# Pile Integrated Geo-Exchange System

Innovia GEO Corp.

Date (2023-10-26)

*Disclaimer: This project is supported by the financial contribution of the Independent Electricity System Operator (IESO), through its Conservation Fund. However, the views, opinions and learnings expressed in this report are solely those of Innovia GEO Corp.*

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# Executive Summary

A demonstration system integrating geo-exchange functionality into steel foundation piles was installed at the service building of the Eby Rush Transformer Station in Waterloo, Ontario. The Eby Rush Transformer Station is owned and operated by Enova Power (formerly Waterloo North Hydro Inc.). The system consists of a conventional deep geo-exchange ground loop as well as a geo-exchange integrated pile array to enable the side-by-side comparison of the two systems. Testing conducted during the measurement and verification program has shown that the system is able to provide efficient space heating and cooling to the building utilizing a geothermal heat pump. Comparative testing with the existing deep conventional geo-exchange ground loop installed at the facility has shown that the substantially shallow steel pile system is able to provide comparable supply temperatures to the heat pump. Test results also indicate the potential of the large working fluid volume of the steel pile systems to be utilized in active control strategies to optimize the performance of a system.

Thermodynamic models were validated using data collected during testing enabling the simulation of a system servicing a detached single-family home located in Southwestern Ontario. A comparative analysis was then conducted comparing the performance of the system against a conventional natural gas furnace and split air conditioner system and a cold climate air-source heat pump system. The comparative analysis found that the geo-exchange integrated steel pile system was the most efficient, lowest emitting, and lowest cost system. Additional analysis comparing the hourly electrical load profiles of the geo-exchange integrated steel pile system and the air-source heat pump system show the geo-exchange system to have a more stable electrical load profile throughout the year and smaller peak loads during both peak heating and peak cooling conditions.

# Introduction and Goal

The goal of this project is to advance clean and energy efficient geo-exchange HVAC systems by successfully demonstrating an innovative system which integrates geo-exchange capability into steel foundation piles, thereby significantly reducing the costs and effort to implement Geo-Exchange systems into buildings.

## Background

Space and water heating accounts for 80% of the energy demand in the residential sector and 63% of the energy demand in the commercial and institutional building sector in Canada. The majority of these energy needs are supplied by electrical resistance heating or combustion heating - with natural gas being the predominant fuel for space heating. Due to the greenhouse gas emissions associated with natural gas combustion, other renewable energy sources such as heat pumps are gaining interest. Heat pumps are electrically powered devices that utilize the refrigeration cycle to provide heating and cooling by moving heat from inside a building to an external heat source/sink. Heat pumps are categorized into two types: (1) Air source heat pumps (ASHP) that exchange heat with the surrounding outdoor air, (2) Ground source heat pumps (GSHP) that exchange heat with the ground. The efficiency at which a heat pump can move heat depends on the temperature difference between inside the building and the external heat source/sink. Because the outside air temperature varies more than the temperature of the ground, GSHP sytems are generally more efficient than ASHP sytems. The *Coefficient of Performance (COP)* is the generally accepted measure of energy efficiency of a heat pump and is a ratio of the heating or cooling energy provided by the heat pump versus the electrical energy needed to operate the heat pump. Typical COP ranges for GSHP systems and ASHPs are 3.8-4.2 and 1.3-3.5, respectively.[1]

The predominant conventional geo-exchange technology uses a GSHP connected to a drilled borehole loop drilled up to 850 feet deep to exchange heat with the ground. Those systems have been impeded from being widely implemented due to their high initial costs, longer payback periods and lesser return on investment. As an alternative, this project tested the use of structural helical steel foundation piles integrated with geo-exchange capability to replace the conventional borehole loops as the in-ground heat exchanger for a GSHP system.

[1] J. D. Spitler, L. E. Southard, and X. Liu, "Ground-source and air-source heat pump system performance at the ASHRAE headquarters building," Heat Pump Conference 2017, 2017. [Online]. Available: http://hpc2017.org/wp-content/uploads/2017/05/O.2.8.3-Ground-source-and-air-source-heat-pump-system-performance-at-the-ASHRAE-Headquarters-Building.pdf.

# Approach/Methodology

A helical steel pile is a structural element drilled into the soil to anchor and support a building. Compared to conventional borehole in-ground heat exchange loops, steel piles are installed much shallower, with typical depths between 30 to 100 feet. The pile-integrated geo-exchange system uses tubular steel piles as the in-ground heat exchanges fitted with plastic inner piping to enable the flow of a working fluid to carry heat to/from a ground source heat pump and the ground. Figure 1 shows a general comparison of a conventional vertical geo-exchange ground loop and a pile-integrated geo-exchange system.

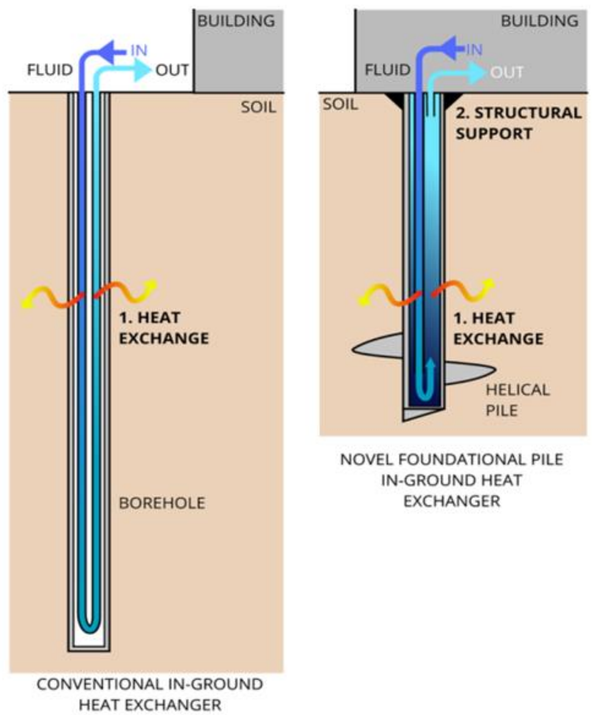


Figure 1: Conventional vertical geo-exchange ground loop versus a pile-integrated geo-exchange system

## Description of Eby Rush TS Building

The Eby Rush Transformer Station is located approximately 2 km West of the University of Waterloo near the NW corner of Fischer-Hallman Rd N and Keats Way in the City of Waterloo, Ontario. The station includes a service building that houses the station switchgear, a site office, and a storage area for warehousing of spare electrical distribution system parts. The two-level building has approximately 5,000 square feet of conditioned floor space and is designed to fit aesthetically with the residential area where the station is located. Since the mid-1990's when the station was significantly upgraded and the current building constructed, the building was conditioned by a 6-ton Waterfurnace Premier 2 geothermal heat pump connected to a conventional vertical geo-exchange ground loop array. Conditioned air is distributed to each level of the building by the heat pump fan blower via standard air ducts.

