Performance Assessment of a Wide Diameter Shallow Bore Ground Source Heat Exchanger

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LEGAL STATEMENT

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EXECUTIVE SUMMARY

This study investigated the in-situ performance of a new ground heat exchanger technology installed as the source for a water-to-water heat pump in a single family residence. The technology is different from traditional ground heat exchangers because it is installed in a shallow wide diameter bore (20' deep x 24" diameter). This design reduces the cost and complexity of drilling compared to deeper heat exchanger bores. Whereas traditional systems consist of a U-shaped pipe in a small diameter bore, the technology studied here consists of a single pipe wound into a 24" diameter helix – in this way, roughly 300' of heat exchanger pipe are fit into each shallow bore.

In this report, we present analysis of two configurations for the shallow bore heat exchanger: "dry" bores and "wet" bores. In the "dry" bore configuration, heat exchangers were simply surrounded by native earth, whereas for the "wet" bore configuration, heat exchangers were encased in a larger reservoir, which was filled with rock, and filled with grey water from the home. Therefore, the "wet" heat exchangers were in direct contact with water. Results indicate that the "wet" heat exchanger configuration provides significant thermodynamic advantages. However due to complications with the physical construction (the gray water leaked out and the dry gravel had low conductivity), we do not recommend that others replicate the specific "wet" heat exchanger configuration that was installed for this project. Other researchers and manufacturers have demonstrated more promising designs for heat-pump assisted drain-water heat recovery than the design studied in this project (Wallin, Baek, Ni, Nexus).

Our analysis focused on thermodynamic performance of each shallow bore heat exchanger, and did not asses the energy efficiency of the home or the heat pump performance. The results demonstrate that this innovative shallow bore heat exchanger design is capable of meeting the thermal demands from a residential heat pump. For space heating and domestic water heating, the return water temperatures observed would allow a water source heat pump to achieve higher efficiency than an air source heat pump.

Cooling loads for the home were much higher than anticipated, and the heat pump operated in cooling for long periods (often 12-15 hours at a time). As a result, the ground mass surrounding these shallow bore heat exchangers became saturated with heat. The shallow bore heat exchangers were able to reject heat from the heat pump, but they were not always able to maintain desirable return water temperatures while doing so. The cause of the unreasonably large cooling loads is under investigation but was not determined at the time of this report. In cooling mode, a detrimental feedback loop was observed where excess cooling loads caused higher ground temperature, and higher ground temperature reduced heat pump efficiency. Reduced efficiency resulted in longer run time and more heat rejection to the ground which caused compounding temperature increases.

Despite the poor cooling performance for the home, results of the study suggest that shallow bore heat exchanger can work effectively, when matched appropriately with the heating and cooling demands for the home. The poor cooling performance underscores the fact that proper sizing of a shallow bore heat exchanger is critical to overall system performance and efficiency of any ground source heating and cooling system.

INTRODUCTION

This report describes the methodology and results from a performance assessment of a shallow bore heat exchanger array installed for a single family home in Davis, CA. The shallow bore heat exchanger studied is a method of rejecting (and absorbing) heat to (and from) the ground, designed to be used with a water source heat pump. The machine installed in the home is a water-to-water heat pump that provides heating, cooling, and domestic hot water for the home. The shallow bore heat exchanger studied is an alternative to the traditional method of deep bore ground heat exchangers. In particular this report evaluates:

1. Temperature response of the ground
2. Comparison of 2 designs studied (wet bore vs. dry bore)
3. Overall performance of the heat pump / shallow bore heat exchanger array and feasibility / cost implications

TECHNOLOGY DESCRIPTION

The performance of cooling and heating systems in single family, multifamily, and small commercial (SMC) settings has a significant impact on overall energy consumption and power draw. According to the US Energy Information

Administration, about 16% of the energy consumed in the U.S. is just for conditioning of residential and commercial spaces (US EIA, 2012). As a result, there has been significant research into reducing the impact of these technologies on energy consumption and power demand.

One area of technology and research growth has been reducing space conditioning energy consumption by using the ground as a heat source, sink, and storage mechanism. Ground temperatures are generally closer to desired room temperatures than outdoor air temperatures throughout the year (Fisher, Rees, 2005). As such, there is significant potential (climate zone dependent) to improve space conditioning efficiency by utilizing the ground as a heat source and sink.

There has been much research and implementation of deep bore ground heat exchangers for heat pumps. A typical setup includes a borehole which can extend deeper than 350 feet, usually with a diameter of around 6 inches. A U-shaped pipe is then placed in the borehole, and the hole is typically filled with a conductive grout. This arrangement can result in better heat pump efficiency compared to an air source system, but the strategy is expensive and thus, adoption of the technology has been limited. A study of cost estimates showed that the drilling and installation for conventional ground heat exchangers can cost over $5,000 per ton of cooling capacity (Hackel, Pertzborn, 2011).

The ground source shallow bore heat exchanger evaluated in this study is less costly than the traditional design, mainly because it is faster and less expensive to auger a 20’ deep bore because the tooling is more readily available and does not require cutting through bedrock, groundwater tables, or other significant geologic features. If the thermal performance of this innovative design is adequate, it would offer a pathway to broader and more cost effective market adoption for ground source heat pump systems.

The shallow bore heat exchanger array evaluated in this study consisted of eight 24” diameter helical coils (heat exchangers) placed in 20’ deep bore holes. Each heat exchanger was constructed of 300 feet of ½” I.D. SDR-9 high density polyethylene (HDPE) tubing. Four of the heat exchangers were installed in “dry” bores, and four of the heat exchangers were installed in “wet” bores. As illustrated in Figure 1, the heat exchangers in both the dry bore and wet bores are identical, but the fill surrounding these heat exchangers is different. The dry bores are backfilled with the soil that was removed from the bores, while the heat exchanger in the wet bore is located inside a reservoir constructed of a 24” diameter corrugated single wall HDPE pipe that is filled with ¾”-1 ½” washed river rock and flooded with grey water from the home. Grey water first drains by gravity into the bottom of the wet bore reservoir, then flows upward through the reservoir and around the heat exchanger, and finally drains from the top of the reservoir into a sub-surface landscape irrigation system.

The wet bore design is expected to improve heat pump performance in two ways:

1. By increasing conductivity and therefore the heat transfer rate from the heat exchanger.
2. By providing additional heat transfer capacity via transport of gray water through the system.

Since the wet bore configuration uses greywater to augment heat pump performance, it should be thought of as a heat pump assisted drain water heat recovery system. Various researchers have shown that this concept can be energetically advantageous (Wallin, Baek, Ni), and we are aware of at least one commercially available product that employs a similar strategy for heat pump water heating (Nexus). Although the strategy has performance advantages, we do not recommend replicating the specific physical design employed for this project because it was complicated to install and difficult to achieve a water tight seal for the 20’ deep reservoir. In fact, for this installation, grey water flow was diverted from three of the four wet bores because they were not water tight. Therefore, our assessment of wet bore performance focuses on one heat exchanger that received all of the grey water flow from the home.

The setup was designed to provide a side-by-side comparison of the dry bore and wet bore configurations exposed to similar thermal loads.

