Coalition For Community-Supported Affordable Geothermal Energy Systems (C2SAGES)

Kaushik Biswas, Eric Boria, Rohit Jogineedi, Ryan Kerr – GTI Energy
Morgan Hood – Vermont Gas Systems
Matt Mitchell, Shadi Abdel Haleem, Saqib Javed – National Renewable Energy Laboratory
George Martin, Greg Estep – LN Consulting

Abstract

This study describes the feasibility analysis for a community geothermal system for a new affordable housing development in Hinesburg, VT. The geothermal system is being designed to meet the heating and cooling and domestic hot water loads. The planned residential development is a mix of single-family, townhomes and duplexes units. Energy modeling of each building type was performed to generate hourly heating and cooling and hot water loads. The hourly loads were used as inputs to physics-based simulations and design of the geothermal network, which defined the preliminary specifications of a geothermal borehole field.

The C2SAGES project also involves significant community engagement activities. Community and local stakeholder input is a key component of the C2SAGES project by generating qualitative insights to inform design and deployment. The project team is engaging local community members, non-profit organizations, homebuilder associations, and disadvantaged community members to achieve this goal. Community engagement is being sought by frequent meetings and the feedback will be conveyed to the technical team members to inform the design and cost considerations of the geothermal system.

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 many other types of HVAC system, their high efficiency, longer lifespans and reduced need for maintenance can mean savings on energy and operating costs in the long run (Dandelion Energy, 2020). In 2023, the U.S. Department of Energy (DOE) selected eleven projects under phase one of the Community Geothermal Heating and Cooling Design and Deployment Funding Opportunity Announcement, to help communities design and deploy geothermal district heating and cooling systems, and create related workforce and training development plans (Geothermal Technologies Office, 2023).

The project described here is one of the eleven projects selected by the DOE Geothermal Technologies Office (GTO). The goals of this project are to perform feasibility analysis and develop a complete engineering and permitting plan for a community geothermal system for a new affordable housing development in Hinesburg, Vermont. The original proposal to GTO stated that the geothermal system will be designed to meet 50% of the heating and cooling needs of the community, with a stretch goal of 100%. As the project progressed, the team chose to design the geothermal system to meet the stretch goal of 100% of the heating and cooling loads, with the option of meeting the domestic hot water (DHW) loads as well. The residential development will be mix of townhomes, duplexes, and single-family units, with a significant

© 2024 ACEEE Summer Study on Energy Efficiency in Buildings

fraction of the homes intended for households with less than area median income. The feasibility analysis will include energy models of the buildings for hourly load estimates, coupled with geothermal system sizing and a borehole plan. The feasibility analysis will include physics-based simulations of the geothermal network, including the ground heat exchanger (GHE), connection piping, and building heat pumps. Network analysis will investigate aspects of the thermal network design, such as piping arrangements, ground heat exchanger sizing, pumping requirements and costs. Finally, the project team will develop a schematic design site layout and perform probable cost analysis for the geothermal system, including operational energy costs.

In late 2019, utility partner, Vermont Gas Systems (VGS) announced a commitment to reduce greenhouse gas emissions for its customers by 40% by 2030 and to be net zero by 2050. The climate commitment has three parts: expanding the successful energy efficiency program, changing what is in the pipeline, and providing new behind-the-meter or in-home services. VGS began exploring the potential for utility community geothermal in mid-2022. In late 2022, VGS co-founded the Utility Networked Geothermal Collaborative (UNGC). The UNGC consists of 24 gas utility members, all in various stages of exploring a gas utility geothermal offering and committed to sharing key learnings with one another. The role of a gas utility is to provide safe, affordable, and accessible thermal energy to customers. As gas utilities look to decrease their negative impact on the climate and diversify their offerings as demand for their products subsides, community geothermal is a natural fit. Gas utilities make long term investments in expensive infrastructure and spread the costs, over time, among many customers. Gas utilities own, operate and maintain pipeline infrastructure. A utility community geothermal service provides the gas utility and its employees with the potential to transition from being a fossil fuel provider to a decarbonized thermal service provider. With this project, VGS is exploring how to transition a workforce and build a community geothermal business model that will work for both the utility and for all customers.

