Techno-economic feasibility of utility-led networked geothermal systems for a new residential development

Kaushik Biswas, Rohit Jogineedi, GTI Energy
Morgan Hood, Vermont Gas Systems
Matt Mitchell, Saqib Javed, National Laboratory of the Rockies
Greg Estep, George Martin, LN Consulting

ABSTRACT

This study will describe the results of the technical and economic feasibility analysis of a community geothermal system for a new affordable housing development in Hinesburg, Vermont. Two geothermal systems were designed to meet 100% of the heating and cooling and domestic hot water (DHW) loads of the planned two-phase development. Energy and cost models compared the geothermal system using water-to-air heat pumps for space conditioning and water-to-water heat pumps for DHW with a baseline system using air source heat pumps and natural gas fired DHW. The results indicated that, while the geothermal systems have higher installed costs, they reduced energy usage by 45-48% and lowered life cycle costs by 10-37%.

Multiple utility-scale financial models were evaluated, based on several ownership models: 1) utility owning the geothermal system; 2) property developer owning the geothermal system; and 3) split ownership between utility and developer. The first and third models were not viable economically and the second model was not attractive to the developer. A fourth model, in which grant funding would cover 90% of the geothermal loop and equipment as part of a demonstration, with the ownership being transferred to the utility or developer at the end of the project, was also evaluated. A key benefit of the grant funding option is to demonstrate the benefits of a networked geothermal system, while partially removing the upfront cost barrier.

Introduction

Community geothermal systems, also called networked or district geothermal, utilize the earth's subsurface for heating and cooling multiple buildings through a shared underground distribution network. While geothermal systems have higher upfront costs than other heating, ventilation and air conditioning (HVAC) systems, their high efficiency, longer lifespans and lower maintenance requirements can reduce life-cycle costs (Dandelion Energy, 2020). This article describes the findings of a project to perform feasibility analysis and develop a complete engineering plan for a community geothermal system for a new affordable housing development in Hinesburg, Vermont. This work was funded by a grant award from the Office of Geothermal, U.S. Department of Energy (DOE). This study supplements the initial findings that were presented at the 2024 Summer Study (Biswas et al., 2024).

The Hinesburg geothermal system was designed to meet 100% of the heating and cooling loads and the DHW loads of the development. The feasibility work included energy models of the buildings for hourly load estimates, coupled with geothermal system sizing and a borehole plan. The work included physics-based simulations of the geothermal network, including the ground heat exchanger, connection piping, and building heat pumps. Network analysis investigated aspects of the thermal network design, such as piping arrangements, ground heat exchanger sizing, pumping requirements and costs. Finally, the project team developed a schematic design site layout and performed probable cost analysis for the geothermal system, including operational energy costs.

This project focused on a 77-unit new residential development, called the Windy Ridge development, in Hinesburg, VT. This development is planned to be built by Champlain Housing Trust (CHT) along with Sterling Homes and Habitat for Humanity. The residential development is planned to be a mix of townhomes, duplexes, and single-family units, with a significant fraction of the homes intended for households with less than the area median income. The Hinesburg or Windy Ridge development is planned in two phases, Phase 1 or South Meadow development and Phase 2 or North Meadow development. Figure 1 shows the planned Phase 1 and Phase 2 developments. Table 1 lists the different building types and square footage of each building type in the Phase 1 and Phase 2 developments.

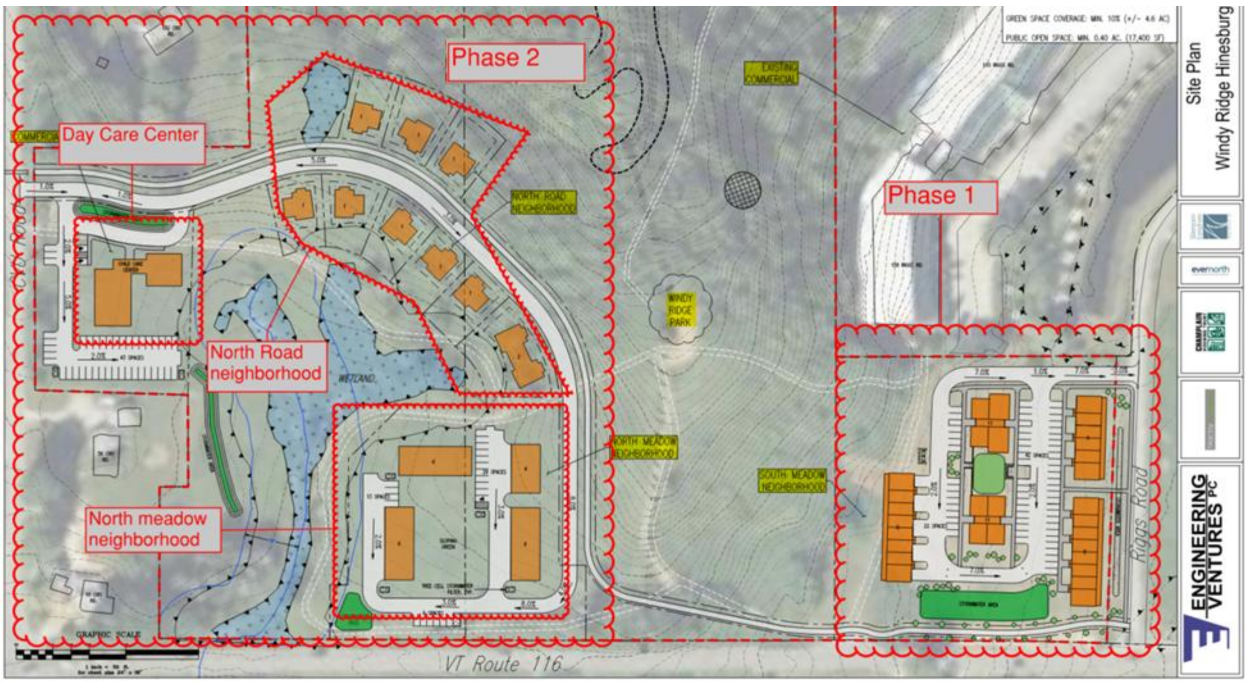

Figure 1. Hinesburg development with Phase 1 and Phase 2 details.

