060,100. Multiple other costs such as erosion control, cutting through pavement, valve installation, and site restoration add up to around another $1,000,000. The total estimated cost for the construction of the ambient loop adds up to approximately $3,600,000.

Table 8 provides a summary of the upfront project costs required to construct the proposed community geothermal system at The Children's Village. The costs described to this point account for the total upfront capital expenditure hard costs for construction. However, in the construction process, there are also associated soft costs. Soft costs include legal fees, permitting fees, insurance coverage, taxes, and other business costs. For the feasibility study, it is assumed that soft costs and contingency costs would add 25% to the associated hard costs. The soft cost addition was only applied to the GLHE and ambient loop construction because those renovations were substantial enough to warrant soft costs, and the estimates were detailed enough to outline each part of the construction process. The soft costs are not expected to have an impact on installing the smaller heat pump units in the cottages because the work is less intensive and will be repeated regularly. The $35/ft^2 cost estimate for the larger campus buildings doesn't have the detail for material, labor, and renovation costs, so it is assumed soft costs are included in that estimate. Therefore, the amount to budget for system construction would be a total of approximately $21,320,370.

Table 8: Summary of Project Upfront Costs

Cost Description	Cost
Two geothermal test bores	$ 70,000
Estimated architectural & engineering design costs	$ 2,000,000
Site survey	$ 100,000
Estimated Pre-construction costs	**$2,170,000**
Heat pump installation: Residential and small buildings	**$ 1,999,000**
Heat pump installation: Larger commercial buildings	**$ 5,571,370**

Energy costs to operate the proposed system are determined using the historical electricity bills of The Children's Village. The electricity for all buildings is combined into one bill for the entire campus. Electricity costs are split between demand charges and supply charges. Demand charges vary depending on the time of year and time of day. Primary demand charges are incurred for peak electricity usage between 8:00 a.m. and 10:00 p.m. with higher rates during the summer months. Primary demand charges from June through September cost $21.35/kW and $13.80 between October and May. An additional demand charge of $9.90 is incurred if peak electricity usage from June through September occurs between 8:00 a.m. and 6:00 p.m. Historically, summer peak electricity usage at

The Children's Village incurs both primary and G&T demand charges for a total cost of $31.25 for usage between 8:00am-6:00pm. Supply charges remain constant throughout the year and add up to approximately $0.10/kWh.

Table 9 provides an analysis of the future electricity bills that are expected after construction of the geothermal system is complete. The Geothermal Usage columns represents the peak electric demand and the total electric consumption necessary to operate the geothermal system. These values are derived from the hourly electricity profile of the proposed system. Baseload Usage is the estimated electricity usage on campus that is unrelated to the HVAC systems. When the existing system is converted to geothermal, peak electricity during the summer will decrease and peak electricity during the winter will increase compared to the current electricity usage of the campus. The projected annual electricity costs under the proposed system are estimated to be $786,000 per year for approximately 5,500,000 kWh of annual electricity usage.

Table 9. Future Campus Electricity Costs with Proposed Geothermal System

Campus Electricity Cost Estimate—Proposed Geothermal System							
	Geothermal Usage		Baseload Usage		Total Peak	Demand Charge	Consumption Charge
Month	Peak kW	Energy (kWh)	Energy (kWh)	Peak kW	kW	$/kW	$/kWh
Jan	524	181,992	384,373	682	1,206	$ 16,638.90	$ 56,404.37
Feb	593	155,184	367,127	721	1,314	$ 18,130.70	$ 52,016.87
Mar	478	116,886	387,565	688	1,165	$ 16,083.16	$ 50,238.28
Apr	231	67,403	322,241	591	822	$ 11,342.05	$ 38,804.62
May	230	64,539	273,725	552	782	$ 10,785.34	$ 33,687.71
Jun	361	97,646	286,959	526	887	$ 27,729.00	$ 38,302.78
Jul	456	147,674	291,299	517	973	$ 30,412.54	$ 43,717.35
Aug	503	199,966	313,304	556	1,089	$ 33,079.23	$ 51,116.55
Sep	481	141,148	359,462	659	1,140	$ 35,637.16	$ 49,855.77
Oct	303	72,351	302,703	537	840	$ 11,598.34	$ 37,351.60
Nov	265	86,191	375,576	689	945	$ 13,158.40	$ 45,987.36
Dec	425	143,785	353,264	627	1,052	$ 14,513.24	$ 49,501.19
Total		**1,474,766**	**4,017,598**			**$ 239,108.05**	**$ 546,984.45**
Combined Total		**5,492,364**				**$ 786,092.53**	

