PROJECT REPORT

DIRECTIONAL-BORE GROUND SOURCE HEAT PUMP FIELD REPORT

Rio Mondego, California

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WESTERN COOLING EFFICIENCY CENTER

UC DAVIS
UNIVERSITY OF CALIFORNIA

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ABOUT THE WCEC

The Western Cooling Efficiency Center was established along side the UC Davis Energy Efficiency Center in 2007 through a grant from the California Clean Energy Fund and in partnership with California Energy Commission Public Interest Energy Research Program. The Center partners with industry stakeholders to advance cooling-technology innovation by applying technologies and programs that reduce energy, water consumption and peak electricity demand associated with cooling in the Western United States.

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GRAPHS

1.0 EXECUTIVE SUMMARY

The residential home at Rio Mondego where the directional bore GSHP demonstration took place (left). A new gas water heater was also installed (middle). Image of the geo-thermal pipes (right).

The project at Rio Mondego was a demonstration of a ground source heat pump system utilizing directional boring technology. The construction of the heat exchanger utilized 5 directionally bored holes of approximately 130' in length emanating from a single point manifold. Into these bores a conventional u-tube heat exchanger was placed and the bore was filled with grout.

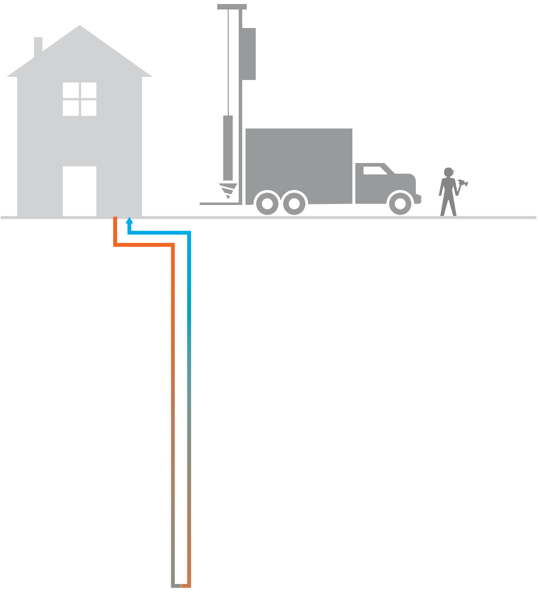
The performance of the earth heat exchanger was shown to be adequate during summer cooling months without any failures; however inspection of the peak entering water temperatures (as referenced to the heat pump) and ambient temperatures showed that these temperatures are nearly the same and as compared to other GSHP systems the daily range of temperatures experienced appears to be higher than typical. This may be an indication that the field was undersized for the load that it is experiencing. It is also suspected that the grout application did not completely fill the bores and that this may have led to reduced performance.

Overall the system proved it was capable of fairly high efficiencies, ranging from 10 – 20 EER in the summer and 3.5 to 6 COP in the winter. However, even though the system was capable of achieving very high efficiencies, the numbers over the complete season for this system were found to be EER of 10.9 for cooling and COP of 3.9 in for heating if the extra energy recovery from the desuperheater is ignored. If this energy is credited, the efficiency numbers are 12 EER and 4.6 COP. The low overall efficiency is most likely the consequence of an undersized or underperforming geo-exchange loop. If the unit was able to operate around 10 F above or below earth temperature EER in the range of 17-18 and COP of around 4.7 would be expected.

2.0 GROUND SOURCE HEAT PUMP TECHNOLOGIES

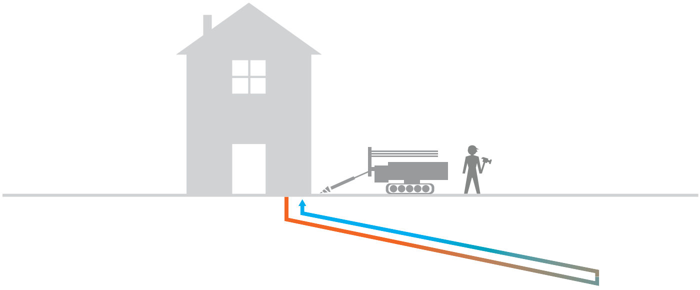
CONVENTIONAL VERTICAL BORE EARTH EXCHANGER

- » 150+ foot drill hole
- » Large, expensive drilling rig



DIRECTIONAL BORE EARTH EXCHANGER

- » 20 foot deep borehole, 150-feet across
- » Compact, less expensive, drill rig
- » Simultaneous drilling and pipe installation



Conventional Vertical Bore Earth Exchanger

Conventional vertical boring is constructed with deep vertical boreholes typically 60 – 200 feet in depth and around 4” – 6” in diameter. Into each bore a U-tube heat exchanger is buried and grouted into place. Fluid is pumped through these heat exchange pipes and transfers heat with the ground. Roughly 270 to 350 feet of piping can provide 12,000 Btu/hr of heat pump capacity, but this rough estimate is subject to pipe surface area and length, temperature difference between the ground, load profile, and other factors.