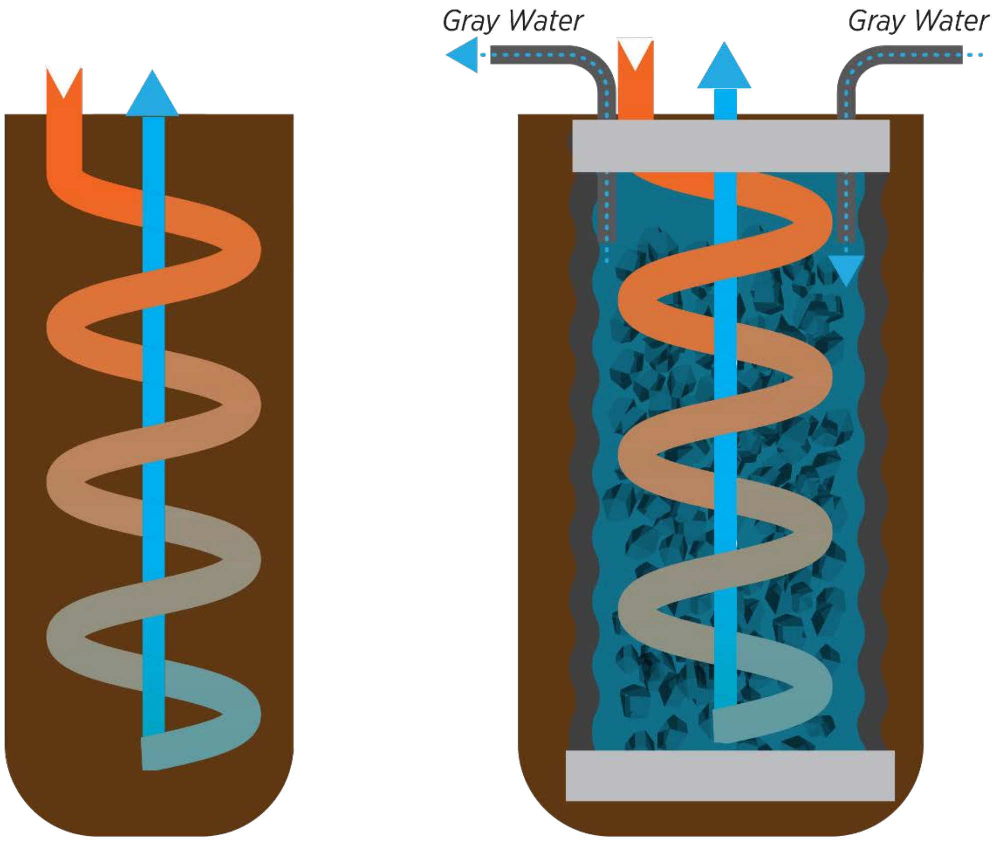

FIGURE 1: DIAGRAM OF DRY BORE (L) AND WET BORE (R) CONFIGURATIONS. (FIGURE IS NOT TO SCALE)

DEMONSTRATION SITE AND MEASUREMENT PLAN

The shallow bore heat exchangers were studied in operation as the source heat exchanger for a multi-function water-to-water heat pump at a home in Davis, California. The heat pump generates heating, cooling, and domestic hot water for the home. Heating and cooling is delivered via a radiant floor and radiant ceiling.

The heat pump operates in six different modes:

1. Space Heating (stage 1)
2. Space Heating (stage 2)
3. Domestic Water Heating
4. Space Cooling (stage 1)
5. Space Cooling (stage 2)
6. Space Cooling + Desuperheater (for domestic water heating)

In space heating modes, the heat pump generates hot water in the “load” circuit, which is circulated through the radiant floor and radiant ceiling in the home. Water in the “source” circuit is cooled by the heat pump and returns to the ground where it absorbs heat before returning to the heat pump. In domestic water heating mode, the “load” circuit is redirected to flow through a hot water storage tank.

In space cooling modes, the heat pump generates cold water in the “load” circuit, which is circulated through the radiant floor and ceiling. In this mode, the heat pump rejects heat to the ground through the heat exchangers. When conditions are appropriate, some of the waste heat from the cooling process can be captured through a desuperheater to heat domestic water. Although the desuperheater provides domestic hot water, it is different from the domestic water heating mode. The desuperheater uses a separate heat exchanger and a separate pump, which only operate during the cooling cycle, and when the domestic hot water storage temperature is low enough to warrant absorbing some waste heat from cooling. When the domestic hot water temperature drops below set point temperature, the heat pump operates in domestic water heating mode, which generates hot water in the "load" circuit, not the desuperheater circuit. System controls always give priority to domestic water heating over demands for space heating or cooling. This analysis did not distinguish between stage 1 and stage 2 cooling.

Figure 2 illustrates the plan view arrangement of the eight shallow bore heat exchangers and eight vertical columns of thermocouples placed to measure temperature of the ground surrounding one of the dry bore heat exchangers, and one of the wet bore heat exchangers. In all, the ground temperature was measured in 40 locations. The heat exchangers were separated at 15' on center according to guidance from the manufacturer, and the L-shaped arrangement of the array was selected to suit the needs of the site and property lines.

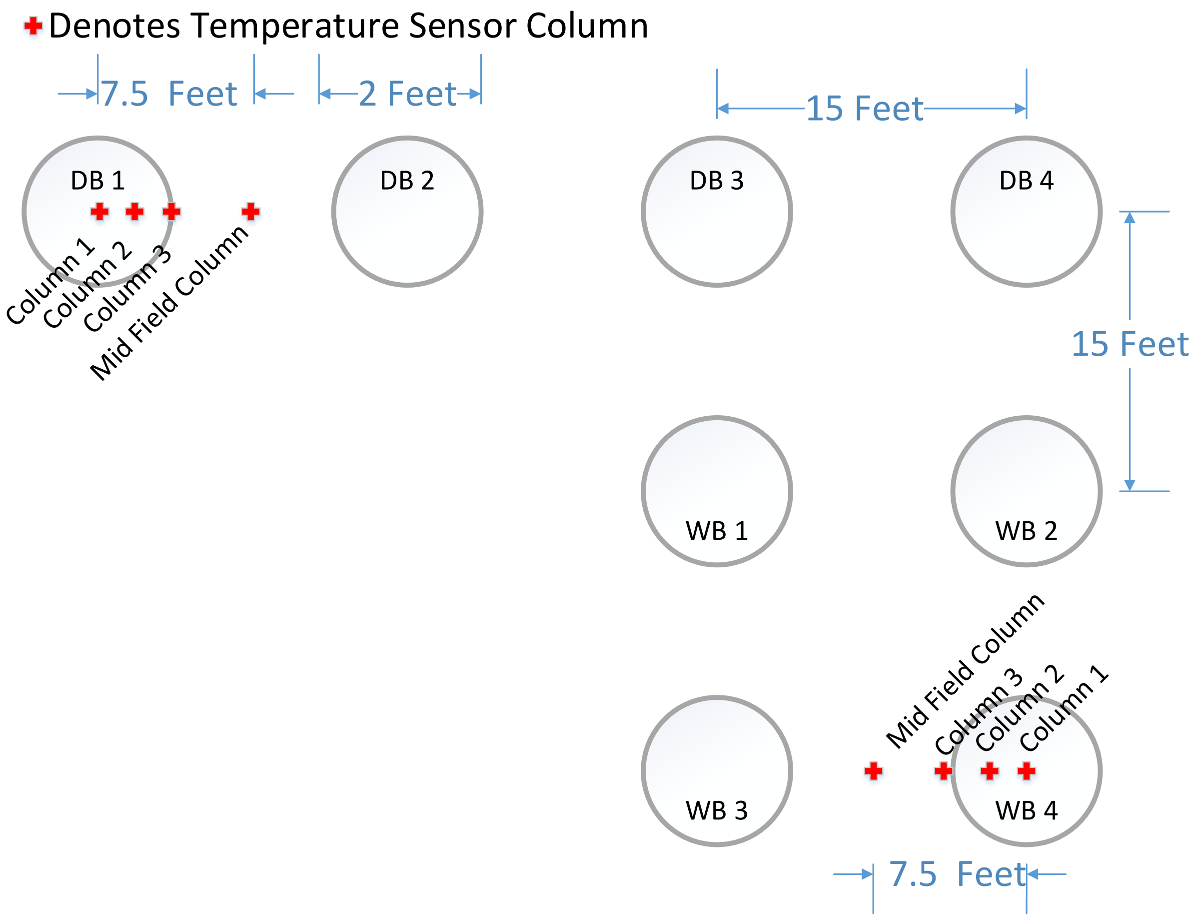

FIGURE 2: PLAN VIEW ARRANGEMENT OF DRY BORES (DB) AND WET BORES (WB) AND LOCATION OF EACH VERTICAL COLUMN OF THERMOCOUPLES PLACED TO MEASURE TEMPERATURE OF THE GROUND SURROUNDING ONE DRY BORE HEAT EXCHANGER AND ONE WET BORE HEAT EXCHANGER.