Finally, this project aims to have a broad impact in addressing energy and environmental burdens by developing a community-informed geothermal system model that can be replicated in other communities. Community and local stakeholder input is a key component of the C2SAGES project by generating qualitative insights to inform design and deployment. C2SAGES intends to accomplish this through the formation of Community and Development Groups to bring relevant parties together on a frequent meeting cadence. The project coalition includes local community members, non-profit organizations, homebuilder associations, and disadvantaged communities. Community engagement is being sought by frequent meetings and the feedback is being conveyed to the technical team members to inform the design and cost considerations of the geothermal system. The aim of this task is to have a feedback loop of information between the community, development, and technical sides to identify needs and perceived barriers, which can be technical, workforce-related, cultural, convenience of use, financing, or other issues. The technical team can then assess which issues identified can be addressed by either design, investment, or deployment decisions and then communicate that back with the groups.

Planned Residential Development

The current project is focused on a 77-unit new residential development planned in Hinesburg, Vermont. While community geothermal systems can benefit from diverse building types and load profiles, VGS has chosen to focus 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 is that natural gas can either not be used at all, be used but with a carbon fee to the customer, or 85% of the energy needs be met with renewable energy. Geothermal systems provide gas utilities with an alternative to natural gas. Another reason is the simplicity, which means these new construction projects cost less and are easier to execute than retrofitting existing residential buildings, especially in the initial stages of implementing community geothermal. The financial model of how the customers will be billed 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, but it does add complexity. A utility would need to be confident that a heat generating facility will in a given location, generating 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 is looking to switch to all-electric systems and is seeking a cost-effective energy solution for future residents. Geothermal systems use less electricity than air source heat pumps and the cost of electricity to run a ground source heat pump is expected to be lower. However, a utility will charge customers for access to the geothermal loop to cover maintenance and as payback on investment. VGS's goal here is for the customer to be paying about the same to electrify with geothermal heat pumps as air source heat pumps. Geothermal systems have additional benefits related to impacts on the electric grid. Liu et al. (2023) noted that mass deployment of geothermal heat pumps 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 air source heat pumps.

The Hinesburg developer has developed and maintains other buildings relying on air source heat pumps and has found the maintenance to be more expensive than originally thought. This developer is interested in exploring an option of the gas utility owning, billing, and being responsible for the performance of a community geothermal loop. VGS also chose this developer because of the partners on the development include Habitat for Humanity, a low-income housing developer. This project provides an opportunity to learn, educate and get a lot of groups comfortable with community geothermal.

The Hinesburg development is planned in two phases, with the work being reported here focusing on Phase 1. The Phase 1 plan includes 44 units with the following breakdown:

- 1 Bedroom: 16 units
- 2 Bedroom: 4 units
- 3 Bedroom: 2 units
- 2 Bed Town Houses: 10 units
- 3 Bed Town Houses: 4 units
- 2 Bed Town Houses with Garage: 6 units
- 3 Bed Town Houses with Garage: 2 units

Figure 1 shows a schematic of the Phase 1 development plan. As described in the following section, a thermal response test (TRT) was performed at the site to estimate the soil properties. The approximate location of the borehole for the TRT is also shown in Figure 1.

© 2024 ACEEE Summer Study on Energy Efficiency in Buildings

Figure 1. Phase 1 development plan; "X" marks the approximate location of the thermal response test borehole.

Plans for Phase 2 of the development are still being developed. The initial Phase 2 plan includes a child-care center, which might provide some load diversity.

Feasibility Analysis

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 a TRT at the site to estimate the properties needed to support 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. After analysis of the data, 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).

A TRT was performed at the Hinesburg site from December 27-29, 2023, and picture of BHE construction is shown in Figure 2. Data from the TRT are provided in Table 1.

© 2024 ACEEE Summer Study on Energy Efficiency in Buildings

Figure 2. Polyethene pipe being inserted in the borehole creating during construction of the borehole heat exchanger used for the thermal response test.

Table 1: Thermal response test data collected from Hinesburg test, December 27-29, 2023.