Table 1: Summary of Phase 1 and Phase 2 buildings.

Phase	Building	Square footage (ft²)
Phase 1 (South Meadow)	Apartment Building: 1-bedroom multifamily	9,660
	Apartment Building: mixed unit multifamily	11,255
	Townhouse building: 6 units	7,394
	Townhouse building: 8 units	9,639
	Townhouse building: 8 units (privately owned)	9,639
	Total Phase 1 Area	***47,589***
Phase 2 (North Meadow)	Three (3) six-unit buildings and one (1) four-unit building	38,884
	Ten single family homes	31,197
	Day care center	6,954
	Total Phase 2 Area	***77,035***

While community geothermal systems can benefit from diverse building types and load profiles, Vermont Gas Systems (VGS) chose to focus their initial efforts on residential or mixed-use new construction developments for several reasons. One key reason is the ordinances around natural gas in new construction projects, which dictate that: 1) natural gas cannot be used at all, 2) used with a carbon fee to the customer, or 3) 85% of the energy needs be met with renewable energy. Geothermal systems provide gas utilities with an alternative to natural gas. Another reason is simplicity. For new construction projects, community geothermal systems are expected to cost less and be easier to execute than retrofitting existing buildings and communities with geothermal systems, especially in the early stages of understanding how to implement community geothermal projects. The financial model of how to bill customers is also easier to develop when one is not relying on load diversity, for example, with a large source of waste heat contribution. Load diversity is certainly desirable for balancing the loads on the geothermal loop, but it adds complexity. A utility would need to be confident that a heat generating facility will remain in a given location and generate the same amount of waste heat for, ideally, the life of the system. A utility would also have to customize how to bill and compensate customers who are adding heat to and/or taking heat from the system. VGS' plan is to build knowledge and experience with new construction developments and ultimately be able to tackle future retrofit projects with greater load diversity.

Regarding the specific Hinesburg development, VGS chose this project because the developer, CHT, is seeking all-electric systems and a cost-effective energy solution for future residents. CHT has developed and maintains other buildings relying on air source heat pumps (ASHPs) and has found the maintenance to be more expensive than originally thought. Geothermal systems use less electricity than ASHPs and the cost of electricity to run a ground source heat pump (GSHP) is expected to be lower. However, a utility will need to charge customers for access to the geothermal loop to cover maintenance and as payback on the initial investment. In this model, VGS would own, operate, and maintain the geothermal loop much as it would traditional utility infrastructure, with customers paying a monthly access fee that helps cover ongoing maintenance, associated property taxes, administrative costs, and recovery of the utility's upfront investment, VGS's current goal is for the customer to be paying about the same to electrify with GSHPs as ASHPs. GSHPs have additional benefits related to the electric grid. Liu et al. (2023) noted that mass deployment of GSHPs can electrify the building sector without overburdening the US electric power system and using geothermal heat pumps to electrify space heating in buildings requires less electricity generation capacity than using ASHPs.

Comparative life cycle cost analyses (LCCA) were performed for baseline scenarios assuming ASHPs and the proposed community geothermal systems. The LCCA included the initial total installed costs, annual maintenance and equipment replacement costs, and operating energy costs. The LCCA indicated that geothermal systems, even with higher initial costs, can yield net savings over a 30-year lifespan.

Full Engineering Feasibility and Technical Design

The project team performed the technical feasibility and cost analyses of the proposed community geothermal system and compared the results to a baseline system consisting of ASHPs for space conditioning and natural gas fueled DHW. The geothermal system is designed to meet all space conditioning and DHW loads.

Energy Modeling

The feasibility work started with developing energy models of the planned buildings. The simulation program used for this project was Design Builder version 7.3, which is a graphical user interface for the calculation engine EnergyPlus (v9.4). EnergyPlus™ is a whole building energy simulation program that engineers, architects, and researchers use to model both energy consumption—for heating, cooling, ventilation, lighting, and plug and process loads—and water use in buildings. Energy models were created using architectural concept drawings of the buildings. For Phase 1, actual architectural drawings were available. For Phase 2 buildings, the exact floor plans were unknown and thus the project team used estimated floor plans, typically used by one of the partner developers (Sterling Homes).

Figure 2 shows model renderings of the Phase 1 and Phase 2 buildings. Table 2 lists the envelope and lighting assumptions that were used as inputs to the Phase 1 and Phase 2 energy models. The energy models used envelope assumptions from the Efficiency Vermont Certified Track and improved infiltration based on the High-Performance Track of the Multifamily New Construction & Major Rehabilitation Program Checklist (Efficiency Vermont, Partner Resources). This checklist includes program requirements that meet or exceed applicable Vermont Residential or Commercial Building Energy Codes.

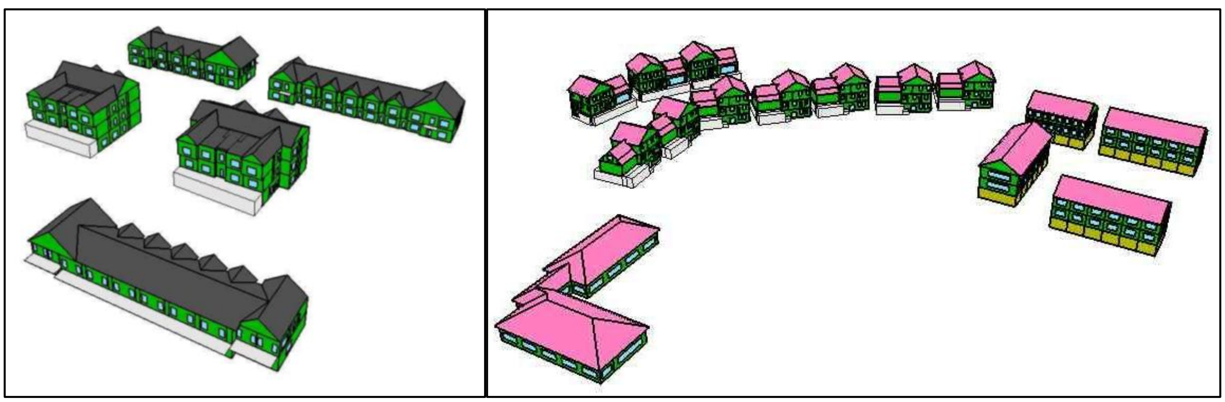

Figure 2. Model renderings of Phase 1 (left) and Phase 2 (right) buildings.