We monitored water temperature at the inlet and outlet of each shallow bore heat exchanger, as well as at the inlet and outlet of the heat pump (the source return and source supply connection). The sensors placed at the inlet and outlet of each shallow bore heat exchanger were affixed to the outside of the pipes, insulated with closed cell foam and a plastic casing then buried underground with the heat exchanger. At the heat pump source return and supply connections, we used insertion sensors which put each thermocouple in direct contact with water inside the pipe. The ground temperature sensors were placed in direct contact with the earth, at the locations indicated in Figure 2.

T-type thermocouples were used for all temperature measurements (Table 2). These sensors have a stated uncertainty of +/- 1.8°F. While this is a small uncertainty for measurement of absolute temperature, it represents a significant portion of the temperature difference between the supply and return at the heat pump and at each shallow bore heat exchanger.

Source circuit water flow rate was measured in one location with an Onicon model F-1300 turbine flow meter (Table 2). Our calculations assume that the flow to each heat exchanger was equal since the layout of supply and return piping to each heat exchanger is equal in size and length. For one period, we corrected the flow calculation for analysis because the valve to one heat exchanger had been shut off.

Data was collected from the home on one-minute increments beginning March 2014. Analysis in this study focuses on data from April 2015 – December 2015, a period when the home was occupied, and operating without major disruptions.

TABLE 1: INSTRUMENTATION TABLE

Measurement	Instrument	Manufacturer	Instrument Range	Manufacturer Stated Uncertainty
Source Circuit Flow Rate	Onicon F-1300 Flow Meter	Onicon Incorporated	0.8 – 38 GPM	+/- 2% of reading
Temperature (All)	T-Type thermocouple	Omega	-328 to 662 °F	+/- 1.8 °F

DATA ANALYSIS AND RESULTS

DATA ANALYSIS

We analyzed data to explore the ways that source water temperatures and ground temperatures behaved in response to heat pump operation and to the amount of heat rejected and absorbed by the heat pump source circuit. We analyzed the temperature response of each shallow bore heat exchanger individually, and compared this to the response for the whole array as represented by the source supply and return water temperatures measured at the heat pump. The assessment of each shallow bore heat exchanger allowed us to compare performance of the wet bore heat exchanger to performance of the dry bore heat exchangers.

One minute increment data from April 2015 – December 2015 was aggregated and sorted according to the following five modes of operation:

1. Space Heating (stage 1)
2. Space Heating (stage 2)
3. Domestic Water Heating
4. Space Cooling
5. Space Cooling + Desuperheater (for domestic water heating)

These are the same modes of operation described previously, except that the two stages of cooling were not disaggregated in our analysis.

After the data was sorted by mode of operation, a filter was developed to ensure that the temperature of the return water corresponded to the reported mode of operation. It is important to filter out data from the first several minutes of operation in each mode because the observed return water temperature would represent operation in the previous mode. The filter removed data from the analysis for the initial period T_f after each change of mode, where T_f was calculated to be approximately 5 minutes using equation 1. This means that a slug of water takes approximately 5 minutes to travel the round trip from the heat pump source supply to the heat pump source return.

EQUATION 1: FILTER CRITERIA

$$T_f = \frac{Source\ circut\ water\ volme}{Source\ circuit\ flow\ rate}$$

We also explored the temperature response of the ground on an hourly scale, in relation to the daily and monthly sums of heat rejected to and absorbed from the ground. This analysis was used to illustrate the temperature response of the earth within and surrounding one dry bore heat exchanger and one wet bore heat exchanger. The array of temperature sensors surrounding these two heat exchangers provided insight about the dynamic temperature profile in the ground as a function of depth and distance from the center of the bore. The amount of heat rejected to or absorbed by each heat exchanger was calculated using equation 2. The calculation was made for every minute of operation, then the results were summed to determine the hourly, daily, and monthly sum of heat transfer with the ground.

EQUATION 2: HEAT FLOW TO BORE EQUATION

$$\dot{Q}_{Source} = (Source\ circut\ flow\ rate) * C_p * (T_{Source\ Supply} - T_{Source\ Return})$$

RESULTS

HEAT PUMP BEHAVIOR AND RESULTING GROUND TEMPERATURES

Figure 3 illustrates the number of operating hours in each mode for each month observed. The figure shows that there were far more operating hours for cooling in the summer than for heating in the winter. In July and August the heat pump ran in cooling modes for more than 350 hours; on average this equates to more than 11 hours a day. Some days, the heat pump ran in cooling for 16 hours. These extended cooling run times rejected far more heat to the ground than would be regularly anticipated. This appears to have had detrimental effects on cooling performance for the heat pump. In particular, while the heat exchangers were able to reject waste heat from the heat pump, they were not always able to maintain a preferable return water temperature.

Figure 4 illustrates the cumulative amount of heat rejected and absorbed by the ground in each month, in each mode of operation. The figure also includes daily average temperatures for:

1. Mid field average earth temperature: The column of temperature sensors located in between two dry bore heat exchangers
    - Average of five sensors at depths 3 to 20 feet.
    - daily average values computed for all minutes in the month
2. Dry bore column 3 average temperature: The column of temperature sensors at the outer edge of one dry bore heat exchanger (column 3)
    - average of five sensors at depths 3 to 20 feet
    - daily average values computed for minutes with heat pump operation
3. Wet bore column 2 average temperature: The column of temperature sensors in the wet bore 6 inches from the center of the bore (column 2)
    - average of five sensors at depths 3 to 20 feet
    - daily average values computed for minutes with heat pump operation

Although the demand for cooling was much lower in October than for the period from July – September, temperature of the earth surrounding each bore was still elevated well above preferred operating temperatures (Figure 4). This appears to have resulted from the fact that the entire heat exchange field was saturated with heat from the previous months. On October 1st, the average of all sensors in the “mid-field earth temperature” column was 80°F.