Test Duration	49.4 hr.
Average Heat Input Rate	10,025 W
Average Heat Input Rate Per Borehole Foot	19.9 W
Circulation Flow Rate	9.8 gpm
Undisturbed Soil Temperature	49°F
Soil Thermal Diffusivity	1.4 ft^2/day
Soil Conductivity	2.1 BTU/hr.-ft-°F

Building Energy Modeling

Energy models for the buildings in the community were created using the building energy modeling (BEM) software, Design Builder, Version 7, which uses EnergyPlus, Version 23.1. 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. Table 2 lists the key envelope or thermal shell requirements based on the Efficiency Vermont Multifamily new construction certified track. These requirements are similar to the 2021 International Energy Conservation Code requirements.

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

Envelope Component	Requirements
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	Maximum of 0.20 cfm50/ft^2 (0.26 cfm75/ft^2) of total thermal boundary surface area

Spaces were modeled to be conditioned with water-to-air heat pumps, which were all connected to a common condenser loop whose temperature was being moderated by simulated district energy objects. By modeling the buildings in this manner, the geothermal network loads could be determined by computing the energy demand from the district energy objects. Figure 3 shows a three-dimensional rendering of the building models for the community.

After initial model creation, the models were extended by adding DHW supplied by the network geothermal system to study the effect DHW supplied by the system would have on overall system design.

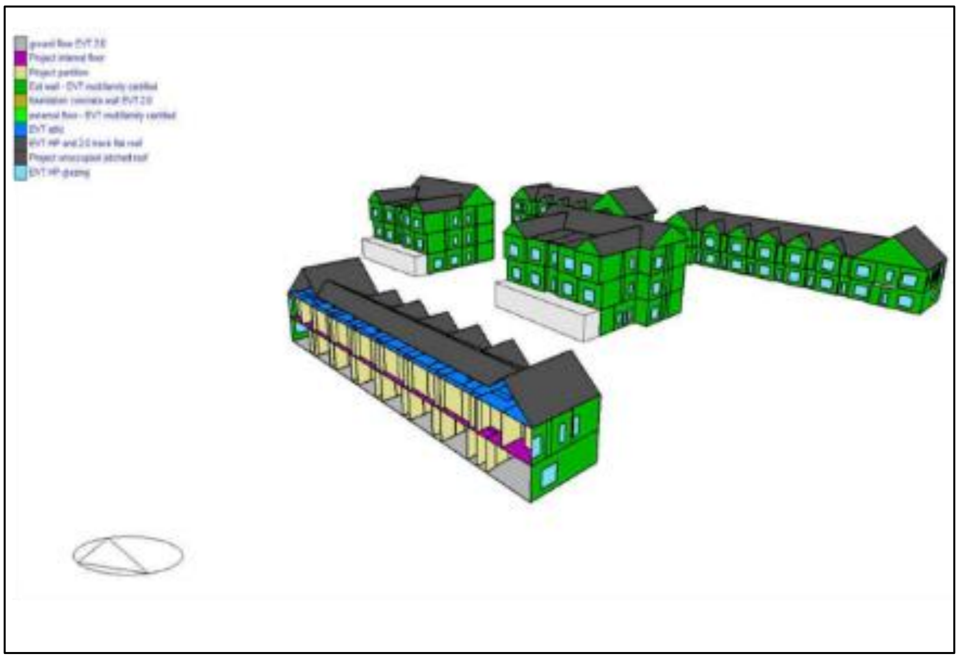

Figure 3. Three-dimensional rendering of the building energy models used for the community.

Geothermal Network Modeling

As noted briefly in the previous section, the building energy models estimated the space heating, cooling, and DHW loads through heat pumps, and the geothermal network loads were determined by aggregating the condenser loads of all heat pump models. Hourly load profiles of the geothermal network loads over a year of operation shown in Figure 4. The left plot shows the geothermal network loads when only space heating and cooling are considered, without the DHW loads. The right plot shows the network loads that include space heating and cooling and DHW. Negative values indicate heating loads. Hours 0 through 8760 indicate operation from January 1 to December 31.

The peak power and energy loads (in thermal MWh or MWh_{Th}) for the geothermal network with and without the effects of DHW are shown in Table 3. The values listed in Table 3 were calculated from the hourly loads shown in Figure 4. It is noted that including the DHW load serves to help balance the geothermal loads, with a lower net ground heat injection load.