Table 2: Efficiency Vermont Multifamily new construction certified track building requirements.

Category	Requirements
Thermal shell / envelope	
Ceiling	R-60 attic and/or R-49 Slope; Air-sealed attic plane
Flat Roof	R-44 continuous above roof deck
Wall	R-25, sheathing joints taped/sealed.
Floor	R-38 or R-5 Continuous and R-30 Cavity
Foundation	R-20 Continuous
Slab Edge (on grade)	R-15 (per code)
Windows	U factor 0.28 or less
Air Leakage	≤0.20 cfm50/ft^2 (0.26 cfm75/ft^2) of total thermal boundary surface area

Lighting	
In-unit and Common area fixtures	ENERGY STAR or Design Lights Consortium qualified LED fixtures. Screw-based fixtures require ENERGY STAR qualified LED lamps.
Interior common area controls	Occupancy controls in all hallways, stairways, laundry rooms, etc. Day lighting control included in common areas with glazing.
Parking lot/Site	LED fixtures installed and lighting power density ≤0.11 watts/sq. ft for interior parking garage, no more than .025 watt/sq. ft for parking lots. LED fixtures listed on Design Lights Consortium qualified products list.

Proposed geothermal system: The proposed HVAC system utilizes a closed-loop ground heat exchanger to source heating and cooling from the ground to supply the zone level water source heat pumps (WSHP). Each residential unit has a zone energy recovery ventilator (ERV), while the building common areas have a central ERV. Neither ERV has heating or cooling coils, only heat recovery device. DHW is provided by a water-to-water heat pump (WWHP) that indirectly heats storage tanks. Vestibules are heated by electric radiators.

Baseline system: The baseline HVAC system for comparison includes zone ASHPs. These are assumed to be mini split systems or packaged terminal heat pumps. Each residential unit is ventilated by zone ERV, while the building common areas are ventilated by a central ERV. None of the ERV's have heating or cooling coils, only heat recovery devices. DHW is provided by direct fired natural gas water heaters. Vestibules are heated by electric radiators.

Table 3 lists the coefficient of performance (COP) and efficiencies of the proposed and baseline HVAC, ERVs, and DHW systems. The proposed geothermal system assumed heating with 50°F source water and cooling with 59°F source water. The Phase 2 daycare ERV includes a heat recovery device. The ERV is controlled to provide dehumidification and neutral supply air temperature; 73°F cooling and 55°F heating.

Table 3: Key HVAC and DHW equipment characteristics

Category	Proposed	Baseline
Heating COP	3.2	3
Cooling COP	7	3
Energy recovery effectiveness (%) ● Central ERV (sensible / latent) ● Zone ERV (sensible / latent)	Central – 80% / 65% Zone – 70% / 50%	Central – 80% / 65% Zone – 70% / 50%
DHW WWHP COP	4	-
Gas DHW heater efficiency (%)	-	90%

Additional significant modeling assumptions: The Phase 1 building geometries matched actual architectural drawings. Architectural drawings for the Phase 2 buildings were not available. Hence, for Phase 2 modeling, LN Consulting worked with the building footprints from the site plan in Figure 1 and made the following assumptions:

- Gable roofs with insulated attics. Insulated pitched roof.
  - 8-foot ceilings (9-foot floor to floor height) for the six and four-unit buildings
  - 9-foot ceilings (10-foot floor to floor height) for the single-family homes
- Window to wall ratio: 30%
- Partitions were included to account for thermal mass
- Daycare center was assumed to be single floor, slab on grade building with 12-foot floor to ceiling height and a pitched roof.

Schedules were used during the hourly simulations to account for occupancy changes, internal gains, ventilation, and HVAC temperature setpoints over the time of day, week, month, and year. The schedules were applied as fractions (0-1) to the design loads. The assumed heating and cooling setpoint and setback temperatures for the non-residential zones were: Heating - 70°F/60°F (setpoint/setback); Cooling - 75°F/80°F (setpoint/setback). The residential units were modeled without setback temperatures. The heating setpoint was 70°F and cooling setpoint was 75°F in the residential units.

Thermal Conductivity Testing

Because the geology and subsurface conditions are highly variable, and because these subsurface properties have a large impact on system performance and ultimately feasibility, it is common to perform thermal response tests (TRTs) to estimate the ground properties needed to support geothermal design work. To perform a TRT, a borehole is drilled and a borehole heat exchanger (BHE) is installed at the site. After BHE installation, water is circulated in the BHE, heated at a constant rate, and the temperature rise of the circulating water is measured and logged. TRTs are used to estimate the effective conductivity and heat capacity of the subsurface, the borehole resistance to heat transfer, and the undisturbed soil temperature. Additional details regarding TRT background and analysis process can be found in Spitler & Gehlin (2015).

The project team worked with a local contractor, Vermont Well and Pump, that performed two TRTs at the Phase 1 and Phase 2 sites during December 27-29, 2023, and June 10-12, 2024, respectively. Figure 3 shows a photo of the BHE installation during the December 2023 test. Data from the two TRTs are provided in Table 4.

Figure 3. Polyethene pipe being inserted in the borehole creating during construction of the borehole heat exchanger used for the thermal response test.

Table 4: Thermal response test data collected from Phase 1 and Phase 2 tests.