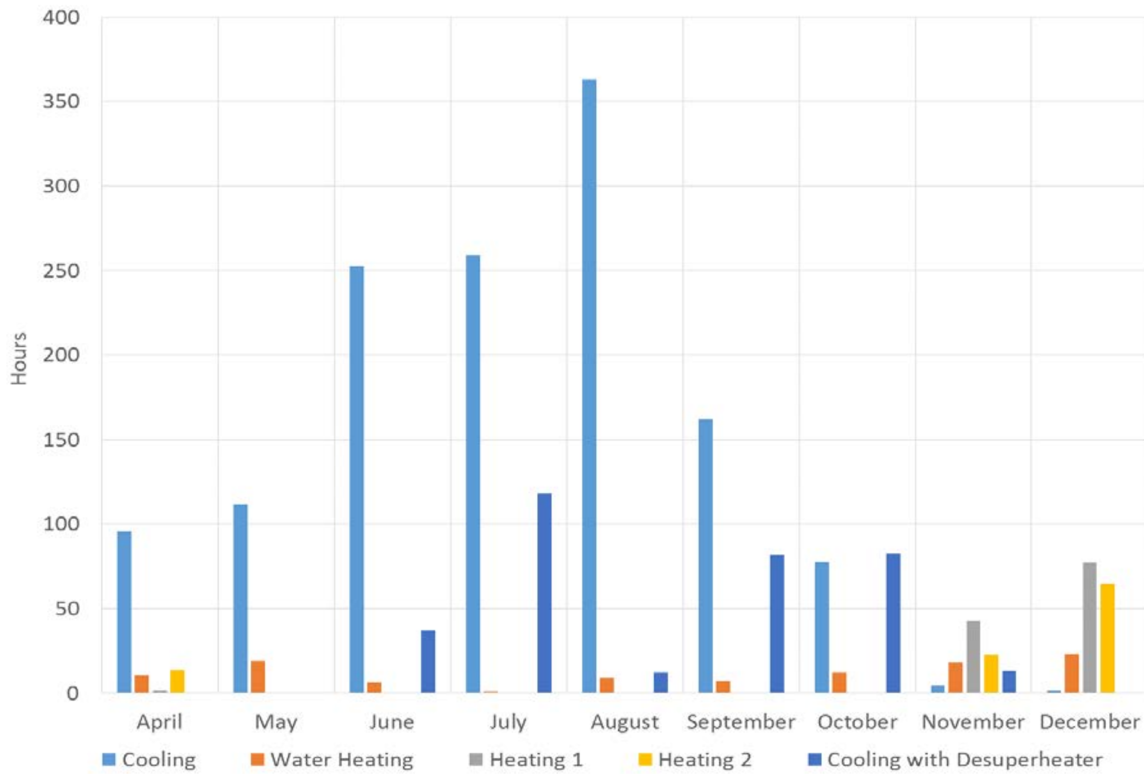

FIGURE 3: MONTHLY HEAT PUMP OPERATING TIME BY MODE

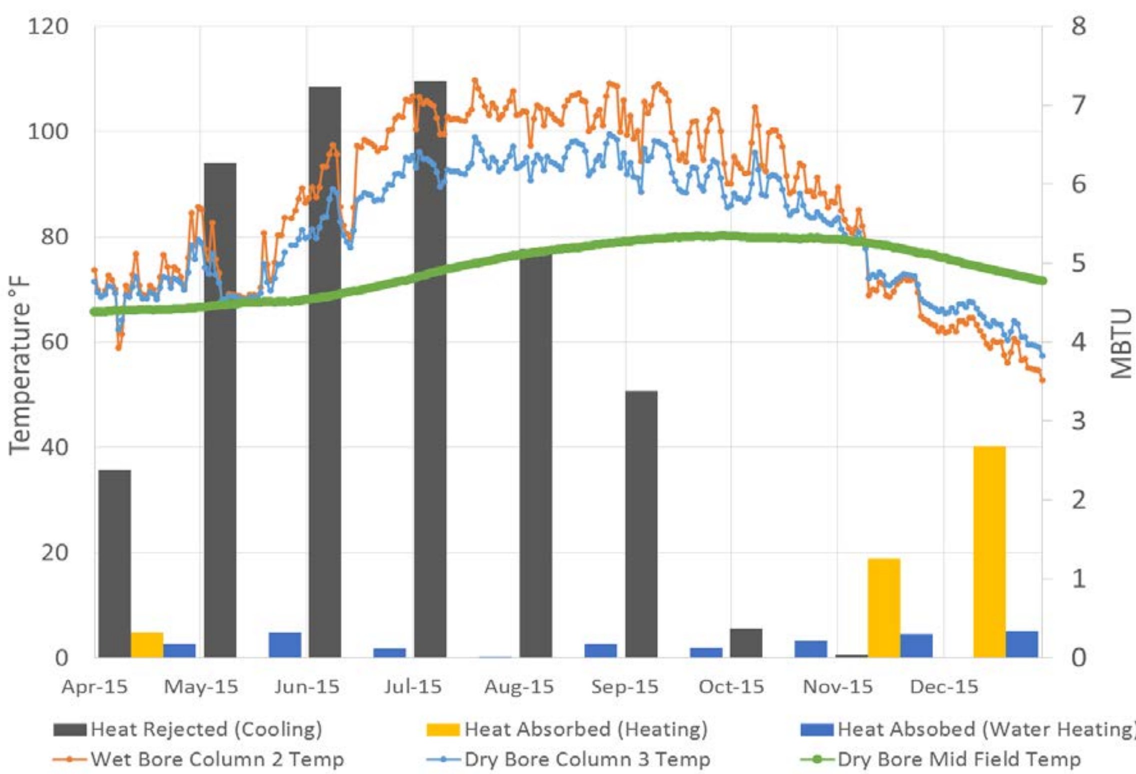

FIGURE 4: CUMULATIVE LOAD TO BORE ARRAY BY MONTH AND MODE

COMPARISON OF HEAT REJECTION RATES FOR EACH HEAT EXCHANGER

Figure 5 and Figure 6 compare the rates of heat rejection from each heat exchanger for each of the modes studied. Each minute of operation between March-December is included. The y-value for each point in these figures represents the heat rejection rate (or heat absorption rate) for each heat exchanger. The x-value for each point is the average heat rejection rate for the four dry bore heat exchangers in the corresponding minute. Heat rejection is presented as the positive convention, so the rate of heat absorption in space heating mode and domestic water heating mode is presented as negative.

The plots show that the dry bores are similar in character to each other, and that the wet bore behaves much differently. Most of the time, the wet bore outperforms the dry bores, but heat rejection rates are highly variable. At times, the wet bore heat transfer rate is twice as large as the average dry bore. Notably, the wet bore appears to improve overall heat transfer rates in both heating, and in cooling. However, in some instances the wet bore does not perform as well. In particular, for cooling with the desuperheater and in space heating (stage 1), there are some instances when the dry bores have better heat transfer rates. Some possibilities for this behavior are addressed in the discussion.