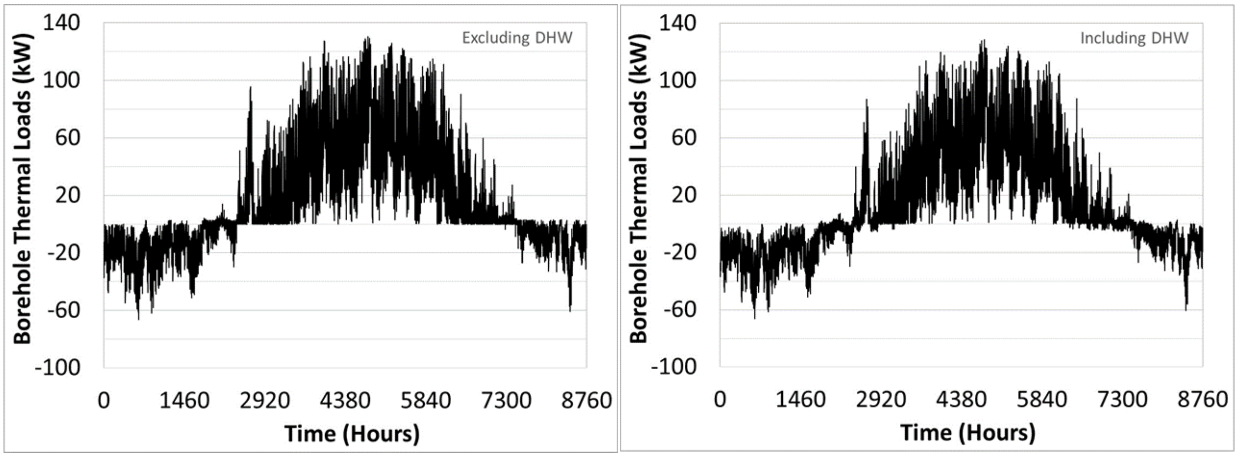

Figure 4. Network load profiles for configuration excluding (Left plot) and including (Right plot) the effect of loads from the domestic hot water system.

Table 3: Geothermal network thermal loads without, and with the effects of domestic hot water.

	Thermal Loads w/o DHW		Thermal Loads with DHW	
	Cooling	Heating	Cooling	Heating
Peak (kW)	131	66	128	66
Total Energy Loads (MWh_{Th})	173	58	162	68
Net Ground Injection Load (MWh_{Th})	115		94	

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

1) The building envelopes were assumed to be very well insulated and airtight. This can dramatically reduce the heating loads and increase cooling load during times of high internal gains. The internal gains were based on an assumed schedule (occupancy, plug loads, lighting, kitchen, laundry, etc.) and serve to reduce the heating loads and increase the cooling loads.
2) Geothermal design loads represent building condenser loads. The loads are from a mixed water loop, i.e., the heat pump 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.

It is noted that the aforementioned reasons are somewhat speculative. To definitively determine the reasons for the cooling loads being higher, extensive parametric modeling will be needed, to systematically vary the envelope specifications as well as the occupancy and internal

© 2024 ACEEE Summer Study on Energy Efficiency in Buildings

load schedules to determine at what point the cooling loads become dominant. Such parametric modeling is not within the scope of this project. The scope of the hourly load calculations was limited to the design specifications of the planned buildings.

A series of simulations were performed to estimate the size of the borehole system to meet the network thermal loads. The first set of simulations were carried out to dimension the borehole system for a lifespan of 20 years to satisfy the network thermal loads while ensuring the heat pump entering fluid temperatures of at least 5°C in the heating mode or at most 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. The resulting borehole field was of sixteen boreholes, each 180-m (590.6 ft) deep. 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 34°C over the entire simulation period.