## Installation of Pile-Integrated Geo-Exchange Array

A new 6-ton variable speed GSHP was first installed in June 2020 to replace the previous GSHP and metered so that data could be collected on the performance of the existing vertical geo-exchange ground loop array. A pile-integrated geo-exchange array (the Pile Array) was then installed and commissioned at the building in February 2021. The Pile Array consists of 8 helical steel piles with an outer diameter of 5.5 inches. Four of the steel piles are 50 feet in length and four piles are 60 feet in length. The Pile Array is connected in parallel with the existing conventional ground loop array, so that either array can operate independently or together to provide heating/cooling capacity to the building. The Pile Array was separated into two groups of 4 piles each enabling each group of piles to operate independently or together as a full array of 8 piles. Electronically activated valves were installed to enable the heat pump to be serviced by the ground loop array, either of the two groups of 4 x Pile Arrays, the full 8 x Pile Array, or a combination of all in-ground heat exchange arrays. The full Pile Array was rated based on a balanced heating and cooling load profile in the SW Ontario region for a capacity of 2 tons. Temperature and flow sensors were installed to measure heat flows between various points of the system and the in-ground heat exchange arrays. Ground temperature sensors were also installed to measure changes in ground temperatures at various distances from Pile#1 in the Pile Array and at various depths. However, due to unknown reasons most of the ground temperature sensors ceased functioning over the 2-year testing period. A control system was installed to enable the remote data collection and operation of the system. Figure 2, Figure 3, Figure 4, and Figure 5 show pictures of the installation of the system. Figure 6 shows a schematic diagram of the system from the control system interface.

Figure 2: Installation of steel pile

Figure 3: Supply and return lines connected to steel piles

Figure 4: Newly installed variable speed geothermal heat pump

Figure 5: Piping systems and control equipment inside building

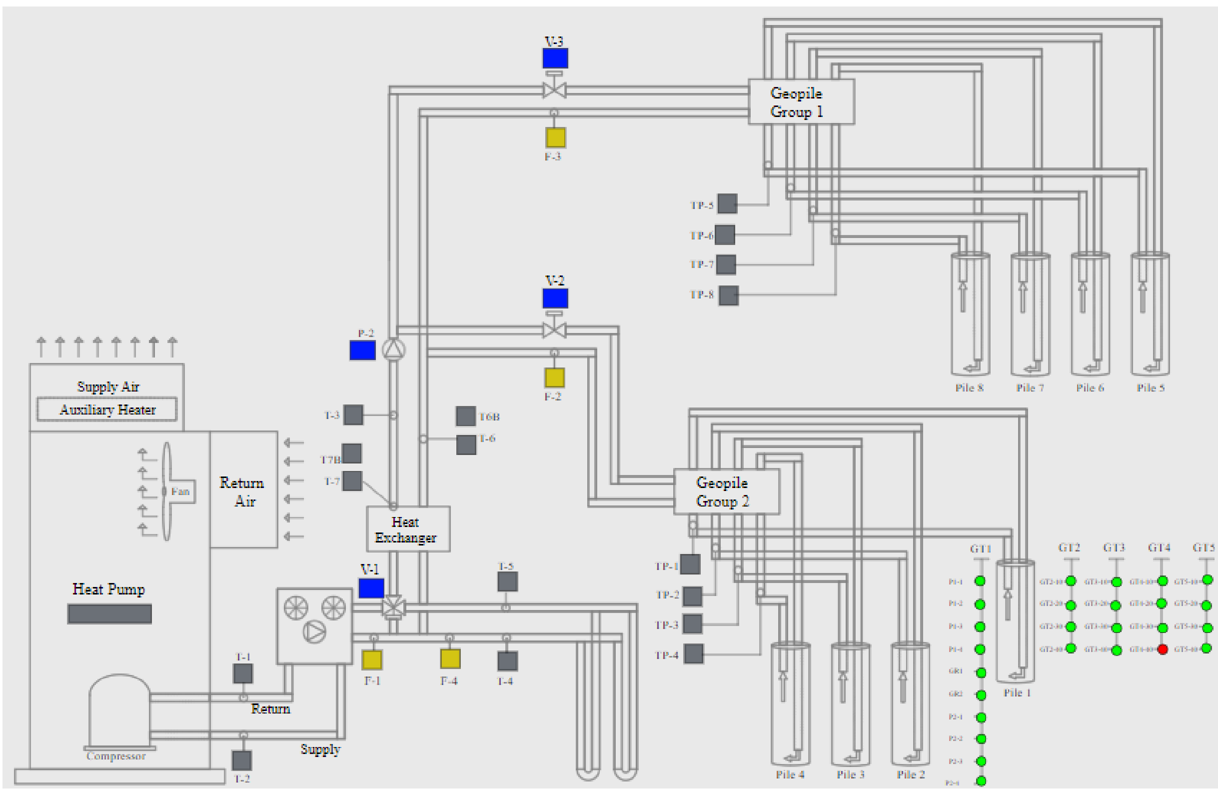


Figure 6: Schematic diagram of the system installed a the Eby Rush TS building

## Testing Approach and Methodology

A combined experimental and simulation approach was utilized to characterize and study the performance of the system. Over a 2-year period from summer 2021 to summer 2023, a series of 10 physical tests were completed. The objective of the tests was: (1) to validate the ability of the Pile Array to act as a geo-exchange system to provide space heating and cooling to a building via a geothermal heat pump, and (2) to compare the performance of the Pile Array with the existing conventional ground loop array. The data collected from these tests was then utilized to validate the thermodynamic models that were developed to characterize and simulate the performance of Pile Array systems. Following the validation of these models and methods, a comparative simulation was completed to predict the performance of a Pile Array system against alternative HVAC systems for a single-family home located in South Western Ontario.

## Testing Constraints

A heat exchanger was included to separate the working fluid loops of the Pile Array and the conventional ground loop array. This was done as a safety measure due to the nature of the system being a demonstration pilot. If any problems were to occur in the Pile Array, the system is designed to allow the heat pump to switchover to fully operate on the conventional ground loop array. However, it was found that the presence of the heat exchanger did result in some constraints during testing. While operating solely on the Pile Array, a short-circuited fluid loop is formed in the interior of the building between the heat exchanger and the heat pump. This short-circuited fluid loop can be considered a primary loop that the heat pump operates on, while the Pile Array operates on a secondary fluid loop on the other side of the heat exchanger. In this mode of operation, heat accumulation or deficit occurs within the primary loop when the load exceeds the capacity of the heat exchanger causing the operating temperature of the primary loop to correspondingly increase or decrease. This led to testing constraints whereby the operation of the heat pump using solely the Pile Array at maximum capacity for prolonged periods could cause the operating temperatures to exceed the recommended operating range of the heat pump. To accommodate this constraint two modifications were made to the initial test plan. First, certain tests were redesigned to be completed through hybrid operation with the conventional ground loop array, this enabled the heat pump to remain operational within recommended operating temperatures by providing a pathway for the accumulated/deficit of heat to move to. Second, several system parameters that could not be directly measured in this testing configuration were calculated instead. In particular, the heat exchanger prevented the Pile Array from being directly connected to the heat pump. Therefore, certain values such as the *Coefficient of Performance* were calculated based on sensor values of the supply flow from the Pile Array and performance charts from the heat pump manual.