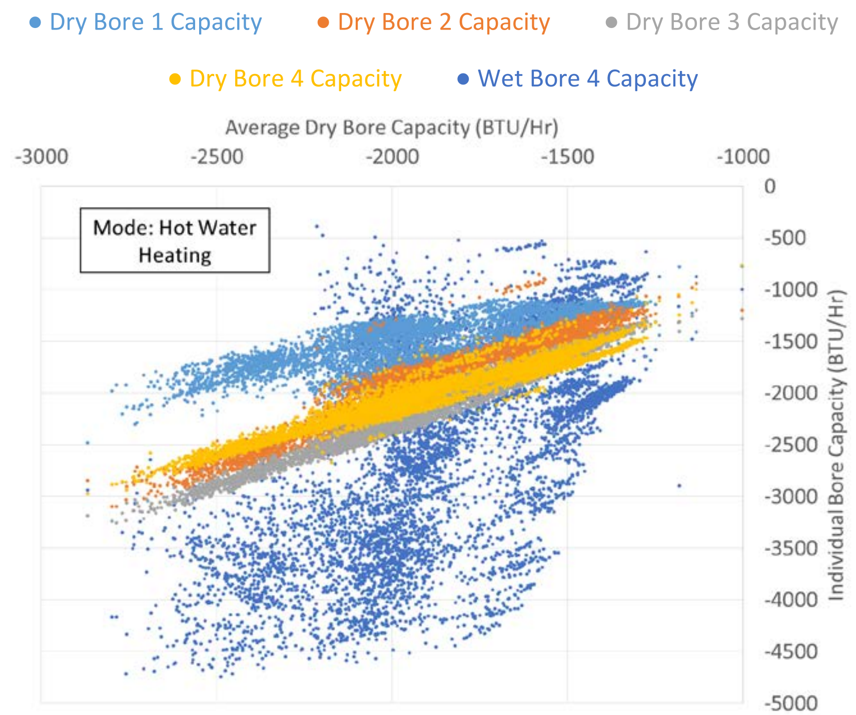

FIGURE 5: COMPARISON OF INDIVIDUAL BORE PERFORMANCE VERSUS AVERAGE DRY BORE PERFORMANCE FOR HOT WATER HEATING

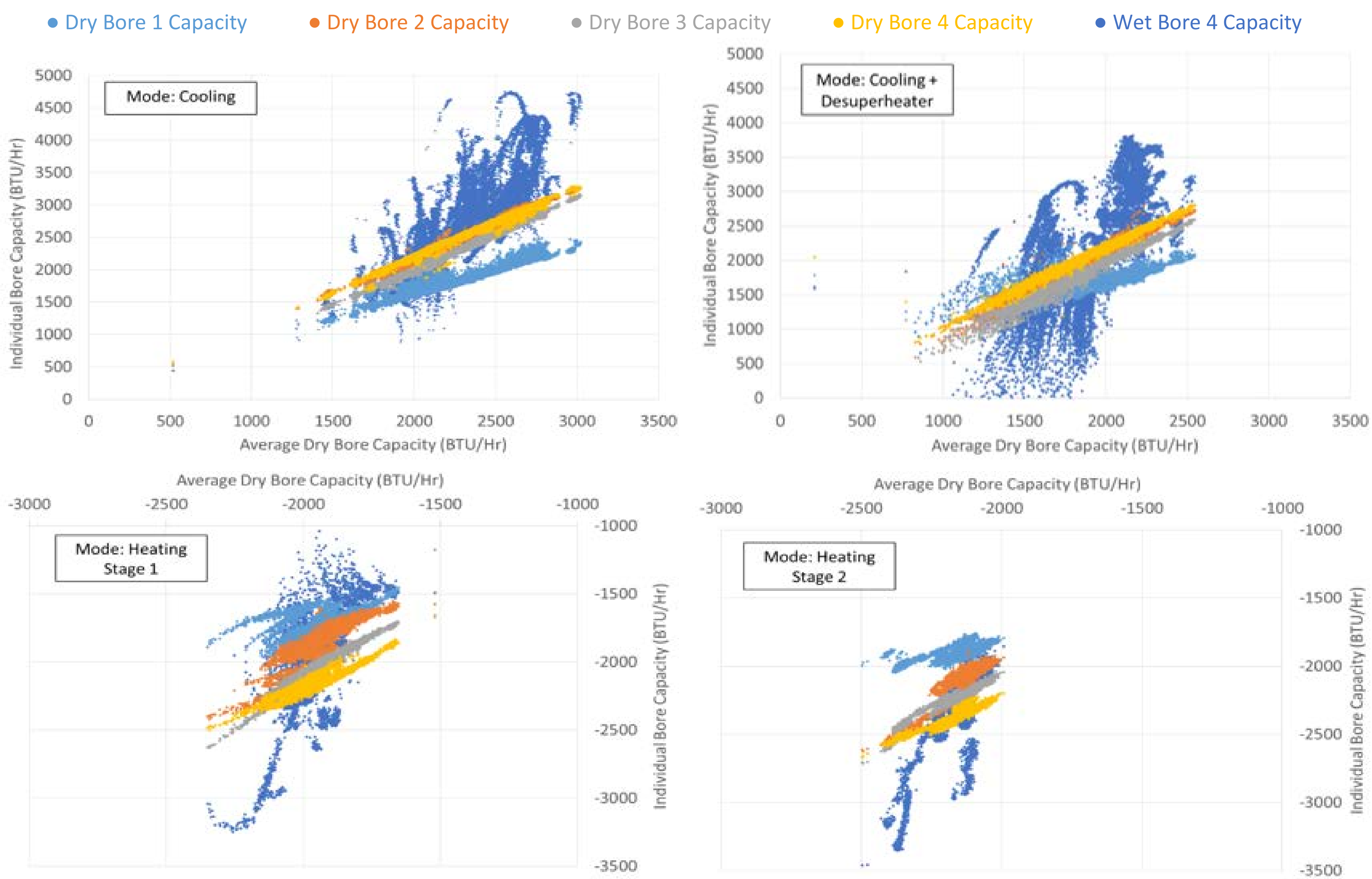

FIGURE 6: COMPARISON OF INDIVIDUAL BORE PERFORMANCE VERSUS AVERAGE DRY BORE PERFORMANCE FOR EACH HEATING AND COOLING MODE

Ground Temperature

Our analysis revealed several important observations about the way that source circuit temperatures and ground temperatures behaved at different time scales.

Figure 7 compares the hourly average temperatures of Dry Bore 1 column 3 and Wet Bore 4 column 2 to the daily minimum, maximum, and average ambient temperatures. The plot shows that:

1. The dry bore column 3 temperature is more favorable to heat transfer than the wet bore column 2 temperature. (lower in cooling season, higher in heating season)
2. The average air temperature is always lower than the bore temperatures (both wet and dry).
3. The dry bore column 3 temperature is close to the maximum air temperature in the cooling season