Closed loop ground source heat pump systems have heating COP ratings between 3.1 and 4.9, while cooling EER ratings range from 13.4 to 25.8. Air source heat pumps, on the other hand, typically have COP ratings between 3 to 3.5 and rapidly loose efficiency at temperatures below freezing and in high temperature regions.

The costs of ground source heat pump equipment is marginally more expensive than the air cooled equivalent, but this is mostly due to the low volume of production as GSHP make up only a small fraction of the total market. The equipment has the potential to be less expensive due to the needs of smaller condenser heat exchangers and pumping motors. The majority of the cost associated with ground source The typical cost of creating vertical deep wells is mostly dictated by field installation expenses. The cost of the HDPE tubing used and couples may only be $1 - $2 per foot. The installation costs however may drive expenses to $25 - $40 per foot.

Directional Bore Earth Exchanger

Directional boring, used largely as an alternative to trenching when laying pipe or running underground conduit, can also be used for the installation of geoexchange fields. The technique takes advantage of the wide availability of the relatively inexpensive and easily transported directional boring equipment. Unlike vertical drilling, where a new setup is required for each bore, a directional bore field takes advantage of being able to originate all bores from a single central location. This eliminates multiple setups and simplifies the connection and manifolding required to connect the earth exchange field to the mechanical equipment. Additionally, unlike vertical bores that remove dirt from the bore that later needs to be hauled away, the directional bore process produces no waste. The earth is compacted around the bore as it is made without removing it. The technique also allows ground source technology to be considered on parcels that would be too small for conventional vertical boring techniques by allowing the bores to be drilled under housing structures, landscaping, and other obstacles.

3.0 DEMONSTRATION: DIRECTIONAL EARTH BORE AT RIO MONDEGO

A directionally bored residential ground source heat pump (GSHP) system was installed in the Pocket neighborhood of Sacramento in mid-2013. The WCEC installed monitoring equipment on this system and collected data continuously from July 17, 2013 to July 16, 2014.

Q3 2013

Installation of the directional geoexchange took place over one week in July. The installation included 5 130' ft. directional bores drilled from one edge of the property under the residence to the far corner of the property. The bores had convential u-tube exchangers installed and were backfilled with grout. Simultaneously work was completed to remove the air source heat pump (ASHP) and install a water source heat pump WSHP. The compressor unit was placed in the garage and integrated with a hot water preheat tank, the air handler unit was placed in a mechanical closet within the house. The system was commissioned and data collection began on July 17, 2013.

Q4 2013

Data was collected and the system was monitored. An unusually cold multiday period in December caused a system shutdown that required adjustments to be made to the control strategy. These changes were expected to correct the issue and allow for extended cold weather operation.

Q1 2014

Data collected and the system monitored. The system operated nearly every day in a heating mode. There have been no reports of failures and no extreme weather conditions of the magnitude of the December period when issues were experienced.

Q2 2014

Data collected and the system was monitored. The weather in the shoulder season was mild and the system has seen sparse usage, especially at the beginning of the quarter.

Q3 2014

June 17th marked a full year of data collection. Data is analyzed and the final report prepared for the sponsor.