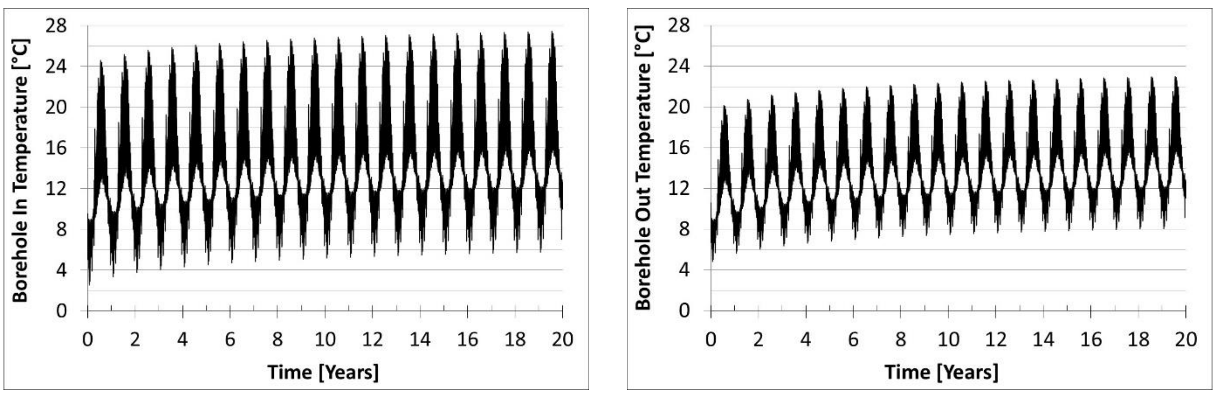

Figure 5. Borehole entering and exiting fluid temperatures for the first set of simulations.

The second set of simulations was performed to determine the borehole field size that would meet the condition of 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 100-m (328.1 ft) 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 34°C design limit.

© 2024 ACEEE Summer Study on Energy Efficiency in Buildings

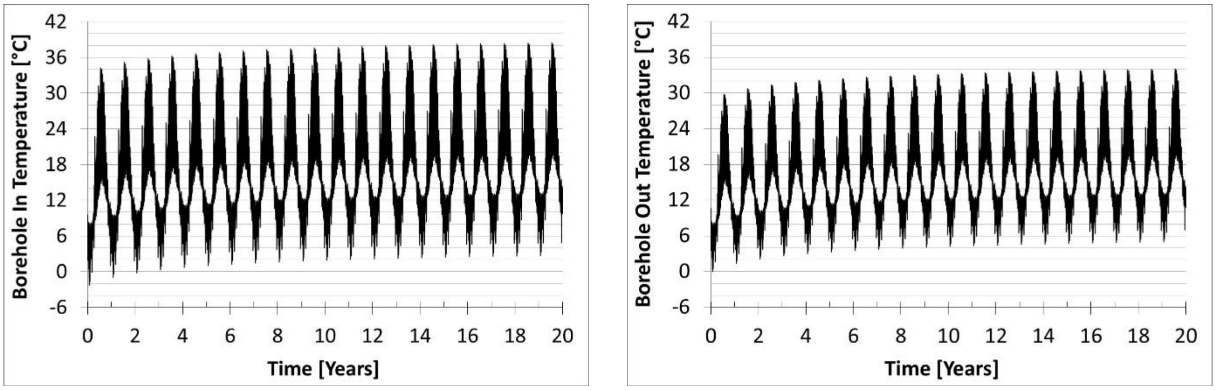

Figure 6. Borehole entering and exiting fluid temperatures.

The two sets of simulations provided indications as to the range of sizes needed for the borehole field to meet the network thermal loads. The simulation results suggested potential network configurations with and without antifreeze as the heat carrier fluid. The alternate thermal network configurations are currently being modelled in Modelica in detail and will be further studied in terms of techno-economic considerations.

Community Engagement and Benefits

In the initial stages, the project team has engaged several stakeholders through group discussions and semi-structured interviews. Some key community stakeholders included representatives from the Champlain Housing Trust (the community developer), Habitat for Humanity, Middlebury College, Energy Action Network, VEIC, Hinesburg Town Planners and Central Vermont Regional Planning Commission. The project team also held an interview with a member of Salas O’Brien, an engineering and technical services firm with geothermal expertise.

The community engagement discussions delved into topics including the opportunities for and challenges with geothermal and what is needed for geothermal projects to succeed. An initial community group (CG) meeting was held to generate preliminary community stakeholder input on priorities, concerns, and perspectives on the feasibility of geothermal projects. The initial feedback noted benefits of geothermal to include lower upfront infrastructure for each home/building with a community geothermal network, lowest operating expense of any electrical HVAC systems due high coefficient of performance, and ability to decarbonize regions using high-carbon fossil fuels without access to natural gas. The challenges mentioned by attendees included high first costs, lack of awareness and resources (workforce and equipment), and a perception that the technology is new or untested. Other shortcomings noted were the lack of “success stories” and the inability to “see” the operation of a geothermal system. Lastly, the attendees noted the need for funding from federal, state and utility sources, workforce development, peer reviews of the geothermal design and increased awareness among stakeholders as key factors for success. Most of the challenges discussed are in line with information available from other developing markets (Abugabbara et al., 2023).