	Phase 1 (Dec 2023)	Phase 2 (Jun 2024)
Test Duration	49.4 hr.	49.2 hr.
Average Heat Input Rate	34.2 kBtu/hr. (10.0 kW)	34.8 kBtu/hr. (10.2 kW)
Average Heat Input Rate Per Borehole Foot	67.8 Btu/hr.-ft (19.9 W/ft)	69.0 Btu/hr.-ft (20.2 W/ft)
Circulation Flow Rate	9.8 gallons/minute	10.0 gallons/minute
Undisturbed Soil Temperature	48.8 – 49.3°F	48.3 – 49.0°F
Soil Thermal Diffusivity	1.77 ft^2/day	2.55 ft^2/day
Soil Conductivity	2.65 Btu/hr.-ft-°F (4.6 W/m-K)	3.81 Btu/hr.-ft-°F (6.6 W/m-K)

The TRT reports noted that the calculated soil diffusivity and conductivity values were too high and recommended a diffusivity of 1.41 ft^2/day and a conductivity of 2.10 Btu/hr.-ft-°F (3.6 W/m-K) for the geothermal network design purposes. A possible reason for the high calculated values is water flow across the test boreholes.

Geothermal Network Modeling

The building energy models estimated the space conditioning and DHW loads through heat pumps. The geothermal network loads were determined by aggregating the condenser loads of all heat pumps. Figure 4 shows the hourly load profiles of the combined geothermal space conditioning and DHW loads over a year of operation. Negative values indicate heating loads. Hours 0 through 8760 indicate operation from January 1 to December 31. The corresponding peak power and energy loads (in thermal MWh or MWh_{Th}) for the geothermal network are shown in Table 5. For Phase 1, the geothermal network loads were also calculated without the DHW loads, i.e., assuming that the geothermal system only serves the space heating and cooling loads, and these results are also listed in Table 5. It is noted that including the DHW load serves to help balance the geothermal loads, with a lower net ground heat injection load.

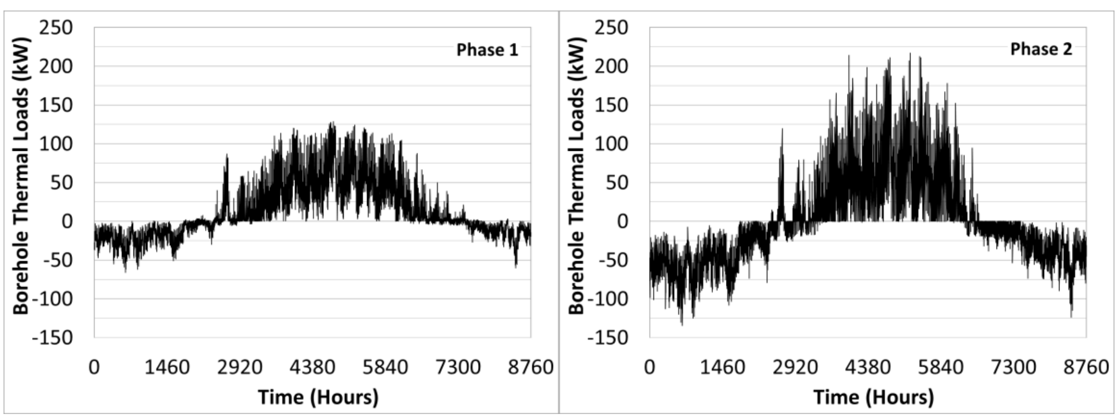

Figure 4. Network load profiles for Phase 1 (left) and Phase 2 (right) buildings.

Table 5: Geothermal network thermal loads with the effects of domestic hot water.

	Phase 1 Thermal Loads (without DHW)		Phase 1 Thermal Loads (with DHW)		Phase 2 Thermal Loads	
	Cooling	Heating	Cooling	Heating	Cooling	Heating

Peak (kW)	131	66	128	66	217	135
Total Energy Loads (MWh_{Th})	173	58	162	68	185	176
Net Ground Injection Load (MWh_{Th})	115		94		9	

Given the climate in Vermont, the calculated cooling loads being higher than heating loads might be contrary to expectations. There are two main possible reasons for this:

- Very well insulated and airtight building envelopes, which can dramatically reduce the heating loads and increase cooling load during times of high internal gains (i.e., thermal energy generated inside a building by occupants, electrical equipment, lighting, etc.). The internal gains were based on an assumed schedule (occupancy, plug loads, lighting, etc.) and served to reduce the heating loads and increase the cooling loads.
- Geothermal design loads represent building condenser loads. The loads are from a mixed water loop that is connected to every heat pump in the community. Each heat pump has a compressor, which generates heat during operation and this heat is always added to the heat pump loop, during heating and cooling modes. The added heat from the compressors can be 20-30% of the entire loop load at any given time, potentially increasing the cooling loads and decreasing the heating loads by that amount.

Simulations were performed to estimate the borehole system size to meet the geothermal loads. For both Phase 1 and Phase 2 designs, following the recommendation in the TRT reports, a lower soil conductivity of 2.0 Btu/hr.-ft-°F (3.5 W/m-K) was used. The first set of simulations were done assuming a 20-year lifespan to satisfy the Phase 1 network thermal loads while ensuring the heat pump entering fluid temperatures of at least 41°F (5°C) in the heating mode or at most 93°F (34°C) in the cooling mode. The temperatures were chosen to avoid freezing in winter and to keep the fluid temperature entering the heat pump below the ambient air temperature in summer.

Figure 5 shows the fluid temperatures entering and exiting the borehole field. It can be seen from the figure that the borehole field size was controlled by the minimum fluid temperature exiting the borehole field and entering the heat pump during the first year of operation. The fluid temperature exiting the borehole system remained well below the maximum allowed temperature of 93°F (34°C) over the simulation period.