# Results

The following results provide an overview of several of the tests completed over the course of the measurement and verification program.

## Functional Cooling Test of the Pile Array

The objective of this test was to test the base functionality of the Pile Array to provide space cooling to the building. The test results showed that the Pile Array was able to supply an entering fluid temperature (EWT) within the operating range of the heat pump to provide space cooling to the building. Figure 7 shows the entering and leaving working fluid temperatures of the Pile Array. With the heat pump operating in cooling mode, heat was being transferred from the building via the heat pump to the supply flow of the Pile Array. As can be seen, the higher temperature of the working fluid flow returning to the Pile Array compared to the temperature of the supply flow from the Pile Array validates the ability of the Pile Array to supply space cooling to the building.

Figure 8 shows the heat exchange rates calculated utilizing the sensor readings collected during the test. The heat exchange rate of the Pile Array is denoted as ($HE_{Geopiles}$). The heat exchange rate of the heat pump to the building is denoted as ($HE_{HP}$). The heat exchange rate of the conventional ground loop array is denoted as ($HE_{ConvLoop}$). The positive value of $HE_{Geopiles}$ indicates the heat transferred into the Pile Array by the heat pump during its operation in cooling mode. This value is higher than the heat exchanged by the heat pump from the building due to the heat pump compressor adding work through the refrigeration cycle that ends up as waste heat that is ultimately transferred into the Pile Array. The zero value of $HE_{ConvLoop}$ confirms that the conventional ground loop array was not active during this test.

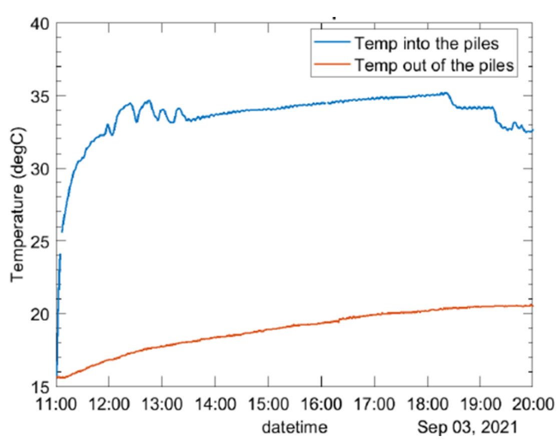


Figure 7: Entering and leaving flow temperatures from the Pile Array during the cooling functionality test

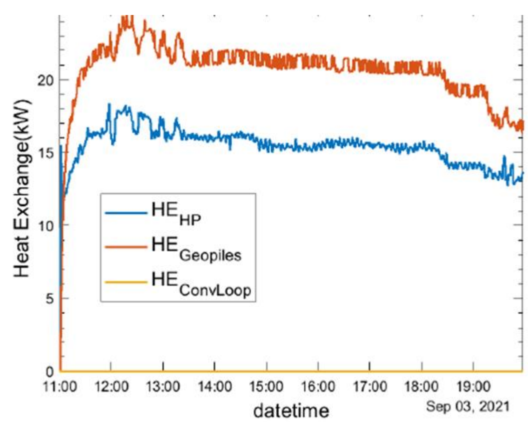


Figure 8: Heat exchange rates during the cooling functionality test

## Functional Heating Test of the Pile Array

The objective of this test was to test the functionality of the Pile Array to provide space heating to the building. The test results showed that the Pile Array was able to supply an entering fluid temperature within the operating range of the heat pump to provide space heating to the building. Due to the testing constraints noted previously, this test was conducted with hybrid operation of the conventional ground loop array, so the results include partial operation of the conventional ground loop array. Figure 9 shows the total flow supplying the heat pump (in gallons per minute) denoted by TotalHPFlow. $PartialFlow_{HX}$ represents the flow directed through the heat exchanger toward the Pile Array, while $PartialFlow_{conv}$ represents the flow directed toward the conventional ground loop array.

Figure 10 shows the working fluid temperature leaving the Pile Array and the working fluid temperature returning to the Pile Array. With the heat pump operating in heating mode, heat was being transferred from the Pile Array into the building via the heat pump. As can be seen, the lower temperature of the working fluid flow returning to the Pile Array compared to the temperature of the supply flow from the Pile Array validates the ability of the Pile Array to supply space heating to the building.

Figure 12 shows the heat exchange rates calculated utilizing the sensor r eadings collected during the test. The total heat exchange rate of the heat pump to the building is denoted as $HE_{HP}$. The portion of heat exchanged by the Pile Array is denoted as $HE_{Geopiles}$, while the portion of heat exchanged rate by the conventional ground loop is denoted as $HE_{ConvLoop}$. The positive value of $HE_{Geopiles}$ indicates the heat transferred from the Pile Array to the building via the heat pump during its operation in heating mode.

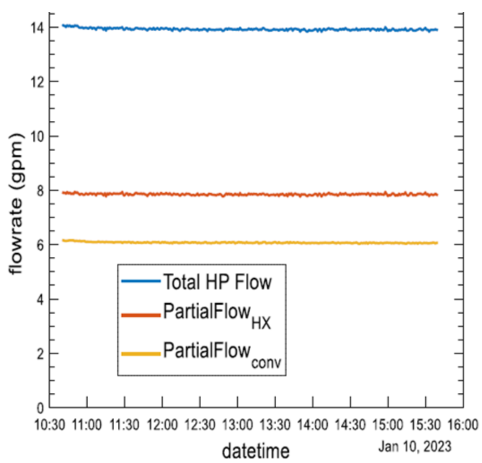


Figure 9: Flow rates utilized in the heating functionality test

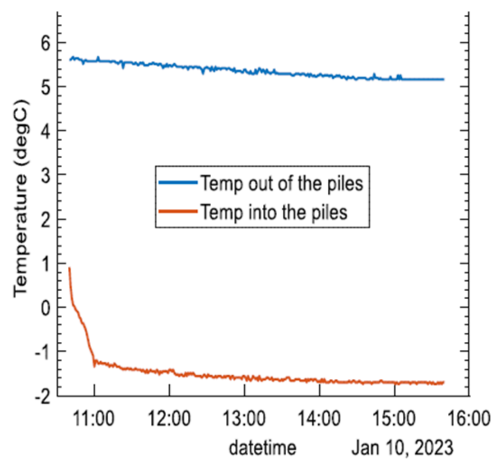


Figure 10: Entering and leaving flow temperatures from the Pile Array during the heating functionality test

## Heating Steady State Capacity Test

The objective of this test was to evaluate the steady state operating capacity of the Pile Array to validate its 2-ton steady state capacity design rating. For this test, the flow from the heat pump was gradually increased toward the Pile Array via opening the three-way valve (V1) in successive increments to direct an increasing thermal load toward the Pile Array. The inlet and outlet flow temperatures of the Pile Array were measured to determine the thermal load at which both inlet and outlet flow temperatures remain stable and no longer change. This stable operating temperature state was achieved during the test with the three-way valve at the 6-volt position as shown in Figure 11. Figure 12 shows that the corresponding steady heat exchange rate measured during the test was 8 kW (2.2 Tons), validating the steady state capacity rating of the Pile Array at approximately 2 Tons.