A follow-on CG meeting emphasized the need for effective messaging to show how geothermal can benefit people across all income levels, ability of geothermal to be paired with renewable energy, and benefits over air source heat pumps (no secondary heating needed in cold climates with geothermal). One recommendation was to include on-site renewable energy generation and storage as part of the model.

During the call with Salas O'Brien, the project team sought their input on design considerations as well as experience with barriers and potential solutions to those barriers. Based on the feedback, a key concern that needs to be addressed is related to environmental impacts, for example, does the geothermal design include a closed or open water loop as well as regulations related to aquifers. Additional concerns are related to soil erosion, noise during construction and surface disturbance (for example, displacement of parking lots). The Salas O'Brien representative noted facing lot of resistance from residential builders and emphasized the need for early stakeholder involvement. On the technical side, the benefit of including buildings with diverse load profiles in a community geothermal design was noted (vs. buildings of similar types). It was also noted that it might be more cost-effective to design a geothermal system to meet a portion of the loads (80%, for example) and use backup sources for the remaining loads. Lastly, workforce development was highlighted as one of the major needs for geothermal systems to be successful.

Summary and Future Work

This project is still in the relatively early stages. The initial energy and geothermal network modeling of the 44-unit, phase 1 development indicated that a borehole field of sixteen boreholes could satisfy the heating, cooling and DHW loads. With adequate borehole depth, the fluid temperatures can be maintained within a certain range to avoid freezing in winter and to keep the fluid temperature entering the heat pump below the ambient air temperature in summer. The next steps in the technical work include finalizing the geothermal network model and performing a detailed cost analysis of the community geothermal system. The cost analysis will include two additional scenarios for comparison: 1) air source heat pump for cooling and natural gas for heating and DHW, and 2) all-electric scenario with air source heat pumps.

The project team is in discussions with the developer to gather information regarding the Phase 2 development plan, to perform the technical feasibility and cost analysis. A second thermal response test at the Phase 2 site is also being planned.

On the Community Engagement side, the project team will continue engaging with and gathering feedback from all relevant stakeholders. The Community Engagement plan includes two in-person meetings in or around Hinesburg. In addition, VGS will create workforce development and business model plans. As noted earlier, VGS began exploring the potential for utility community geothermal in mid-2022 as part of its commitment to reduce greenhouse gas emissions for its customers. A utility community geothermal service provides the gas utility and its employees with the potential to transition from being a fossil fuel provider to a decarbonized thermal service provider. With this project, VGS is exploring how to transition a workforce and build a community geothermal business model that will work for both the utility and for all customers. The workforce development plan will identify the skills and certifications needed to install, maintain, and repair geothermal systems, and building partnerships with local educational institutions and relevant organizations to develop the knowledge base for geothermal work. The aim is to develop a skilled and ready workforce in communities and develop local workforce capabilities. The business model plan will describe the proposed model for implementation of community geothermal, including "energy as a service" package.

References

Abugabbara, M., Gehlin, S., Lindhe, J., Axell, M., Holm, D., Johansson, H., ... & Javed, S. 2023. *How to develop fifth-generation district heating and cooling in Sweden? Application review and best practices proposed by middle agents*. Energy Reports, 9, 4971-4983. https://doi.org/10.1016/j.egyr.2023.04.048.

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

Geothermal Technologies Office (GTO), 2023, Community Geothermal Heating and Cooling Design and Deployment, https://www.energy.gov/eere/geothermal/community-geothermal-heating-and-cooling-design-and-deployment

Liu, Xiaobing, Ho, Jonathan, Winick, Jeff, Porse, Sean, Lian, Jamie, Wang, Xiaofei, Liu, Weijia, Malhotra, Mini, Li, Yanfei, and Anand, Jyothis. Grid Cost and Total Emissions Reductions Through Mass Deployment of Geothermal Heat Pumps for Building Heating and Cooling Electrification in the United States. United States: N. p., 2023. Web. doi:10.2172/2224191

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.

Acknowledgements

The work presented here is funded by the Department of Energy's Office of Energy Efficiency and Renewable Energy under Award No. DE-EE0010669.