4.0 THERMAL ANALYSIS

4.1 Climatic and Geothermal Conditions

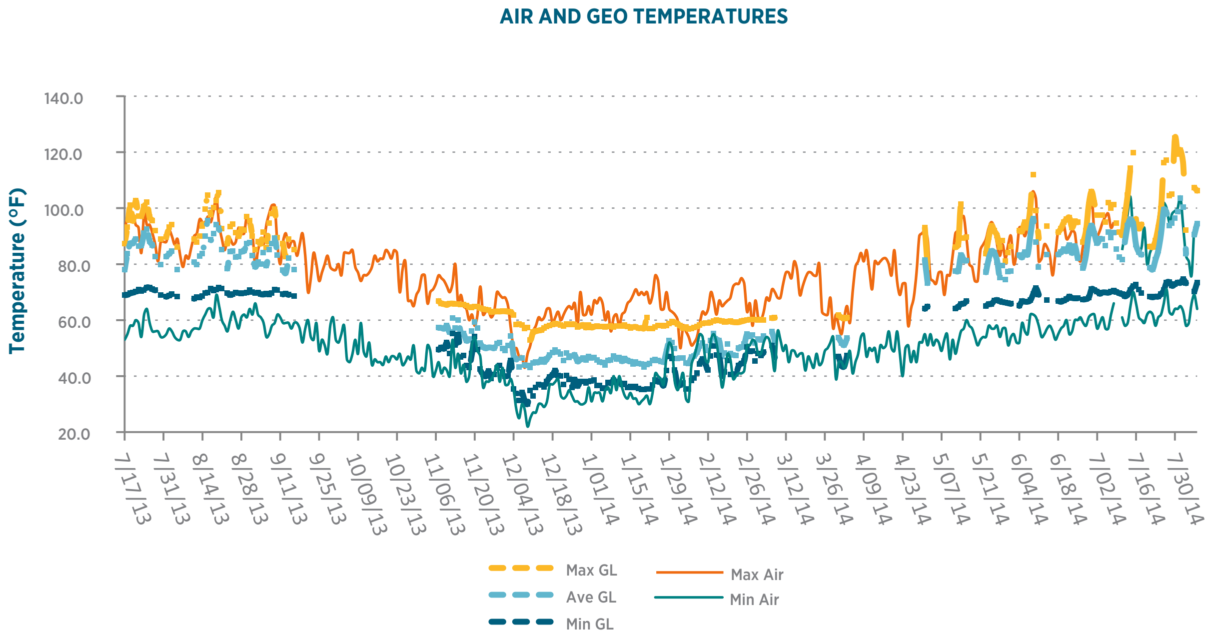


Figure 1: Ground loop temperatures as a function of outside air temperature

The system was installed in the middle of summer and started collecting data just after an extended time period of high temperatures. Figure 1 shows the daily high and low temperatures for outside air as solid lines. The ground loop temperatures are indicated by dashed lines, with markers. Areas in which markers are absent indicate days when the heat pump system did not operate at all. The maximum and minimum ground loop temperatures are recorded. The maximums and minimum ground loop temperature is can be from either the GEO_EWT or the GEO_LWT sensor, so during the cooling season the minimum will be from the GEO_EWT sensor, but during the heating season the GEO_LWT will record the minimum temperature. The average ground loop temperature is the average of the GEO_EWT and GEO_LWT temperature over the entire 1 minute date points taken throughout the day.

Figure 2: Entering Water Temperature (EWT) and Leaving Water Temperature (LWT) during the peak cooling and peak heating day of the year.