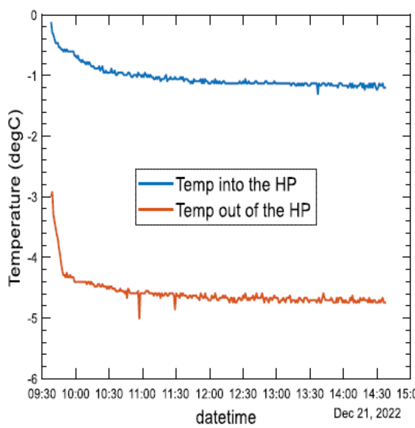


Figure 11: Inlet and outlet Pile Array flow temperatures for 3-way valve at 6-volt position

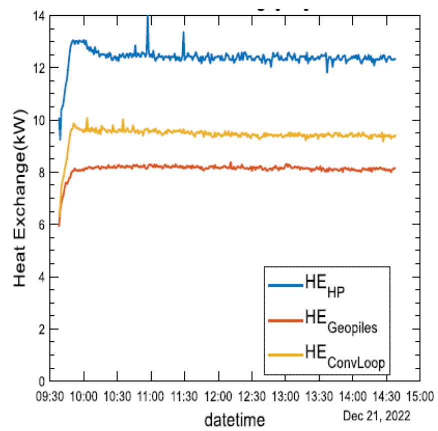


Figure 12: Heat exchange rates for 3-way valve at 6-volt position

## Comparative Test

The objective of this test was to compare the performance of the Pile Array with the conventional ground loop array. The test was completed by operating each system independently during two days in August 2021 with similar outdoor conditions with the heat pump manually configured to operate at maximum capacity for the duration of the test. Figure 13 and Figure 14 show the temperature differences between the inlet and outlet flows for both the conventional ground loop array and the Pile Array during the test. Several observations were made from these results: (1) The Pile Array was able to operate at a much larger temperature difference (nearly 20°C) as compared to the conventional ground loop array, which operated at a temperature difference of approximately 6°C. (2) The supply temperature from the conventional ground loop array increased quickly at the onset of the test from approximately 17°C to 21°C within less than an hour of operation, eventually reaching a steady state temperature of approximately 24°C. In comparison, the supply temperature of the Pile Array rose much slower starting at approximately 13°C and only reaching a temperature of 20°C at the conclusion of the test.

The differing behaviour is a result of the large working fluid volume of the Pile Array in comparison to the conventional ground loop array creating a thermal buffer capable of absorbing more heat (or dissipating it in heating operation) from the heat pump with less change in temperature compared to the conventional ground loop array. With supply temperature directly impacting the efficiency of a heat pump, this unique characteristic of the Pile Array has the potential to be utilized in active control strategies to optimize the performance of a system.

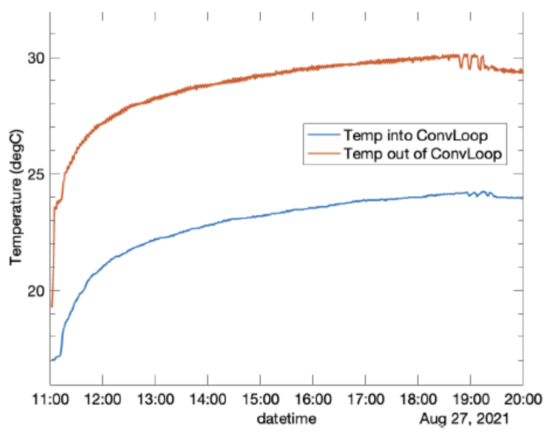


Figure 13: Entering and leaving flow temperatures from the conventional ground loop during the comparative test

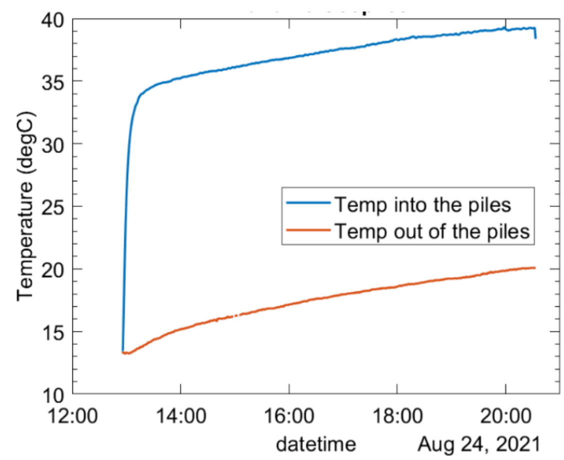


Figure 14: Entering and leaving flow temperatures from the Pile Array during the comparative test

Figure 15 to Figure 18 show the heat exchange rates as well as the power consumption of both the conventional ground loop and the Pile Array over the comparative test.

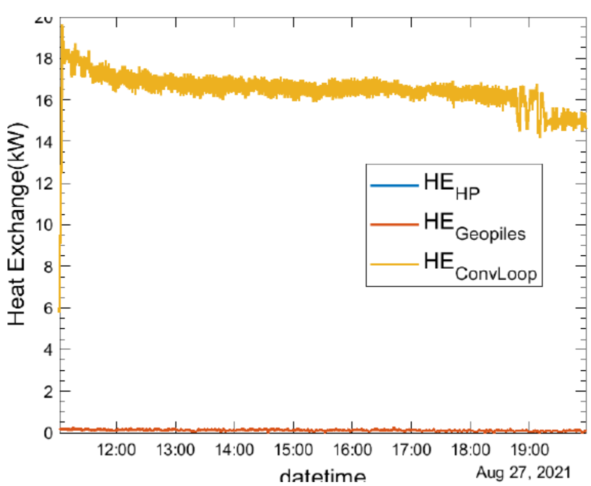


Figure 15: Heat exchange rate of conventional ground loop during the comparative test