Currently, The Children's Village pays approximately $710,000 per year in electricity bills. These bills cover the operation of the existing HVAC equipment plus non-HVAC baseload electricity usage. Implementing the proposed geothermal system will increase annual electricity bills by approximately

$76,000. However, the new geothermal system will eliminate the need for heating fuel oil. The buildings on the Children's Village campus consume approximately 280,000 gallons of fuel oil per year at an estimated cost of $720,000 annually. In total, the net annual energy savings from implementing the geothermal system will save The Children's Village approximately $644,000 each year compared to keeping their existing equipment.

An added annual cost The Children's Village currently pays includes operation and maintenance costs. The Children's Village currently has a service contract for routine maintenances on most of the existing HVAC systems. The cost of this contract plus the cost of labor from in-house maintenance staff adds up to an annual campus maintenance cost around $650,000 per year. Under the new proposed geothermal system, maintenance costs are expected to decrease by 35%. Geothermal heat pumps generally have lower maintenance costs compared to conventional systems. Conventional combustion heating requires regular cleaning of impurities and regular tune-up and combustion analysis testing to ensure clean burning of fuels. Additionally, conventional AC systems locate condensers outside and exposed to the elements, which increases maintenance requirements and shortens life spans. The new geothermal equipment is free of both concerns because there is no combustion taking place, and the heat pumps are placed in the basement, not exposed to the outside elements. The new maintenance costs of the proposed system would be approximately $422, 500.

In the business-as-usual scenario where the geothermal system is not implemented, existing equipment will need to be replaced gradually over the next 25 years. A cost approximation of $\$15/\text{ft}^2$ of buildings is used to estimate the replacement costs. For the campus which has 448,000 square feet of building area, the total cost estimate for system replacements is $6.72 million dollars in nominal value over the next 25 years. A present value of $1,430,000 in equipment replacement costs are added for the geothermal system. The value is lower than the business-as-usual case which would have many more equipment replacements to replace the current aged equipment.

The following escalation parameters are used in the life-cycle cost analysis to increase annual costs from one year to the next. An inflation rate of 2.5% is used for maintenance costs. The electricity and fuel oil escalation rates are both 1.5%. The capital escalation rate of 4% is used for baseline equipment replacements. Table 10 shows how the annual costs increase overtime by comparing the annual cost for the first year of operation versus the 25th year under both systems. Using a discount rate of 5%, the present value of the proposed geothermal system and business-as-usual cases are compared in Table 11.

A 5% discount rate is a safe assumption for a long-term investment for a tax-exempt organization at current low-interest rates.

Table 10. First-Year versus Last-Year Comparison of Annual Costs

	Baseline Annual Costs				Geothermal Annual Cost	
	Fuel	Electric	Maintenance	Replacements	Electric	Maintenance
Year 1	$ 730,000	$ 730,000	$ 650,000	$ 270,000	$ 800,000	$ 422,500
Year 25	$ 1,040,000	$ 1,040,000	$ 1,175,000	$ 690,000	$ 1,150,000	$ 750,000

Table 11. 25-Year Life-Cycle Cost Comparison

	25-Year Present Value		Comparison	
Option:	Baseline System	Geothermal System	Dollar Difference	% Difference
Electric Utility Cost	$11,900,000	$12,960,000	+$1,060,000	+9%
Fuel Oil Utility Cost	$11,800,000	$0	$11,800,000	100.0%
Maintenance Costs	$11,770,000	$7,870,000	$3,900,000	33%
Upfront Construction Cost	$0	$23,320,370	+$23,320,370	+100%
25 Years of Replacement Costs of Equipment	$5,720,000	$1,430,000	$4,290,000	75%
25 Year Life-Cycle Cost	**$41,190,000**	**$45,580,370**	**+$4,390,370**	**+10.6%**