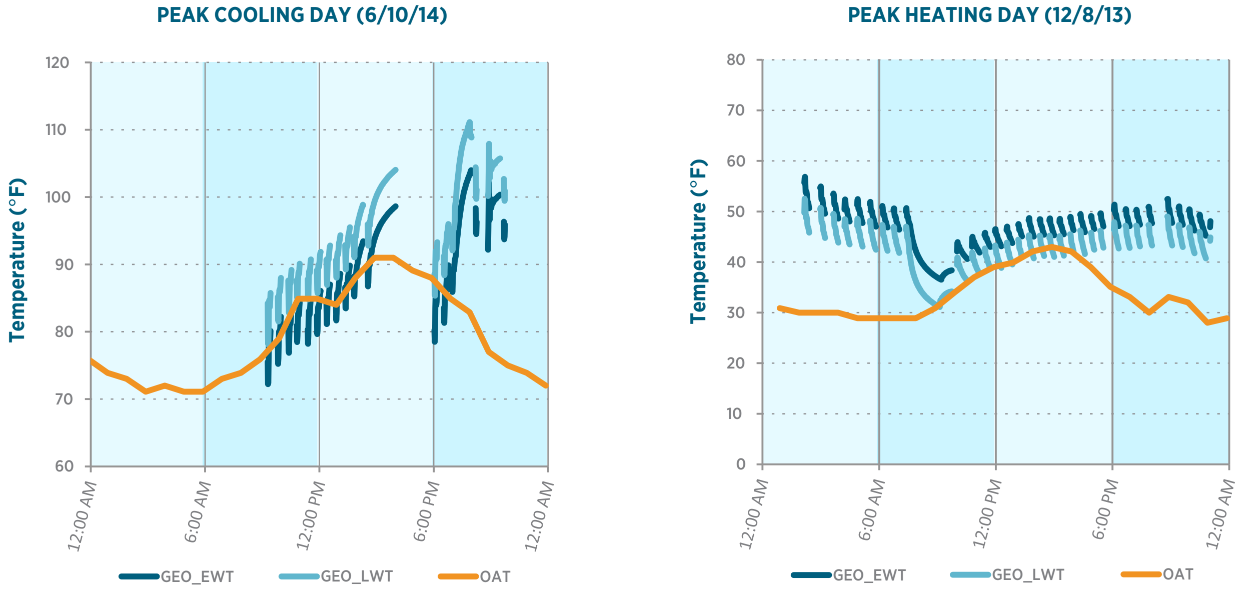


Figure 2 shows the entering water temperature (EWT) and leaving water temperature (LWT) as referenced from the GSHP for the peak cooling and peak heating day of the year. It is of interest to note that each cycle of the GSHP changed the EWT by approximately 5 degrees F, but over a complete day the change in EWT might be greater because of multiple cycles each starting at an EWT successively higher (when cooling) or lower (when heating). During the heating period on 12/8/13 it was noted that the GSHP reached a lower temperature limit with LWT from the GSHP approaching freezing. During the peak cooling day in the summer it can be seen that a significant rise in EWT over the course of the day is apparent. These are both indications that the geoexchange field was not well matched to the load.

This figure illustrates that it may be possible that during certain hours of the day, and in certain conditions, it may not always be better to use a GSHP. At least during the peak cooling day, there are times in the late afternoon when air temperature has fallen below the ground temperature.

Calculations were made for the thermal energy delivered to the home, as well as a metric for heating degree days (HDD) and cooling degree days (CDD). HDD and CDD were calculated using the sine wave approximation method. The base temperature was adjusted so that good correlation could be made between the xDD calculation and Q_del to the building