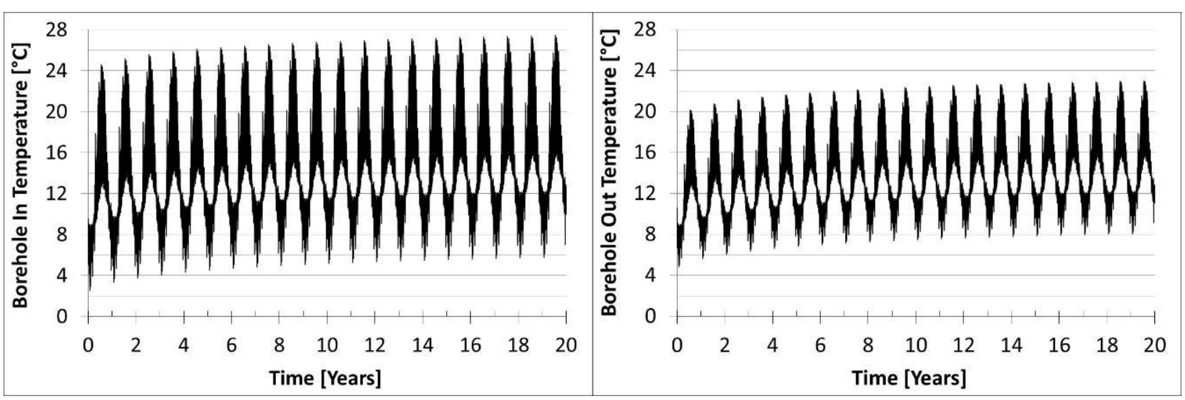

Figure 5. Phase 1 borehole entering and exiting fluid temperatures for the first set of simulations.

The second set of simulations was performed to determine the borehole field size to meet the maximum fluid temperature exiting the borehole field and entering the heat pump instead of meeting the minimum fluid temperature limit exiting the borehole field. These simulations were conducted without any control on the minimum fluid temperature exiting the borehole field. A field of sixteen boreholes, each 328.1 ft (100-m) deep, was found adequate to meet the network thermal loads. Figure 6 shows the modelled fluid temperatures entering and exiting the borehole field. The figure illustrates that in the first few years of operation, the fluid temperatures entering and exiting the borehole field could be below or close to freezing in the heating period. The figure also indicates that the maximum fluid temperature exiting the borehole field and entering the heat pump in the final year of operation would be just below the 93°F (34°C) design limit.

These simulations helped estimate the range of required borehole field size to meet the Phase 1 geothermal loads. The results suggested potential network configurations with and without antifreeze as the heat carrier fluid. Similar simulations were performed to estimate the size of the Phase 2 borehole system for 20-year lifespan. The results are shown in Figure 7. The final design had the fluid temperature exiting the borehole system just below 39°F (4°C) under peak winter loads and slightly above 68°F (20°C) under peak summer loads.

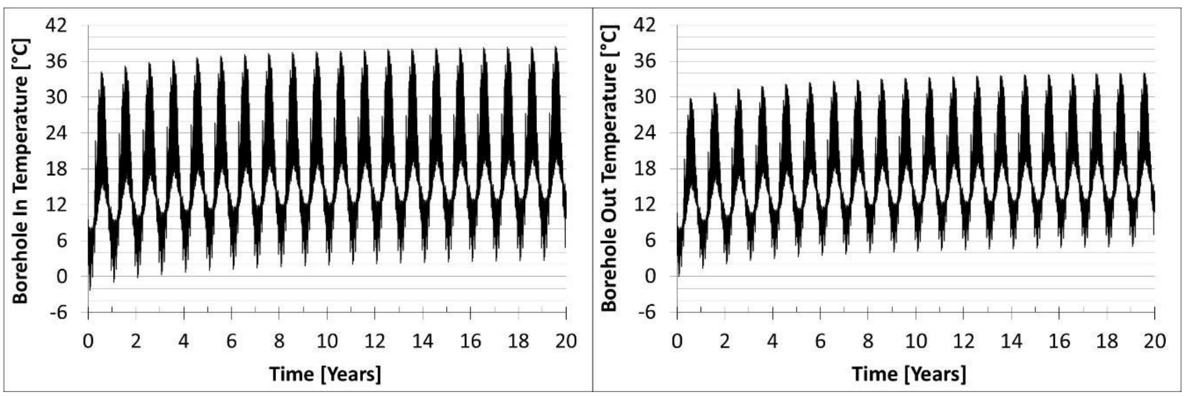

Figure 6. Phase 1 borehole entering and exiting fluid temperatures.

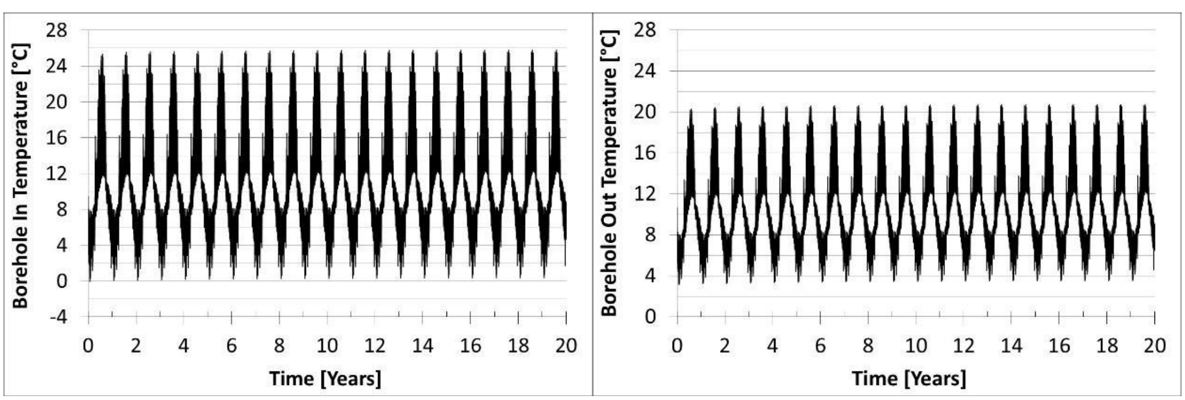

Figure 7. Final Phase 2 borehole entering and exiting fluid temperatures.

Figure 8 shows the geothermal network designs for the Phase 1 and Phase 2 buildings. The final Phase 1 borehole field was of fifteen (15) boreholes in a 3 x 5 configuration with 19.7

ft (6 m) spacing. Each borehole was 639.6 ft (195 m) deep and the total borehole length was 9,596.5 ft (2925 m). The Phase 2 borehole field consisted of twenty-four (24) boreholes in a 4 x 6 configuration with 16.4 ft (5 m) spacing. Each borehole was 590.6 ft (180 m) deep and the total borehole length was 14,173.2 ft (4320 m). Figure 8 also shows the approximate locations of the test boreholes for soil conductivity tests, marked as TRT1 and TRT2.