The total life-cycle cost of ownership between the proposed geothermal system is higher than the business-as-usual case over the next 25 years of operation. While the proposed geothermal system may have a 10.6% higher cost over the next 25 years, the energy and cost savings will continue after that time. These long-term considerations should be considered especially for an organization such as The Children's Village which has been in operation for more than 170 years. The ambient loop and heat exchangers will have a lifespan closer to or beyond 50 years and are a valuable long-term investment. The geothermal heat pump equipment will also last longer than conventional equipment and should have a lifespan of 25 years.

Two additional factors that have not yet been considered but would positively impact the finances of the proposed geothermal system are sustainability incentives and reductions in carbon emissions. Two incentive sources are available through the New York State Energy and Research and Development Authority (NYSERDA). The first is the grant funding through PON 4614 to study the viability of community heat pump systems such as this project. Through the rounds of funding, if awarded, the project could qualify for up to $500,000 in funding to cover design costs through the Category B award and $4,000,000 in funding to cover construction costs through the Category C award. This is dependent upon the available funding in the program at the time of application whether these funds could be awarded (New York State Energy Research and Development Authority n.d.). Additionally, NYSERDA oversees the Clean Heat Program which provides funding for the phase out of fossil fuels in New York State. The Children's Village campus located in Dobbs Ferry could receive some funding from the local utility company, Con Edison. On its electricity bills, The Children's Village pays the system benefit charge, which qualifies it to receive funding. The children's cottages, staff housing, and smaller campus buildings would qualify for the Category 3, Full Load Geothermal incentive at the Con Edison rate which is $5,000/10,000btu-hr capacity. Based on the number of 4-ton heat pumps in these buildings, the potential incentive could be as high as $2,424,000. The larger buildings on campus would be eligible for the Category 4 custom incentive which would pay $200/(Million British thermal units (mmbtu) energy reduction. Energy reduction is counted based on the fuel oil and electricity usage of the existing HVAC system minus the electricity usage of the proposed geothermal system. It is estimated that the larger campus buildings could qualify for approximately $2,000,000 based on anticipated energy savings from cutting fuel oil usage (NYS Clean Heat Program Manual n.d.). Overall, NYSERDA and Con Edison Clean Heat funded incentives could reduce the upfront costs of the proposed geothermal system by approximately $8,424,000.

An additional benefit of the proposed geothermal system includes the reduction in carbon emissions from cutting out on-site fossil fuel burning. Current operation of buildings at The Children's Village produces an estimated 2,867 metric tons of CO_2 equivalent ($MTCO_2e$) for fuel oil combustion and 1,184 $MTCO_2$ in electricity usage for a total of 4,051 $MTCO_2e$ each year. By comparison, if the campus were converted to the energy efficient all-electric geothermal system, emissions would be reduced to 1,310 $MTCO_2e$. Additionally, as New York State progresses toward its goal of Zero Emission Electricity by 2040, the emission of The Children's Village will decrease over time and would be zero in 2040 assuming New York reaches its goal (New York State n.d.). The New York State Department of Environmental Conservation explains the external costs created by carbon emissions and provides guidance on how to estimate that cost. In their estimation, the negative social cost of carbon is approximately $121/$MTCO_2e$ (New York State Department of Environmental Conservation n.d.). Including the social cost of carbon in the feasibility study shows the financial benefit to society the proposed geothermal system could offer. Additionally, if carbon pricing ever gets implemented in the State or national level there are potential costs that could be incurred if the existing fuel oil system is left in operation long-term. Emission estimates in the analysis assume 10.3 kilogram of equivalent carbon dioxide (kg/CO_2e) are emitted per gallon of fuel oil, and 252 kg

Corbon dioxide equivalent per Megawatt-hour (CO_2e/MWh) of current grid electricity. Table 12 provides an updated cost comparison analysis between the business-as-usual case and the proposed geothermal system after considering clean energy incentives and social cost of carbon.