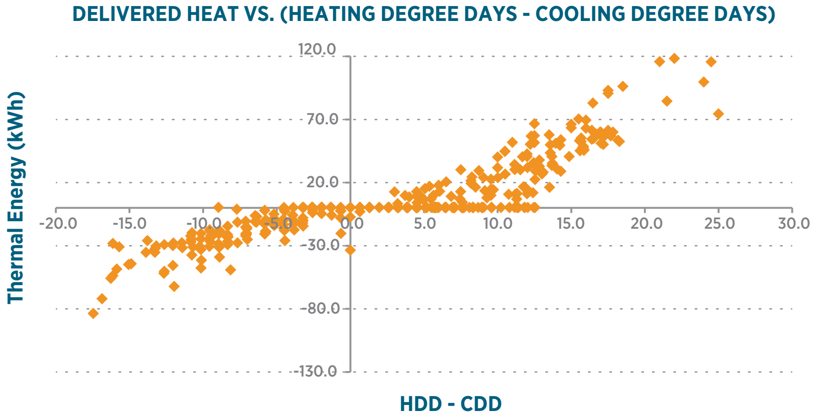


Figure 3: Delivered Heat vs. heating degree days minus cooling degree days

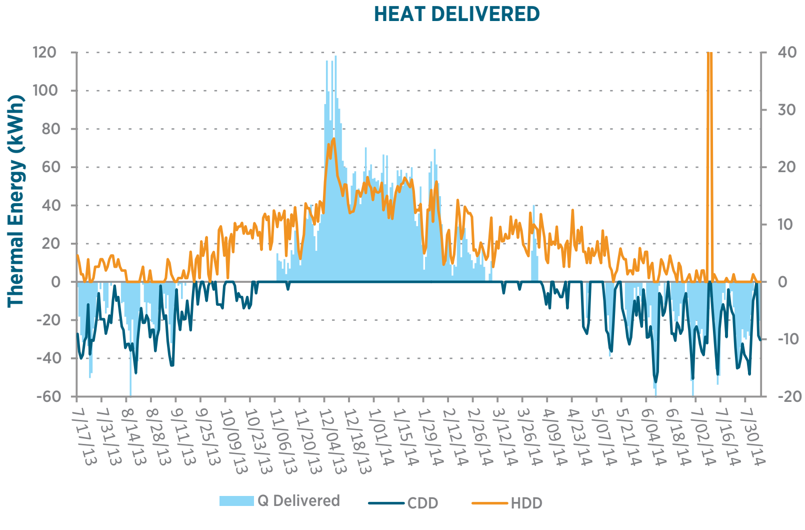


Figure 4: Amount of heat delivered in kWh

4.2 Energy Usage

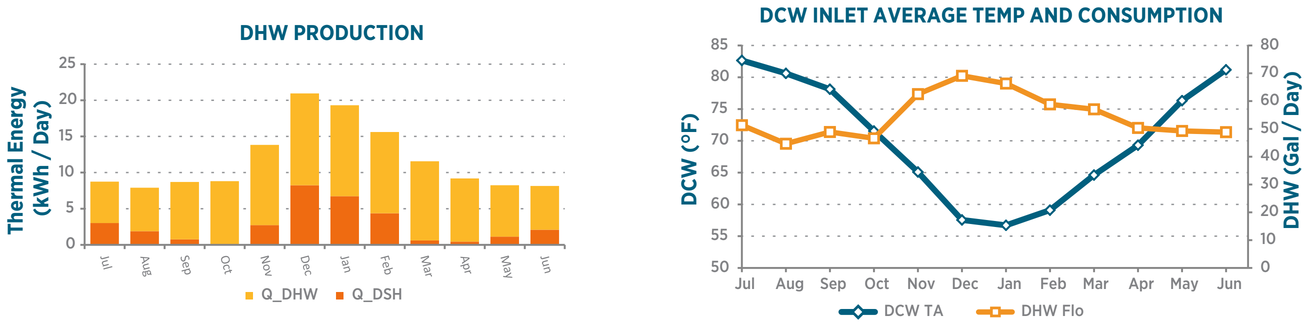


Figure 5: Domestic hot water (DHW) production, Domestic Cold Water (DCW) inlet average temperature and consumption

and may not match other sources for tabulations of HDD and CDD.

A visualization for the amount of heat delivered to the space and the calculated degree days was produced in Figure 4. It was found that a fairly good correlation could be obtained if the thermal energy was plotted against the quantity [HDD – CDD].

Measurement of the domestic hot water energy with the fraction heated by the NG heater and the heat pump was one of the most challenging calculations to make. The system installed utilized a hot water preheat tank that was heated by the desuperheater. The preheated water from this tank was drawn into the NG hot water heater and was heated to the final supply temperature.

A distinct increase can be seen in total heating energy for hot water during the winter season. Upon analysis it was found that two factors contributed to this increase. First, during the winter months somewhat more water was used. More importantly though, it was found that the entering water temperature was much lower in winter months, thus requiring more heat to bring the DHW up to its final delivery temperature and also requiring more DHW to mix with DCW to reach the desired usage temperature.

Over the year it was found that 36% of the DHW need was supplied by the GSHP desuperheater, the remaining 64% was supplied by the natural gas fueled hot water heater.

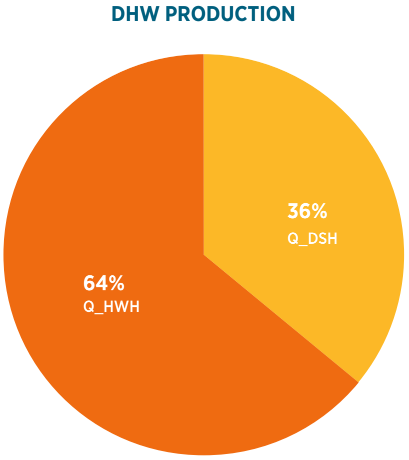


Figure 6: Domestic Hot Water demand percentages met by the hot water heater (Q_HWH) and the desuperheater (Q_DSH)

Heat pump input energy was evaluated in two different ways. Figure 7 shows a plot with input energy split out by component for Fan, Ground Loop Pump, and Compressor.