The geothermal network design split the Phase 1 and Phase 2 buildings into 9 and 11 sections, respectively. The buildings within each section are connected to two geothermal network loops, as shown in Figure 8. The figure annotates the characteristics of the pipes connecting the different sections to the geothermal network loops, including flow rates, pipe sizes (ID), and wall thicknesses (in the form of SDR or Standard Dimension Ratio, which is a measurement of a pipe's wall thickness relative to its outside diameter). The total estimated flows for pump design are 172 and 316 gallons per minute (gpm) for the Phase 1 and Phase 2 geothermal network loops.

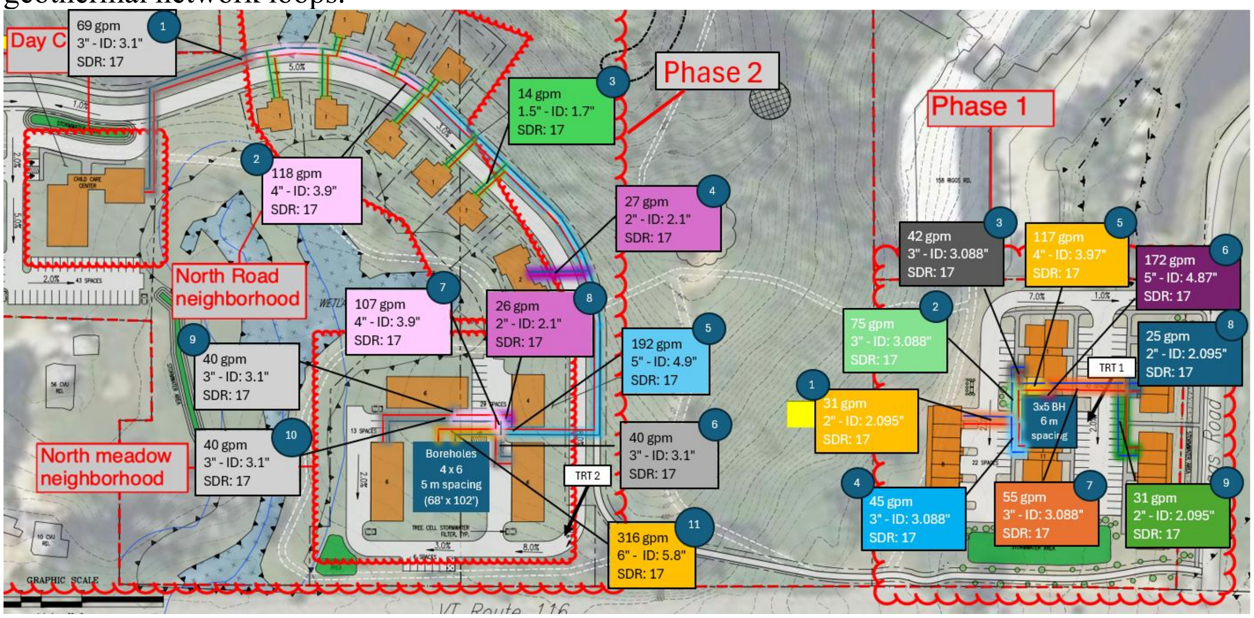

Figure 8. Phase 1 and Phase 2 borehole system design

Technical and Economic Assessment

This section describes the technical analyses related to energy usage, operating expenses (OpEx) and life cycle costs. Using the estimated cost data, VGS developed and evaluated multiple business and financial models.

Energy Use and Cost Analysis

The project team modeled the Phase 1 and Phase 2 buildings with the proposed geothermal and baseline HVAC systems to estimate the respective energy usage and OpEx. Table 6 compares the estimated energy use intensity (EUI) and energy usage of the baseline (ASHP + gas fired DHW) and geothermal systems. In Table 6, all end use categories except the baseline DHW used electricity. The baseline DHW usage is based on natural gas.

Table 6: Comparison of estimated annual energy use and percent savings with the geothermal systems.

Category	Phase 1			Phase 2		
	Baseline	Geothermal	% Savings	Baseline	Geothermal	% Savings
EUI (kBtu/ft^2)	32	25	22%	26	19	27%
Heating (kBtu)	224,472	123,670	45%	526,098	310,091	41%
Cooling (kBtu)	140,829	122,488	13%	167,293	141,235	16%
Fan (kBtu)	39,790	35,513	11%	53,251	43,155	19%
Pumps (kBtu)	31	34,131	-110000%	75	68,581	-91341%
DHW (kBtu)	275,482	41,065	85%	456,300	101,960	78%
Total HVAC + DHW (kBtu)	680,604	356,867	48%	1,203,016	665,022	45%

Following are some key takeaways from the end use energy comparison:

- The geothermal systems can reduce the HVAC + DHW energy use by 45-48%.
- The cooling savings of 13-16% are less than expected. The models assumed no natural ventilation and cooling is required in some interior units when outdoor temperatures are mild. Under mild outdoor conditions, ASHPs operate with improved COP. The geothermal loop is assumed to provide water to the heat pumps at 75°F during cooling. This temperature could be lowered at the cost of more pumping energy.
- The significantly higher pump energy usage for the geothermal systems is due to the central pumping stations associated with the community geothermal systems.
- The geothermal system saves 85% on DHW energy.

Table 7 compares the estimated OpEx of the baseline and geothermal systems. The residential electricity costs are the combined costs of private and rental units in Phase 1 and the multi-family and single-family units in Phase 2.

Table 7: Comparison of estimated OpEx and percent savings with the geothermal systems.