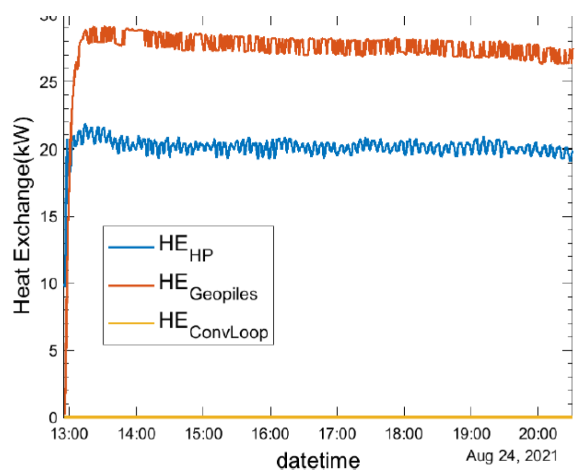


Figure 16: Heat exchange rate of the Pile Array during the comparative test

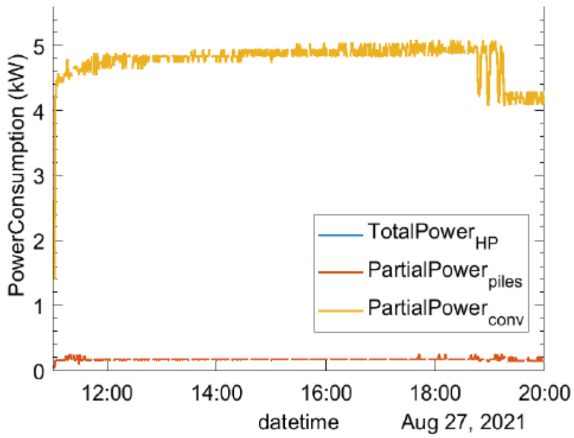


Figure 17: Power consumption of conventional ground loop during the comparative test

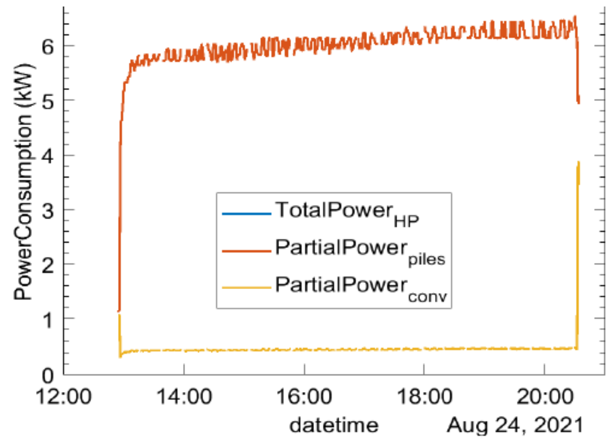


Figure 18: Power consumption of Pile Array during the comparative test

The following three figures show the coefficient of performance for both the conventional ground loop array and the Pile Array during the comparative test. The system COP was determined by including the power requirements of the two circulating pumps that circulate the working fluid in the system (P1 and P2). As can be observed in Figure 19 and Figure 20, the COP of the conventional ground loop array was higher than the COP of the Pile Array. While, this result is valid from the measurements obtained, the operating constraint due to the presence of the heat exchanger meant that the Pile Array was not directly connected to the heat pump with the short-circuited operating fluid loop supplying the heat pump with a higher temperature than if the Pile Array was directly connected to the heat pump. As a result of this constraint, Figure 21 below shows the COP calculated based on the heat pump's performance characteristics from the manufacturer's manual as if the Pile Array were directly supplying the heat pump. Due to the more favourable temperature of the supply flow from the Pile Array, this calculated COP is higher than the COP of the conventional ground loop array.

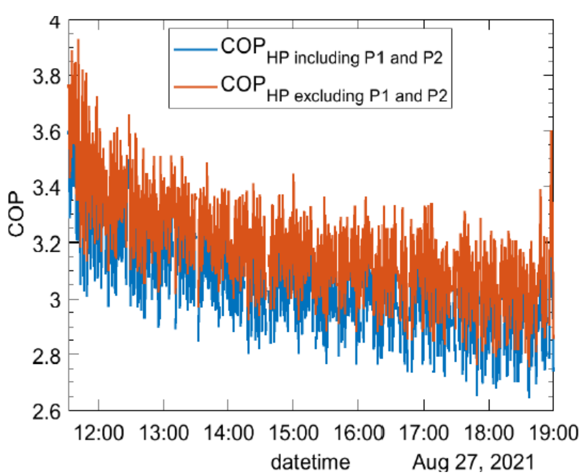


Figure 19: COP of conventional ground loop during the comparative test

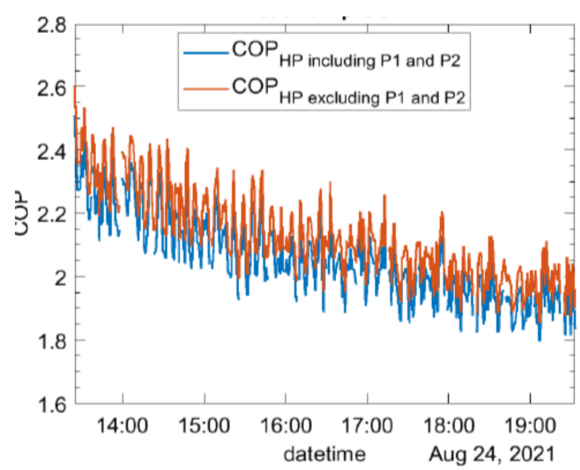


Figure 20: COP of Pile Array during the comparative test

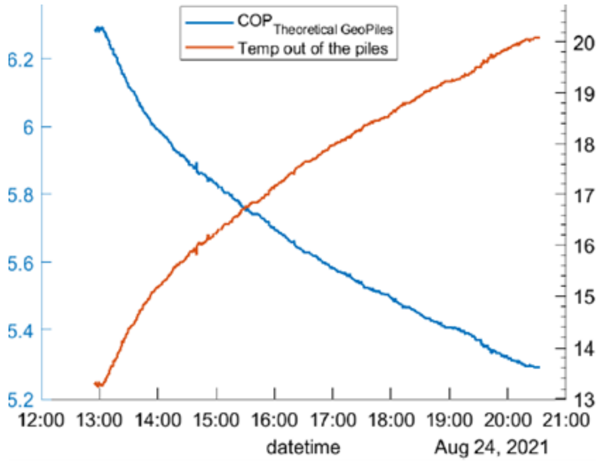


Figure 21: Calculated COP if the Pile Array were directly connected to the heat pump

## Intermittent Test

The objective of this test was to investigate the potential to utilize the large operating fluid volume within the Pile Array to influence system COP through active control. In this test, the first group of 4 piles in the array (Pile Group 1) was cycled to be active (on) for 30 minutes followed by inactive (off) for 90 minutes over a period of 4 hours. The second group of 4 piles in the array (Pile Group 2) was left active for the entirety of the test as a control group to measure steady operation.