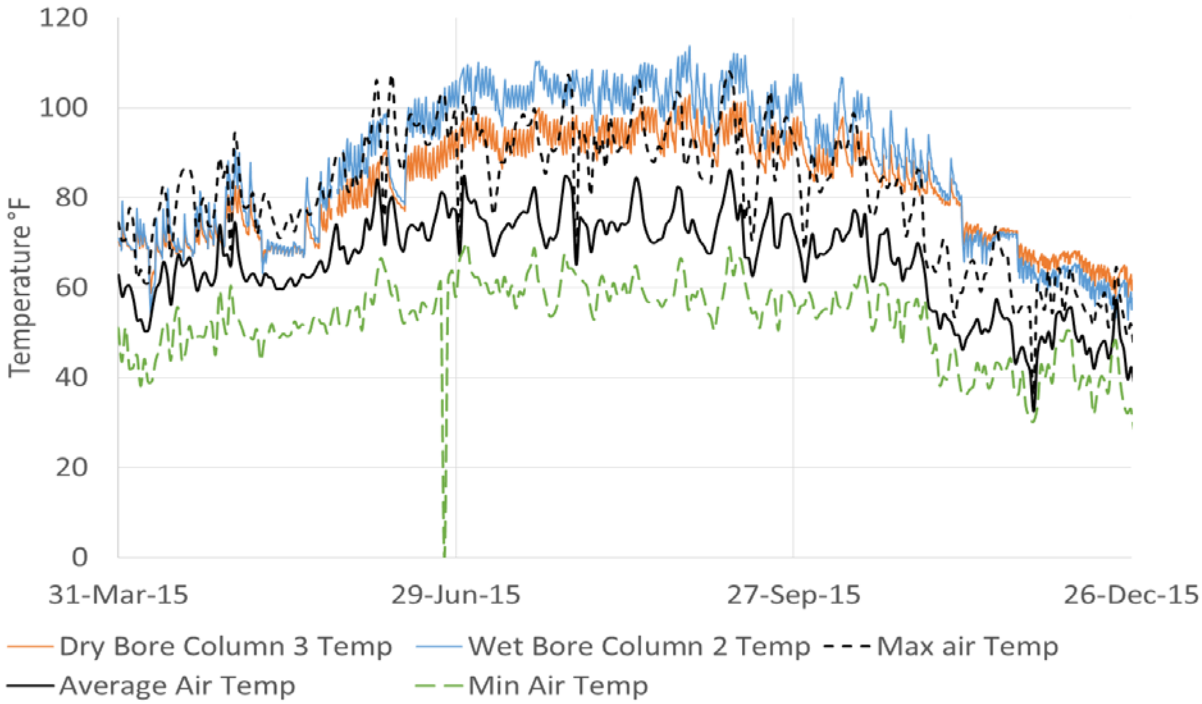

FIGURE 7: AIR AND GROUND TEMPERATURES

Figure 8 compares the time-series behavior of hour-average ground temperature measurements for Dry Bore 1 and Wet Bore 4 during two different five day periods. We chose to present one five day period for cooling and one five day period for heating corresponding to those days with the largest total heat rejected and absorbed. The figure reveals several interesting characteristics about the heat exchangers:

1. In cooling mode, temperature at the interior (columns 1 and 2) of Dry Bore 1 and Wet Bore 4 fluctuated by almost 10°F over the course of each day.
2. In heating mode, temperature at the interior (columns 1 and 2) of Dry Bore 1 and Wet Bore 4 fluctuated less than 5°F over the course of each day.
3. Each day, the bores dissipated much of the energy gained (or absorbed) while the heat pump was off, but over the course of these five day periods the daily average temperature of each column drifted by 2.5°F.
4. For the wet bore, the column 3 average temperature is much different than the interior temperatures (columns 1 and 2). This occurs because the temperature sensors for column 3 are located on the outside wall of the corrugated HDPE pipe (Figure 2 shows the specific location). In cooling mode, the

temperature change from column 2 to column 3 is almost as large as the change from column 3 to the mid-field earth temperature. This indicates that the pipe wall, and the associated water-wall-earth interface impose a significant thermal resistance.

5. The mid-field earth temperature drifts much more slowly, but changes by about 1°F during each of the five day periods observed. Our analysis was not sufficient to determine the extent to which temperature change for the mid-field earth temperature is driven by heat exchange with the heat pump source, and the extent to which it is influenced by ambient conditions.

Figure 9 and Figure 10 present the time-series behavior for source return water temperature during the same two five day periods presented in Figure 8. These figures also include the daily sum of heat rejected to or absorbed from the ground in cooling and heating mode respectively. The one-minute increment time-series temperature data in Figure 9 and Figure 10 is measured at the heat pump source return, is grouped by mode of operation, and only shows instances when the heat pump is on and in a non-transient state.

The most significant observation from these charts is that in the heating season the heat pump cycled several times each day, while in cooling mode the heat pump operated continuously for many hours at a time. Typically, the amount of heat rejected to the ground each day in the cooling season was larger than the amount of heat absorbed from the ground each day in the heating season. However, for days with comparable amounts of ground heat exchange, return water temperature changed more during the cooling season than it did in the heating season. For instance, on September 9th the system rejected approximately 175 kBTU heat to the ground and on December 28th the system absorbed 190 kBTU heat from the ground. However, on September 9th the return water temperature rose by 15°F while on December 28th the return water temperature drifted by less than 10°F. This difference is likely due in part to the fact that the heat pump cycled more in heating mode, which allowed more time for heat to dissipate.