Category	**Phase 1**			**Phase 2**		
	Baseline	Geothermal	% Savings	Baseline	Geothermal	% Savings
Electricity (Phase 1 common areas / Phase 2 daycare)	$11,485	$8,800	23%	$17,825	$12,723	29%
Electricity (Phase 2 DHW pump)				$271		
Electricity (Geothermal pumps + DHW)		$5,933			$10,503	
Electricity (Residential)	$62,368	$57,466	8%	$79,008	$70,192	11%
Natural gas (DHW)	$4,218			$6,759		
Total	***$78,071***	***$72,200***	***8%***	***$103,863***	***$93,418***	***10%***

Life cycle cost analyses (LCCA) were performed using opinion of probable costs of the baseline and geothermal system components. These results are presented in Table 8. The following are the key assumptions used for the LCCA:

- 30-year expected life span; 2.5% inflation rate; 5% discount rate
- OpEx includes all meters and loads
- Initial costs only include HVAC and DHW
- Baseline ASHP and DHW: 12-year life, replaced 2.5 times over the 30-year life span
- Geothermal WSHP and WWHP (DHW): 20-year life, replaced 1.5 times over the 30-year life span

- Geothermal pumps: 20-year life, replaced 2 times over the 30-year life span
- The uniform series present worth (USPW) factor calculation assumed a discount rate of 5% over the 30-year life span

The LCCA results show that the proposed geothermal systems have significantly lower present worth after 30 years. The proposed geothermal systems have lower annual OpEx and maintenance costs and lower equipment replacement costs, but higher initial total installed costs. Over an assumed 30-year lifespan, even with the higher initial investments, the geothermal systems are estimated to save 37% and 10% for the Phase 1 and Phase 2 developments, respectively. There are significant savings in equipment replacement future costs. The geothermal system components have longer lifespans and need fewer replacements than the baseline system components, as noted above.

Table 8: Life cycle cost analysis results.

	Phase 1 / South Meadow				**Phase 2 / North Meadow**			
	Baseline		**Geothermal**		**Baseline**		**Geothermal**	
	Annual energy and water costs							
Electricity	$94,933		$89,062		$97,104		$93,418	
Natural gas	$4,218		-		$6,759		-	
Water	$16,862		$16,862		$26,239		$26,239	
	Significant equipment replacement costs (Constant 2.5% inflation)							
	Current	Future	Current	Future	Current	Future	Current	Future
ASHP	$1,087,000	$4,568,007	-	-	$939,000	$3,946,052	-	-
Gas DHW	$149,500	$628,259	-	-	$154,500	$649,271	-	-
WSHP	-	-	$446,000	$1,198,581	-	-	$607,000	$1,631,252
GSHP DHW	-	-	$155,000	$416,547	-	-	$272,500	$732,317
Pumps	-	-	$80,000	$283,669	-	-	$90,000	$319,128
	Annual maintenance and initial total installed costs							
Maintenance costs	$38,500		$24,000		$36,350		$28,750	
Installed costs	$2,272,864		$2,294,039		$2,508,629		$3,724,493	
	Life cycle costs							
One time cost	$7,469,130		$4,192,836		$7,103,952		$6,407,189	
Annual operating cost	$148,114		$125,924		$166,452		$148,407	
USPW (5%, 30 years)	15.37		15.37		15.37		15.37	
Present Worth	**$9,746,002**		**$6,128,598**		**$9,662,727**		**$8,688,574**	
% Present Worth Savings			**37%**				**10%**	

Utility-Scale Geothermal Business Model Concept

As more natural gas utilities explore community geothermal as a path for decarbonized growth, several different business models are expected to emerge based on a multitude of configurations and approaches (e.g. new construction vs. retrofits, networked systems vs. stand-alone single building systems) and regional variables (e.g. state and local policies, state incentives, regulatory jurisdiction and processes, climate commitments). How geothermal ultimately fits into a natural gas utility business model is likely to be determined in a multitude of ways depending on these factors.

In this project, VGS explored multiple ownership and financial models. In each scenario, VGS would have a role to assist in overcoming market barriers (e.g. first cost, comfort, and managing and servicing underground infrastructure). The financial modeling included assumptions based on applicable tax incentives and credits when this work was performed. Within each model VGS explored, the following criteria were considered:

- The monthly access fee VGS would charge residents using the loop should be comparable to what the residents would pay to utilize ASHPs (equipment costs, maintenance costs, and operating costs).
- VGS would receive its traditional return on investment for owning, operating, and maintaining thermal energy delivery infrastructure.

VGS considered several different financial models, which are described below.

VGS Owns the Entire Geothermal System

For VGS to take on full ownership of the entire system, including ground loops and inside equipment, in a manner that would be acceptable to shareholders and regulators, there need to be two financial components of the business model.

1. Ground Loop Model: VGS would employ a cost-recovery model for the ground loop mirroring how it recovers costs for capital investments today. A financial model would amortize the customer repayments, through a monthly loop "access fee," across an investment horizon aligned with the measure life of the ground loop (30-50 years).
2. Equipment Lease Model: The second component, required to recover utility investment in the inside equipment, would be an equipment lease model for a period not less than five years and not more than ten years. VGS is currently the only gas utility in the country with an existing equipment leasing program.

The advantages of this model are that it creates a turnkey solution for the customer and VGS could utilize tax incentives. The disadvantages are that the OpEx is not cost-competitive with alternative HVAC solutions (ASHPs) and the equipment lease is prohibitively expensive. In conclusion, without subsidization, this is currently not a viable pathway. Once loop access fee, equipment lease, and service and maintenance on both are incorporated into the utility financial model, the monthly charge per residential unit would total $365.83.

Developer/Owner Owns the Entire Geothermal System

The developer/owner would own the ground loops and inside equipment. But to overcome the property developer's professed discomfort with servicing and maintaining the ground loops, VGS would provide the servicing and maintenance through a Master Services Agreement.

The advantage is that with access to certain tax rebates, which could amount to a 30% direct pay rebate, the developer's overall CapEx and OpEx become lower than alternative HVAC solutions (i.e. ASHPs). The disadvantage is the lack of familiarity of developers with the service and maintenance of geothermal systems. Furthermore, developer ownership of the inside equipment complicates the relationship with the buyers of the units that are to be sold.

This could be a viable pathway if the property developer/owner changes their current stance and are comfortable taking on the responsibility of owning a community geothermal system and if they are willing to tolerate the complications of owning the in-home equipment (5 year minimum) in units they will sell. Without utility mark-up, the total cost of equipment, as well as a service plan on equipment and loop, would total a monthly payment of $59.66 per month which could be charged independently or incorporated into the rent for rental units.