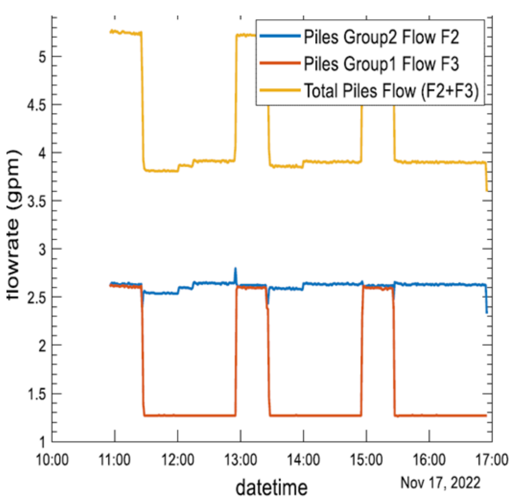


Figure 22: Pile Group Flow Rates During Intermittent Test

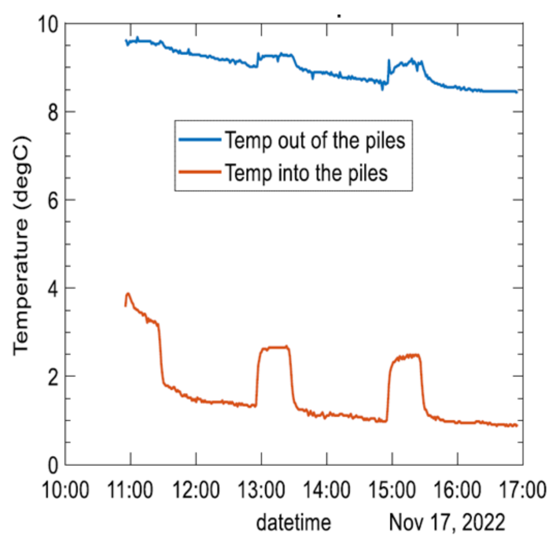


Figure 23: Entering and leaving flow temperatures from the Pile Array during the intermittent test

Figure 22 shows the flow rates for each of the pile groups as well as the combined flow rates for the entire Pile Array through the intermittent test. Figure 23 shows the entering and leaving flow temperatures from the full Pile Array during the intermittent test. As can be observed, intermittent operation resulted in measurable increases in supply flow temperature from the Pile Array during the 30-minute periods that Pile Group 1 was active following the 90-minute cycles of being inactive.

The higher supply temperature during the 30-minute on periods resulted in a corresponding increase in heat exchange from the Pile Array as shown in Figure 24. Utilizing the higher heat exchange rate, the COP was calculated as if the Pile Array was directly connected to the heat pump showing a corresponding increase to COP during the 30-minute periods when Pile Group 1 was active as shown in Figure 25. These results show the ability to influence COP of the system through intermittent operation of the Pile Array.

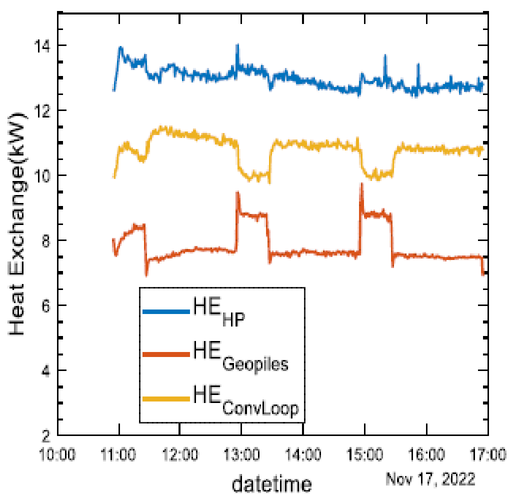


Figure 24: Heat exchange rate during the intermittent test

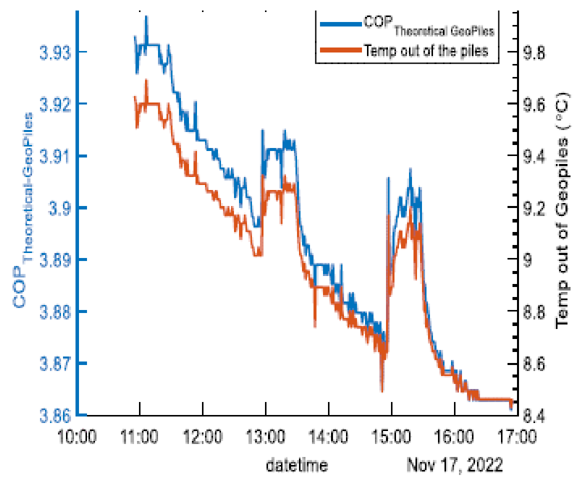


Figure 25: Calculated COP if the Pile Array were directly connected to the heat pump

## Model Validation

Thermodynamic models to characterize the Pile Array were developed using combined thermo-fluid (computational fluid dynamics) and thermo-mechanical (finite element analysis) using the COMSOL Multiphysics software suite. These models were validated by running simulations using the operating conditions during testing and comparing the simulated results with the experimental data collected. Examples of model validation completed for two tests are provided in Figure 26 and Figure 27 below. The relative error between the model's predictions and the experimental values ranged from 2% to 8.75% indicating the reasonable predictive capability of the model.

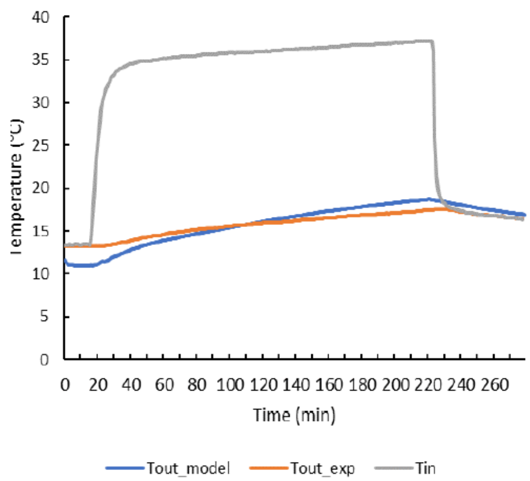


Figure 26: Model versus experimental results (08/22/2021 test)

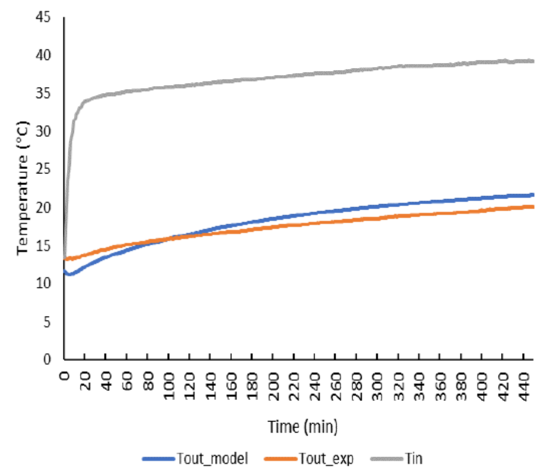


Figure 27: Model versus experimental results (08/24/2021 test)

## Comparative Analysis between Alternative HVAC Systems

Following the completion of the experimental testing program and the validation of the thermodynamic models, a comparative analysis was performed to evaluate the energy use and greenhouse gas emissions between alternative HVAC systems. For the comparative analysis, a newly constructed 2,000 square foot detached single-family home located in South-Western Ontario was utilized as a basis to evaluate three alternative HVAC systems: (1) a steel pile integrated geo-exchange system (GSHP), (2) a conventional natural gas furnace and split air-conditioner system (Combustion System), and (3) a centralized cold-climate air-source heat pump system (ASHP). The detached single-family home has an annual heating load of 14,736 kWh, an annual cooling load of 1,451 kWh, and peak heating and cooling loads of approximately 2 tons.