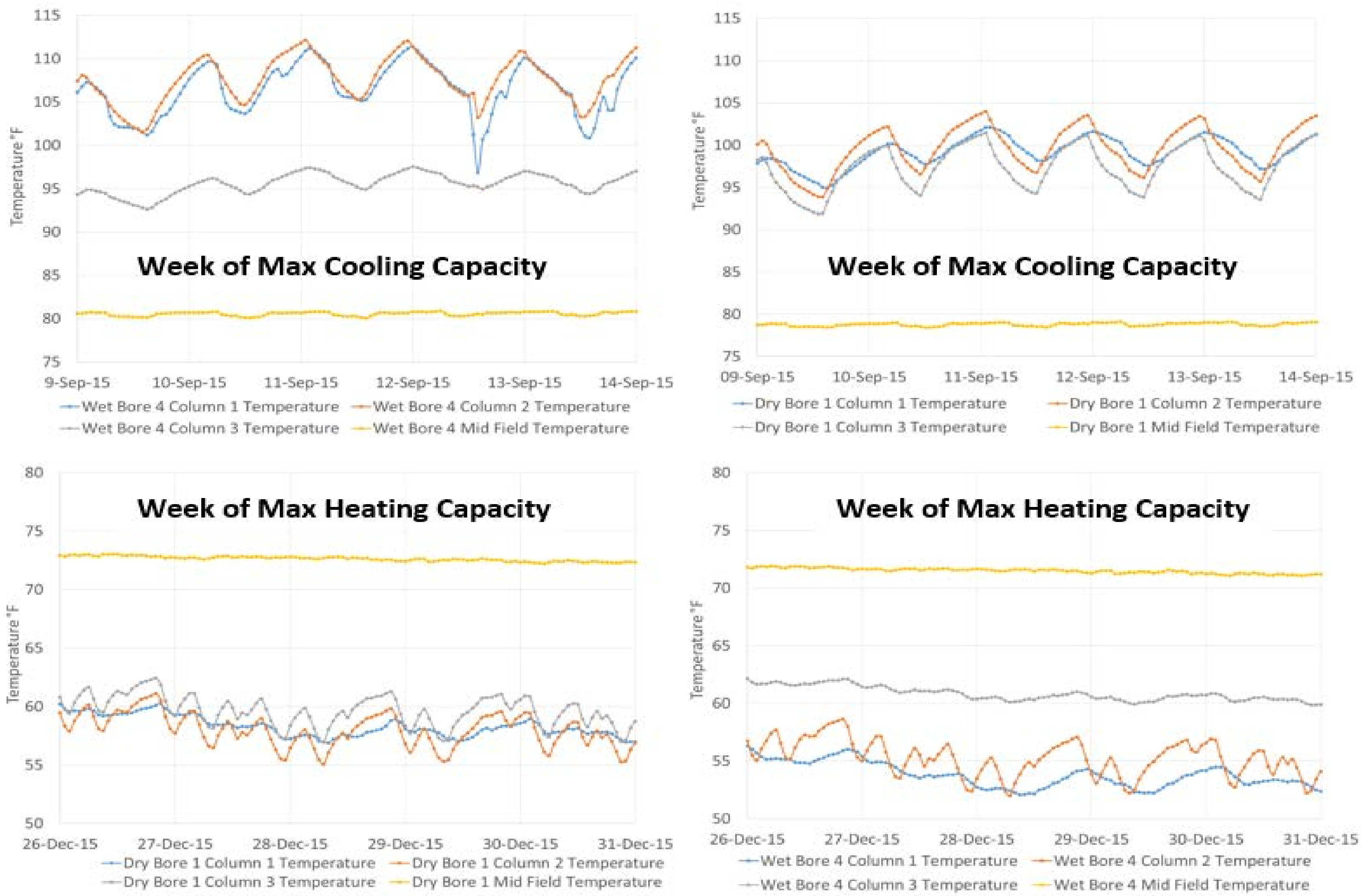

FIGURE 8: SHORT PERIOD GROUND TEMPERATURE RESPONSE

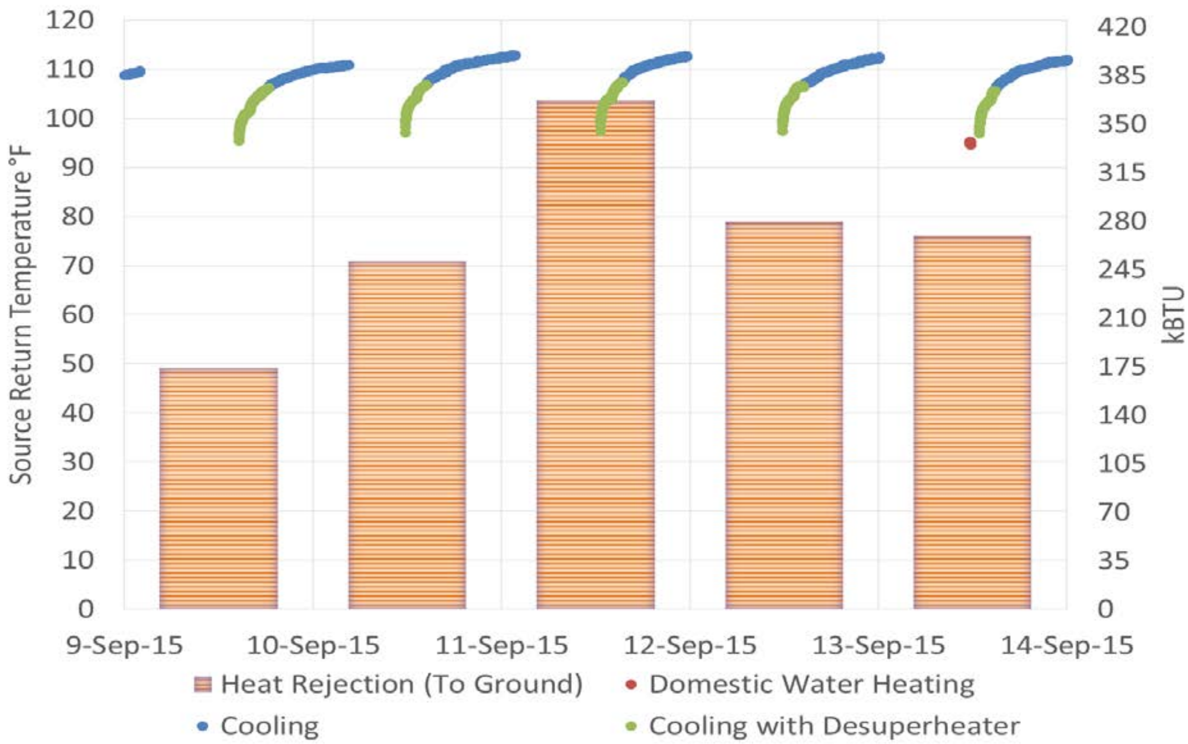

FIGURE 9: COOLING SEASON HIGHEST HEAT REJECTION BEHAVIOR

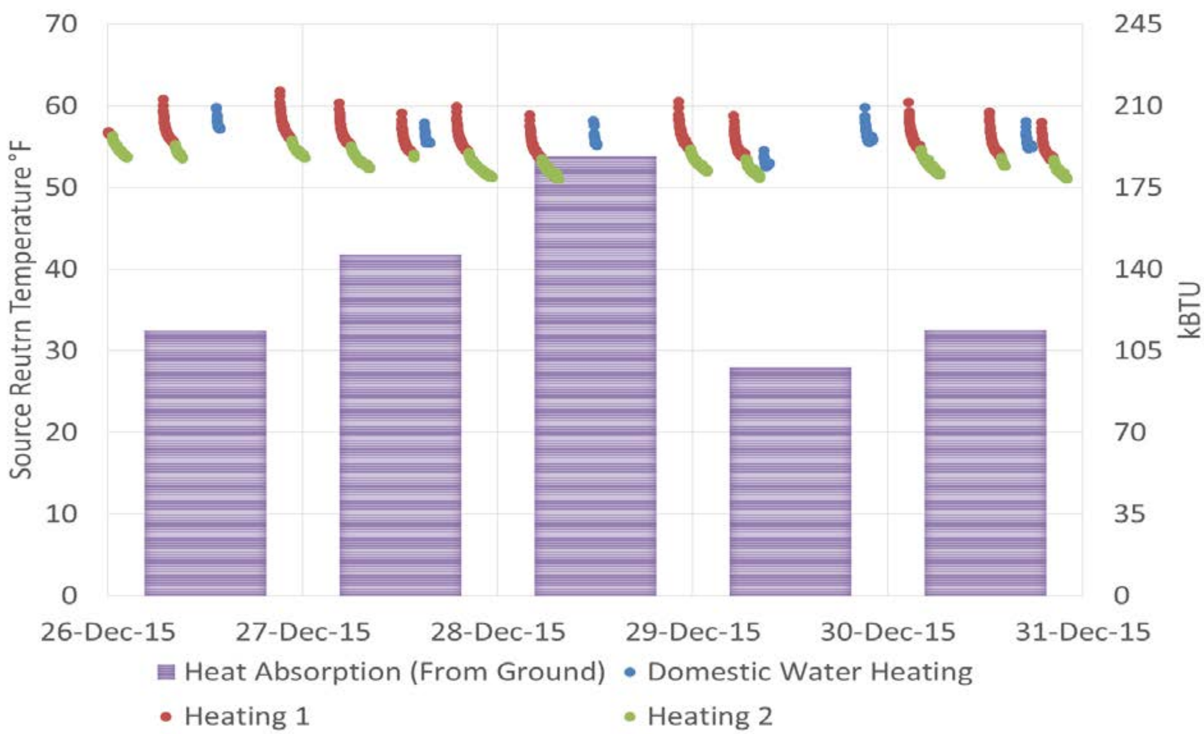

FIGURE 10: HEATING SEASON HIGHEST HEAT ABSORPTION BEHAVIOR

DISCUSSION

The results show the overall performance of a system designed to provide heating, cooling, and water heating to a home. The performance of this system is indicative of performance of the following 3 subsystems

1. Performance of the home
2. Performance of the heat pump
3. Performance of the bore array

The characteristics of any of the 3 subsystems above affects the performance of the whole system, and interpretation of the results should account for the interdependence of the subsystems.

BORE ARRAY PERFORMANCE, COOLING

During cooling season, the bore performance suffered toward the end of the cooling cycle each day. The temperature of the return water toward the end of the cooling cycle were between 110°F to 115°F, whereas at the beginning of the cycle the temperature was typically between 95°F and 100°F. The large temperature rise each day indicates that the rate of heat rejection through the heat exchanger was larger than surrounding earth was able to dissipate continuously at a fixed temperature. The high temperature at the beginning of each day suggests that there was not enough off time each day to allow the ground to recover to preferable operating temperature.

Cooling loads for the home were much higher than anticipated, and the heat pump operated in cooling for long periods (often 12-15 hours at a time). As a result, the ground mass surrounding these heat exchangers became saturated with heat. The shallow bore heat exchangers were able to reject heat from the heat pump, but they were not always able to maintain desirable return water temperatures while doing so. The cause of the unreasonably large cooling loads is under investigation but was not determined at the time of this report. The increased ground temperature caused a compounding problem in cooling mode. As the heat exchangers operated throughout the season they significantly heated the ground around the bores. As the bores and ground heated up the heat pump capacity and efficiency decreased. As a result, the compressor ran longer than it would otherwise, which resulted in larger overall heat rejection to the ground, and further warming. In this experiment, the heat rejected from the home was larger than what the ground could dissipate without increasing in temperature.