Split-ownership Model Between VGS and Developer/Owner

This model consists of separate ownership of the two primary components. The ground loop would be owned and operated by VGS much like it owns and operates its gas distribution pipes. VGS would employ a cost-recovery model for the ground loop mirroring how it recovers costs for capital investments today. A financial model would amortize the property developer/owner repayments, through a monthly loop "access fee," across an investment horizon aligned with the measure life of the ground loop (30-50 years). The HVAC GSHP equipment would be paid for by the developer/owner, exactly as they would with any real estate development.

The resulting annual OpEx for the property developer and customers would look like:

VGS loop connection charge + electricity costs + equipment maintenance = total annual OpEx

This model aligns well with the core competencies of both the utility and developer/customer. It removes the uncertainty around care and maintenance of the ground loop (the utility has ownership responsibilities) and mirrors traditional utility and property owner relationships. However, this option could not utilize tax incentives and the resulting OpEx for the Developer/Customer is not cost-competitive compared to alternative HVAC solutions (ASHPs). The cost-recovery utility model revenue requirements make this not viable for the developer/owner, particularly since annual affordability (OpEx) is a prime objective.

Model with Grant Funding

This model assumed that continued DOE grant funding could be utilized to cover 90% of the cost of both the community geothermal loop and the in-unit GSHP equipment. During the grant period, VGS operates and maintains the external loop system. This model makes the following key assumptions:

- At the close of the grant period, VGS takes title of the external loop and continues in perpetuity to operate and maintain it.
- During the grant period, the developer/owner is responsible for maintaining the in-unit equipment; at the close of the grant period equipment ownership passes to the developer/owner.
- During and after the grant period, the developer/owner can opt to contract with VGS as the service and maintenance provider on all internal GSHP equipment.

This model overcomes property developer/owner market barrier of owning and maintaining below-ground community energy infrastructure (i.e. the external networked ground loop). It provides affordable housing residents with the benefits of a community geothermal system at a rate lower than what they would pay for HVAC alternatives like ASHPs. This approach can also provide qualitative and quantitative data on the performance and costs of a community geothermal system at minimal risk to affordable housing developers and residents and with minimal risk to VGS.

The disadvantages are that replicable and scalable business models utilizing third party (utility) ownership of the external ground loops are not immediately tested due to higher-than-expected project costs (e.g. use of subcontractors for drilling and ground loop installation). There are additional measurement and verification equipment and labor involved with the system monitoring and quantitative analysis. Increased developer/owner engagement efforts associated with the qualitative analysis.

In conclusion, the benefits made possible by a grant-supported community geothermal system can demonstrate to property developers, utilities, and municipalities the benefits of a networked geothermal system.

At the Windy Ridge Phase 1 development, VGS proposes to charge the customer for the monitoring, servicing, and maintenance of both the external and internal components of the community geothermal system. The charges are listed in Table 9.

Table 9: Comparison of estimated OpEx and percent savings with the geothermal systems.

	Total Annual Cost	**Monthly Charge per Unit**
External Loop Monitoring, Service and Maintenance	$3,500	$6.34 (per residential unit)
GSHP Service and Maintenance	$20,500	$20.83 (per GSHP being served)

This assumes that the developer will incorporate the monitoring, service, and maintenance costs into the monthly rent for the rental units. The residential units sold will pay VGS a monthly fee of $48.00, associated with two heat pumps per unit and the loop fee. The monitoring, service, and maintenance charges will be evaluated annually and future increases in monthly charges will reflect an increase in labor and materials costs.

Additional Considerations

With the assumption of the grant funding being included, VGS was able to model a utility loop access fee that fell within the range that CHT serving low to medium income residents deemed acceptable. However, this did not proceed from the Feasibility Stage to the Deployment Stage, where the DOE funding would have been available. Without the DOE funding, the access fee for the community geothermal system rose beyond the acceptable limit.

At that point, CHT and VGS explored an alternative path to geothermal, which was to develop independent loops, each serving a single multifamily building, i.e., not a networked or community geothermal system. This shift allowed VGS to provide the requested loop access fee while still enabling the development to use geothermal heating and cooling.

It is also worth noting that this development did not offer significant load diversity. If the development had included a broader mix of building types and uses, the value proposition for a networked geothermal system may have been stronger.

Summary

This article describes the findings of technical and economic feasibility, geothermal network design, and utility-scale business model development to support community geothermal systems. While the geothermal systems have higher installed costs compared to baseline ASHP and natural gas DHW system, they showed significant potential for energy savings, lower OpEx and maintenance costs, and lower life cycle costs. However, a networked geothermal project following the traditional gas utility financial model results in customers being charged a monthly rate that would not be amenable to affordable housing. Within the parameters of this feasibility study, cost subsidy, whether through tax incentives or grant funding, would be a key component for economic viability.

References

Biswas et al., 2024, Coalition For Community-Supported Affordable Geothermal Energy Systems (C2SAGES), 2024 ACEEE Summer Study on Energy Efficiency in Buildings

Dandelion Energy, March 2020, Geothermal Pros & Cons: Is Geothermal Right For You? https://dandelionenergy.com/geothermal-advantages-disadvantages

Efficiency Vermont, Partner Resources, Multifamily New Construction & Major Rehabilitation Program Checklist, https://www.efficiencyvermont.com/trade-partners/resources?cat=construction-renovation&type=residential

Spitler, J.D. and S.E.A. Gehlin. 2015. Thermal response testing for ground source heat pump systems - An historical review. Renewable and Sustainable Energy Reviews. 50:1125-1137. https://doi.org/10.1016/j.rser.2015.05.061.

Acknowledgement

The work presented here was funded by the Department of Energy under Award No. DE-EE0010669.

Disclaimer

This work was authored in part by the National Laboratory of the Rockies for the U.S. Department of Energy (DOE), operated under Contract No. DE-AC36-08GO28308. Funding provided by the Office of Geothermal, Hydrocarbons and Geothermal Energy Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.