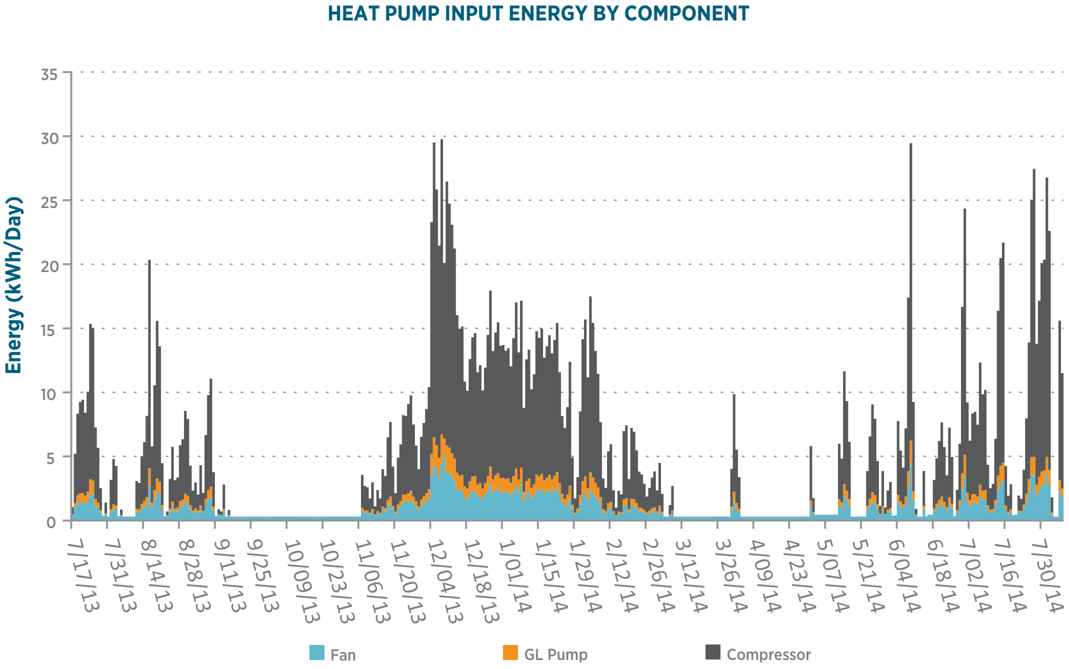


Figure 7: Heat pump input energy by component

The heat pump energy was also split out by operating mode. Figure 8 shows the same energy split out of the total by mode and condenser and air handler unit (AHU). The condenser unit represents the energy used by the compressors and water pump, while fan power is the power consumed by the indoor air handling unit.