Since the amount of cooling generated by the heat pump was much larger than what was anticipated, it is difficult to assess how the shallow bore heat exchangers would perform in a system where they are appropriately matched to heat rejection needs. The reasons for the excessive cooling are currently under investigation, but were not determined at the time of this report.

Bore Array Performance, Heating

The bore array performance in heating was significantly different than cooling. The highest recorded heat absorption from the ground was 192 kBTU in a day, and the highest temperature change in return water temperature was a 10°F drop in a day. In addition to having lower loads delivered to the ground, the heat pump cycled on and off several times a day in heating, allowing the ground to recover heat between cycles. This heat recovery period is crucial, and allowed the return temperature to the heat pump to operate for more cumulative time at a higher temperature, which is preferred in heating.

In water heating the system performed exceptionally well in the cooling season, and also seems to have performed well in the heating season. During the cooling season it was common for most of the domestic hot water needs to be met by the desuperheater, the domestic water heating mode was only needed occasionally. This was at least partially a consequence of the excessively long run times in cooling. In the heating season, water heating had a minimal impact on the bores and represented only 10%-20% of the monthly load on the bores.

COMPARISON BETWEEN WET BORE AND DRY BORE

The capacity of the wet bore was usually larger than the capacity of each dry bore, however the performance of the wet bore heat exchanger was highly variable. The variation was likely due in part to the variation in grey water flow through the bore, as well as the temperature of grey water supplied to the well. An overall comparison of both types of bores in the cooling season revealed that the wet bore rejected about 16% more thermal energy than the average dry bore. Despite this performance advantage, we do not recommend that future projects replicate the specific design used in this project. The 20' deep reservoir was complicated to construct and was prone to leaking. Other researchers and manufacturers have demonstrated more promising designs for heat-pump assisted drain-water heat recovery than the design studied in this project (Wallin, Baek, Ni, Nexus). The dry bores functioned as designed without any failures.

Cost Analysis

We developed a comparison of estimated costs for the heat exchanger heat exchanger and a traditional ground heat exchanger. The estimate was developed using relevant market data to determine the cost of each system. For a traditional system, our research indicates that costs are highly variable due in part to geography and variations in site geology. Since deeper wells are more likely to encounter problematic geologic features, the variation in cost per foot increases with the depth drilled. Since the shallow bore heat exchanger only requires an auger to 20' depth, we anticipate that there would be less variation in cost between sites. Also, our research suggests that there is large variation in the cost of traditional ground heat exchangers because there is very little marketplace competition. Since the shallow bore heat exchanger uses tooling that is more widely available, we anticipate that there would be less variation in cost between sites. The cost estimate for the shallow bore shallow bore heat exchanger was developed based on expected labor and material costs. The traditional system cost is presented as range based on literature estimates and input from experienced contractors.

Traditional System

The range of cost for the traditional system was developed by considering the expected costs of installing the traditional heat exchanger for a residence with a 4ton heat pump. Such a system was expected to be split into 4 bores with the depth of each bore ranging from 150' to 200'. A 2011 study by Hackel et al. reviewed the installed costs for more than 50 ground heat exchanger installations; their results show that cost per foot of installed heat exchanger is expected to range between $8 and $17.50 (Hackel, Pertzborn, 2011). The cost range is only for the cost of the installed heat exchangers and does not include installation of the heat pump. Therefore, for the 4-ton scenario, the expected cost range is $6,000 to $22,000. The median expected cost is $13/foot for 4 bores at 175' each; this works out to a median expected cost of $9,100.

Shallow Bore Heat Exchanger System

The cost estimate for the shallow bore heat exchanger system was developed assuming installation of multiple systems at once, and therefore reflects a volume discount on materials, and more efficient mobilization of equipment. The prices are based on expected material and labor costs associated with the system. The number of coils needed to serve a 4 ton home is assumed to be 12. The following assumptions are made based off manufacturer data (Bourne, 2016).

Heat Exchanger Material

The typical retail price for a fully assembled heat exchanger is $175 per coil.

Borehole Drilling

It is estimated that it would take about 4 hours to drill 12 boreholes with the dimensions needed for the shallow bore heat exchanger at a cost of $180/hr. Therefore, each borehole is priced around $60.

Borehole Filling

Labor to backfill the bores with native earth costs would require 3 hours at about $80/hr. Therefore, it would cost about $20 per bore.

Excess Dirt Removal

No excess dirt removal would be required for the bores if they were backfilled with native earth.

Cost to connect system to Heat Pump

The cost to connect either system to the heat pump includes the costs of trenching, piping, connecting, and testing each heat exchanger. The cost of the piping from the shallow bore heat exchangers to the heat pump is estimated to be about $180. This number is derived from the use of 150 ft. of piping at $1.20 per ft. The labor cost to connect and test the units is estimated to take about an hour per home at $40 per hour. The labor cost to create trenches for the connection piping as well as level the pipe and backfill the trenches is totaled at $360 under the estimate that it would take 3 hours per home at $120 per hour.

Cost Comparison

TABLE 2: COMPARISON OF GROUND SOURCE HEAT PUMP INSTALLATION COSTS COMPARING A TRADITIONAL BORE SYSTEM TO A HELICAL BORE SYSTEM

Residential Ground Heat Exchanger Installation	**Expected Cost of Dry Shallow Bore Heat Exchangers**	**Traditional System Cost Range**
Number of Bores	12	**Range: $6,000 - $22,000**
Heat Exchanger Material Cost	$2100	
Bore Hole Drilling	$720	
Bore Hole Filling	$240	
Connect System to Heat Pump	$580	
Haul Excess Dirt	$0	
Install Projected Cost	**$3640**	

Conclusions and Next Steps

The data obtained from the performance assessment of the shallow bore heat exchangers shows the potential risks and benefits associated with the technology. In heating mode, the energy efficiency of the shallow bore ground source system is expected to be superior to an air source heat pump in part because the ground temperatures of the bores were consistently higher (by about 5°F – 10°F) than the air temperatures over the course of the demonstration. In cooling modes, the ground was overwhelmed by an excessive amount of heat rejected from the cooling system, and regularly operated with return water temperature exceeding 100 °F. Since performance of the home and heat pump system were not studied for this report, we cannot explain why the cooling load was so much higher than anticipated. It is particularly striking that the cooling system operated well into the late evening and early morning hours, when the outdoor air temperature was 70°F or lower. The data shows that in this installation, there was a negative feedback loop where in cooling where high ground temperatures led to poor performance of the heat pump, this caused the heat pump to run longer and reject more heat to the ground which caused accumulation of heat in the ground. This observation suggests that appropriate sizing of the shallow bore heat exchangers is very important for performance, whereas traditional air cooled systems essentially have an unlimited the supply of air for heat rejection.

The cost analysis showed that, due to the reduced depth, drilling costs associated with the technology are significantly lower than the existing deep bore technology. In fact, the projected costs are very attractive, and could offer a more cost effective path to ground source heat pumps.

The technology has potential and the work at this demonstration site highlights some of the areas where future research should be directed. In particular it would be helpful to understand the capacity-temperature response of the helical coil / ground system independent of the home system. It is especially important to develop clear guidelines for how to size these heat exchanger arrays. It would be very helpful for future research to determine the maximum daily heat rejection or absorption capacity of the coils without significantly altering the average daily ground temperature. Additionally, if such test data were to be used to develop a physical model of the bore array, the model could be used to explore different bore arrangements and optimize performance.

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