A full year hourly transient simulation was completed to simulate the performance of the GSHP system, while an hourly simulation was conducted to simulate the performance of the ASHP system utilizing the hourly outdoor air temperatures for the City of Kitchener/Waterloo for 2022. Performance of the combustion system was evaluated on an annual basis using the annual heating and cooling loads. Table 1 shows the relative performance metrics between the three systems. Table 2 presents the results of the comparative analysis in terms of annual electricity consumption and annual $CO_2$ emissions.

Table 1: Energy Performance Metrics for Comparative Systems

| | GSHP | ASHP | Combustion System |
|---|---|---|---|
| Heating COP | 3.6 | 3.0 | - |
| Cooling COP | 7.3 | 5.0 | 3.4 |
| Heating Load Serviced by ASHP | - | 92% | - |
| ASHP Defrost Factor | - | 7.5% | - |
| Furnace AFUE | - | - | 96% |

Table 2: Total Electricity Consumption and $CO_2$ Emissions for Comparative Systems

| | GSHP | ASHP | Combustion System |
|---|---|---|---|
| Annual heating electricity consumption (ekWh) | 4,154 | 7,154 | 15,350 |
| Annual cooling electricity consumption (ekWh) | 198 | 289 | 430 |
| Total Heating and Cooling electricity consumption (kWh) | 4,352 | 7,443 | 15,781 |
| Annual Emissions (Tons $CO_2$) | 0.12 | 0.21 | 2.8 |

Table 3 presents comparative annual energy and $CO_2$ emissions as well as long-term operating cost comparisons between the systems. Both the GSHP and ASHP systems substantially reduce energy use versus the Combustion System due to switching from natural gas combustion heating to electric driven heat pumps. Due to the low emissions factors of electricity from the Ontario grid, both the GSHP and ASHP systems substantially reduce $CO_2$ emissions compared to the Combustion System. The GSHP reduces energy use by approximately 40% versus the ASHP system due to higher efficient performance.

In terms of operating costs, the GSHP is the lowest cost system to operate resulting in annual energy cost savings of approximately $400 when compared to both the Combustion System and the ASHP system based on current energy prices in Southwestern Ontario. The ASHP system was essentially cost-neutral with the Combustion System. Both the GSHP and ASHP cost savings are projected to gradually increase versus the Combustion System due to the increasing carbon tax. With expected lifespans of up to 50 years or greater, the accumulated cost savings from a GSHP system indicate an economic benefit for its adoption when compared to the ASHP and Combustion System alternatives.

Table 3: Annual and Long-Term Energy and Cost Comparisons

| | **GSHP vs Combustion System** | **GSHP vs. ASHP** | **ASHP vs. Combustion System** |
|---|---|---|---|
| Energy Reductions (ekWh) | 11,428 | 3,091 | 8,337 |
| Energy Reductions (%) | 72% | 42% | 53% |
| Emissions Reductions (Tons $CO_2$e) | 2.6 | 0.1 | 2.6 |
| Emissions Reductions (ekWh) | 96% | 42% | 92% |
| Annual Cost Savings: | | | |
| 2022 | $407 | $402 | $5 |
| 2025 | $542 | $426 | $116 |
| 2030 | $776 | $471 | $306 |
| Accumulated Cost Savings After: | | | |
| 5 Years Operating | $2,484 | $2,091 | $393 |
| 10 Years Operating | $6,091 | $4,400 | $1,691 |
| 20 Years Operating | $14,291 | $9,764 | $4,527 |
| 30 Years Operating | $23,271 | $16,302 | $6,969 |
| 50 Years Operating | $44,294 | $33,988 | $10,306 |

Adoption of GSHP and ASHP systems in Ontario will generally result in switching from natural gas combustion heating to heat pumps as a form of electrical heating. This will result in increased electrical demand in heating season, and potentially greater electrical demand in cooling season if the GSHP or ASHP is adopted in a building that does not currently have cooling. An hourly analysis of electrical demand profiles for both the GSHP and ASHP systems was also completed in the comparative analysis.

Figure 28 and Figure 29 show the hourly electrical demand profiles for both the GSHP and ASHP in heating and cooling operation respectively. The GSHP system provides a much more stable electrical load profile versus the ASHP system through both heating and cooling seasons. The peak electrical loads for both the GSHP and ASHP system occur during the winter as outdoor temperatures lower thereby increasing the heating demand in the home. While the GSHP system has a lower electrical peak load than the ASHP in both winter and summer, the magnitude of the electrical peak load reduction is much more significant during the winter due to the lower efficient performance of heat pumps for heating as compared to cooling in the SW Ontario climate.

Figure 30and Figure 31 show the winter and summer peak week electrical loads for the GSHP and ASHP, respectively. In the simulations conducted, the peak heating electrical loads occurred during different weeks for the ASHP and GSHP system due the ground temperature not being constant and reaching a colder state towards the end of the peak heating month of February. The peak cooling electrical loads occurred in the same coincident week. The peak electrical heating load for the GSHP is 1.83 kW versus 4.51 kW for the ASHP, a reduction of 2.68 kW. The peak electrical cooling load for the GSHP is 0.54 kW versus 0.85 kW for the ASHP, a reduction of 0.31 kW.