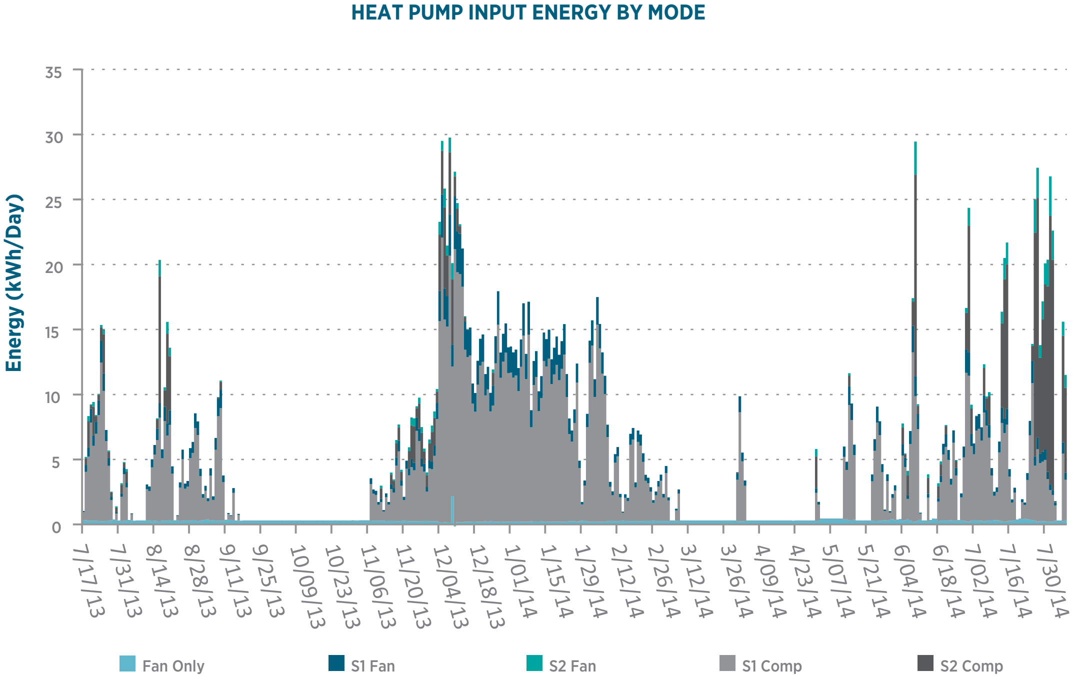


Figure 8: Heat pump input energy by mode

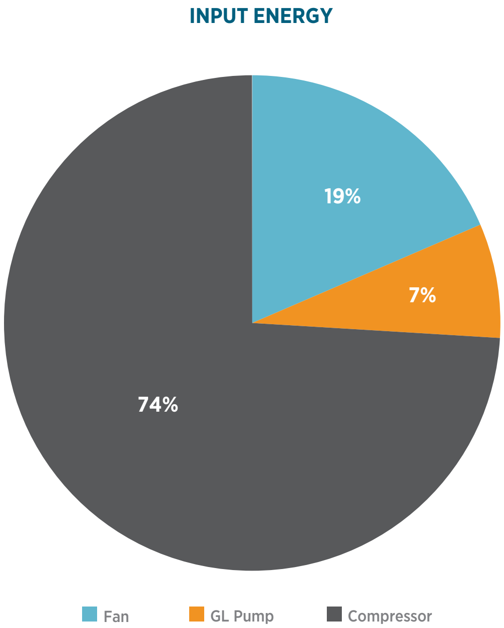


Figure 9: Input Energy by Mode

Figure 9 shows the split of input power over the complete season. As can be seen the ground loop pump uses less than half of the energy as the indoor supply fan. The majority of the energy is used by the compressor.

Figure 10 shows the amount of heating or cooling delivered to the home over the period of observation. As can be seen in Figure 11, heating accounts for 68% percent of the thermal energy delivered to the home.