Table 12. 25-year Life-Cycle Cost Comparison, Including Incentives and Cost of Carbon

	25-Year Present Value		Comparison	
Option:	**Baseline System**	**Geothermal System**	**Amount Difference**	**% Difference**
Electric Utility Cost	$11,900,000	$12,960,000	+$1,060,000	+9%
Fuel Oil Utility Cost	$11,800,000	$0	$11,800,000	100.0%
Maintenance Costs	$11,770,000	$7,870,000	$3,900,000	33%
Upfront Construction After Rebates & Grants	$0	$14,420,370	+$14,420,370	+100%
25 Years of Replacement Costs of Equipment	$5,720,000	$1,430,000	$4,290,000	75%
Social Cost of Carbon	$6,360,000	$1,200,000	$4,800,000	80%
25-Year Life-Cycle Cost	**$47,550,000**	**$37,880,370**	**$9,670,370**	**20.3%**
25-Year Carbon Emissions	**83,200 $MTCO_2e$**	**12,400 $MTCO_2e$**	**70,800 $MTCO_2e$**	**85%**

Both the sustainability incentives and social cost of carbon have a large positive effect on the financial viability of the geothermal system. With these benefits, the system is expected to break even with the costs of the baseline system in approximately 10 years and to have an estimated 25-year return on an investment of $9.67 million. Even if the social cost of carbon is excluded because it is not an actualized dollar amount, The Children's Village would be responsible for paying the NYSERDA incentives. The project would break even financially in approximately 10 years with a return on investment of $4.87 million compared to operation of the baseline system.

1.6 Lessons Learned

The feasibility study has determined that a community geothermal system is technically and financially feasible at The Children's Village campus. The site is an ideal candidate for a decentralized one-pipe ambient loop system due to the availability of open fields spread throughout the campus. There is more than enough space to accommodate the necessary 280 vertical geothermal bores to provide 100% of peak loads with ground heat exchangers as a thermal source. With cost sharing and rebate incentives, the buildout of the proposed community geothermal system is expected to break even in approximately 10 years compared to the business-as-usual case of operating the existing fuel oil heating equipment. The carbon reductions associated with the switch to geothermal can reduce annual emissions of the campus by approximately 32%. Additionally, since the proposed geothermal solution is an all-electric system, its associated carbon emissions will decrease as grid-supplied electricity phases out fossil-fuel generation. If the New York State achieves the full transition to zero emission electricity by 2040, then The Children's Village would be a zero-emission campus.

Additional clean energy solutions such as solar PV systems could also be implemented on the campus. With current PV system costs and the existing electricity rate structure, a PV system at The Children's Village could recoup upfront cost with annual energy savings in approximately 13.5 years. Battery storage systems can also be incorporated into the PV system to reduce monthly electricity bills and improve system resiliency. Given the high-demand charges during peak hours of the summer months, a battery storage system could supply electricity to the campus during hours of high-electricity demand and recharge during the night when cost of electricity is cheaper. The peak-shaving benefits are not expected to fully cover the cost of the battery storage system, but the battery could also provide system resiliency as an emergency backup supply to replace the existing diesel generators.

The next phase of the project will be the design study phase in which test bores will be drilled and thermal response tests will provide valuable information on the thermal properties of the geology on site. The information from these tests will be used to produce more accurate modeling of ground loop heat exchanger performance, so the final system can be correctly and optimally sized. Throughout the design process, detailed drawings and site plans will be generated and project viability will regularly be assessed. With more detailed information, the goal would be to convince a third-party company that the project is worth an upfront investment under terms that The Children's Village could accept.

The target audience of this study would be leadership teams that oversee a district of mixed-use buildings. Universities are a prime example of how lessons learned from the proposed community geothermal project at The Children's Village campus could translate to other campuses with diverse building uses and available greenspace for geothermal heat exchangers. Some important lessons to take from The Children's Village feasibility study include how to make the most of a campus layout such as how a one-pipe ambient loop can utilize the multiple open fields on campus to reduce the necessary upfront infrastructure. Also, finding ways to incorporate circuits within an ambient loop can help add system resilience and spread the construction process over a longer period of time in order to spread out the upfront cost to fund the system.

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