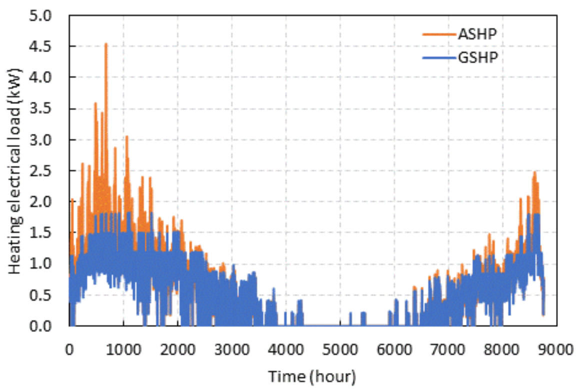


Figure 28: Hourly heating electrical demand profiles for the GSHP and ASHP systems

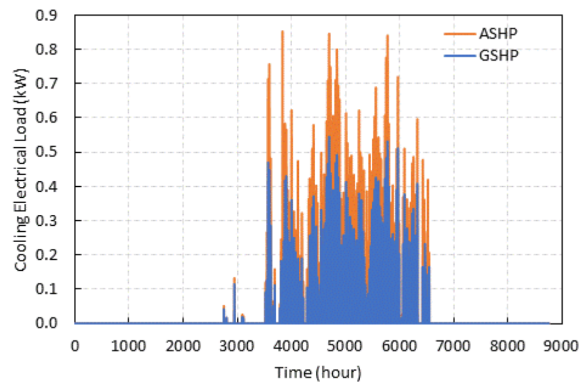


Figure 29: Hourly cooling electrical demand profiles for the GSHP and ASHP systems

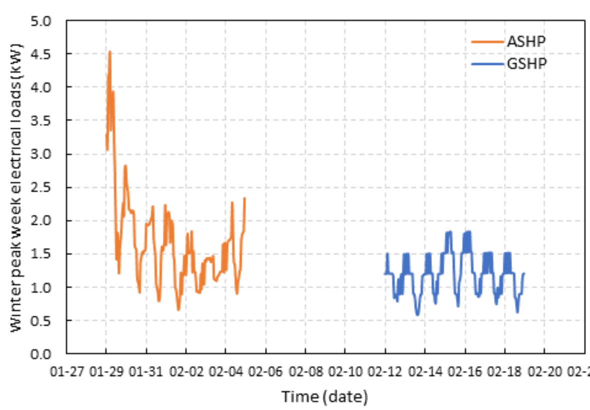


Figure 30: Winter peak week electrical demand profiles for the GSHP and ASHP systems

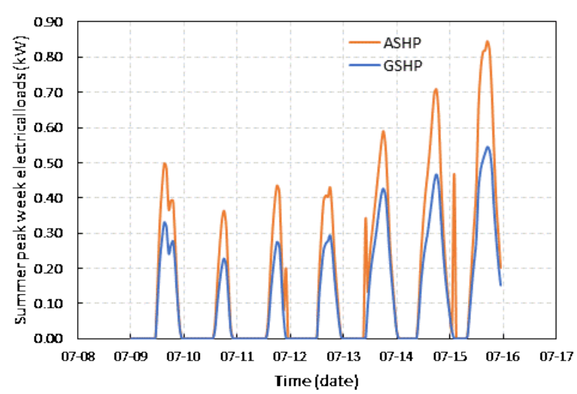


Figure 31: Summer peak week electrical demand profiles for the GSHP and ASHP systems

Several important considerations must be made when interpreting these results. The electrical demand profile of the ASHP was from an idealized simulation. The ASHP winter peak electrical loads were generated based on manufacturer's specifications for a range of temperatures for heating loads between -21°C and 18°C. However, at outdoor temperatures below -21°C the capacity of the ASHP reduced such that it did not meet the heating requirements of the home indicating that a supplementary heating system would be needed.

Backup heating can either be provided by a conventional combustion-based system or through an electric resistance backup system. If the backup heating system is combustion based, then the electrical demand profile will be less than the idealized profile presented. If the backup heating system is electric resistance based, then the electrical demand profile will be higher than the idealized profile presented. Another factor that may impact the idealized ASHP electrical demand profile is the periodic requirement of an ASHP to defrost the outdoor coils. Common methods of defrosting outdoor coils in ASHP systems are through electric strip heaters that directly heat the outdoor coils or by operating the heat pump in reverse (i.e. cooling mode) to heat the outdoor coils. In the latter case, a common control strategy is to turn on the backup heating system during defrost operation so as not to impact the comfort within the home. Detailed simulations of ASHP systems with different backup system configurations and control sequences for periods of extreme cold and during periods of defrost are recommended to further refine the idealized ASHP electrical load profile generated in this study.

# Conclusion

A system integrating geo-exchange functionality into steel foundation piles was installed at the service building of the Eby Rush Transformer Station. Testing conducted during the measurement and verification program has shown that the system is capable of providing efficient space heating and cooling to the building utilizing a geothermal heat pump. Comparative testing with the existing conventional geothermal ground loop array installed at the facility has shown that the shallow steel pile system is able to provide comparable supply temperatures to the heat pump. Test results also indicate the potential of the large working fluid volume of the steel pile system to be utilized in active control strategies to optimize the performance of a system.

Thermodynamic models were validated using data collected during testing enabling the simulation of a system servicing a detached single-family home located in Southwestern Ontario. A comparative analysis was then conducted comparing the performance of the system against a conventional natural gas furnace and split air conditioner system and a cold climate air-source heat pump system. The comparative analysis found that the geo-exchange integrated steel pile system was the most efficient, lowest emitting, and lowest cost system to operate. Additional analysis comparing the hourly electrical load profiles of the geo-exchange integrated steel pile system and the air-source heat pump system show the geo-exchange system to have a more stable electrical load profile throughout the year and smaller peak loads during both peak heating and peak cooling conditions.

# Lessons Learned

Due to its nature as a demonstration of a new technology, the system was implemented with a heat exchanger to separate the fluid loop serving the steel pile array with the fluid loop serving the conventional geothermal ground loop array and heat pump. The system was implemented this way as a safety measure to enable the heat pump to fully operate on the conventional ground loop array in the event of the steel pile array requiring maintenance or becoming inoperable. During testing it was found that this design led to constraints requiring modifications to the original test plans. While operation and testing of the system was able to be accomplished, subsequent systems will be designed without the inclusion of a heat exchanger.

While the steel pile integrated geo-exchange system was shown to be effective as a geo-exchange system, the high cost of steel results in systems installed solely for the purpose of geo-exchange (and not dual use as a building's foundation system) as being not practical. As a result, a system utilizing plastic piping instead of steel has been developed that can be economically installed at similar shallow depths as the steel piles by repurposing techniques used in the foundation construction industry. These systems are being developed to be economically viable as standalone geo-exchange systems for both new and existing low-midrise structures including new single family home subdivisions.

# Next Steps

*1. Research and Development of Active Control Strategies*

Test results have shown the potential to actively utilize the large working fluid volume of the steel piles to optimize the performance of a system. Research and development activities are underway to analyze control strategies based on different desired outcomes, such as reducing energy consumption, reducing emissions, or reducing costs. Since performance will vary based on the heating and cooling load profiles of different buildings, these research and development activities will investigate different types of buildings as well as different climates.

*2. Standalone Shallow Depth Geo-Exchange System Utilizing Plastic Instead of Steel*

Research and development activities are also underway to develop and test a system utilizing plastic instead of steel so that a much larger market consisting of both new and existing low-midrise buildings can be addressed.

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