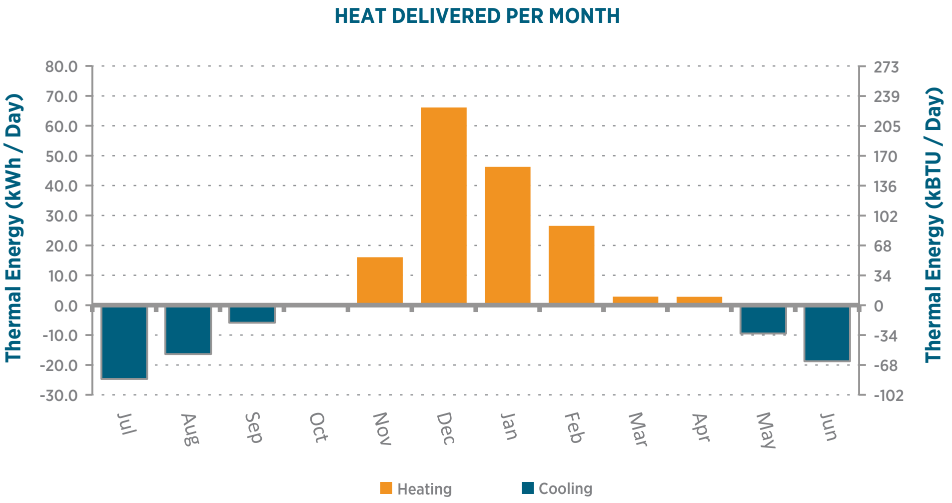


Figure 10: Heating/Cooling delivered to home during observation period

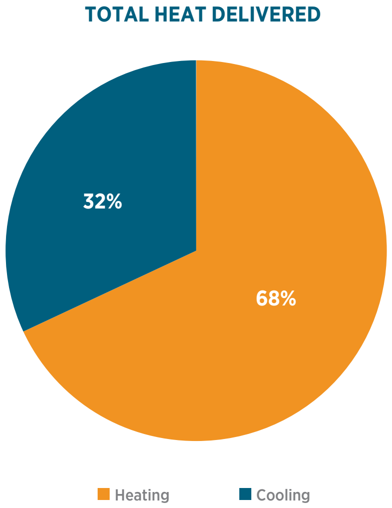


Figure 11: Total heating and cooling delivered by the GSHP system

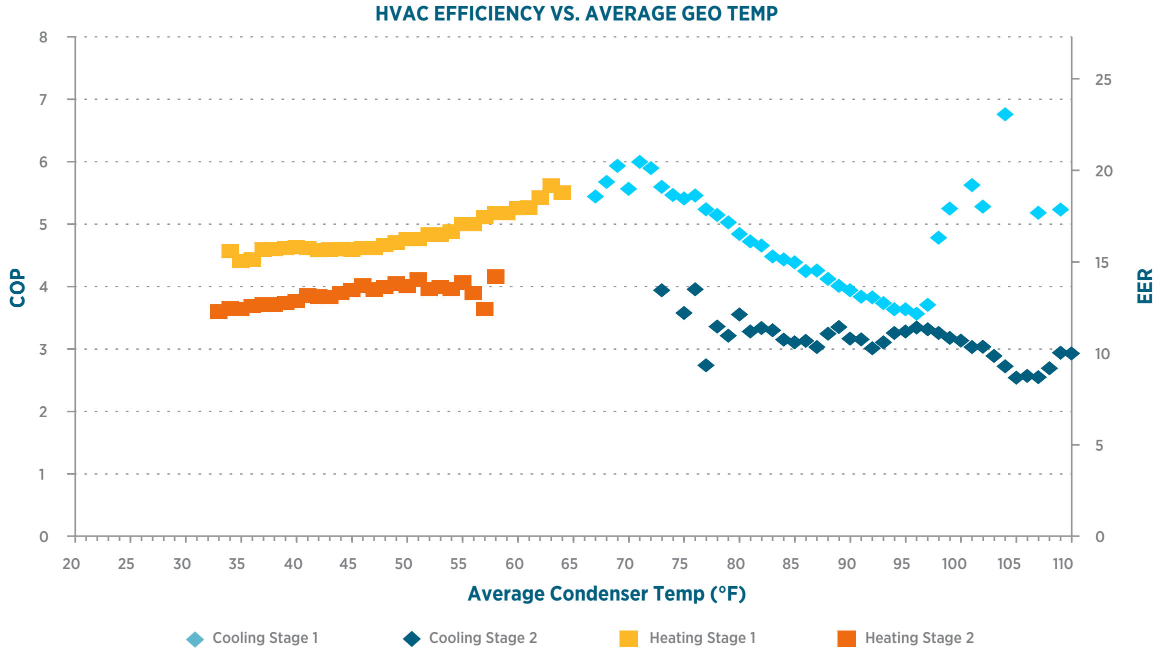


Figure 12: Efficiency of installed system as a function of the average condenser temperature

Figure 12 shows the efficiency of the system plotted against the average condenser temperature. As expected, the efficiency of stage 1 operation is generally higher than the corresponding stage 2 operation. Efficiency also improves as the average condenser temperature approaches the ground temperature, which the data would suggest as being around 66 F.

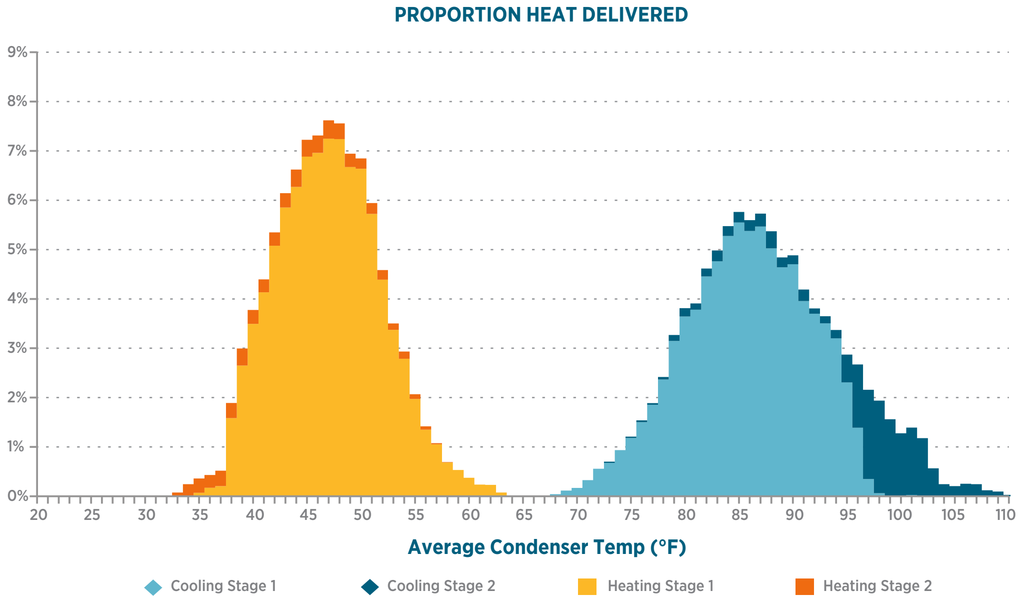


Figure 13: Proportion of time unit spent in each mode based on the condenser temperature

Figure 13 is a histogram showing how much time the unit spent in each mode binned for different temperatures. This plot shows that the mean temperature of operation was around 46F in heating, and around 86F in cooling.

5.0 Conclusion

The installation at Rio Modego showed that a directional drilling technique can be employed to install ground loops on small parcels of land with minimal disruption to surface features. Based on performance of the system, it is possible that this geo exchange loop was undersized, or under-performing as demonstrated by the temperature lockout experienced during the peak heating day of the year. Greater efficiency can be expected if the EWT temperature excursions can be minimized during the day.

6.0 Collaborators

Sacramento Municipal Utilities District and the California Energy Commission provided funding for this demonstration at Rio Mondego, California. UC Davis Western Cooling Efficiency Center, provided project management, technical guidance, and performance evaluation.

Any questions about this project, including technology costs, can be directed to:

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