Advanced Analysis of Geothermal Heat Pump System Data

Ground Energy Support LLC and University of New Hampshire

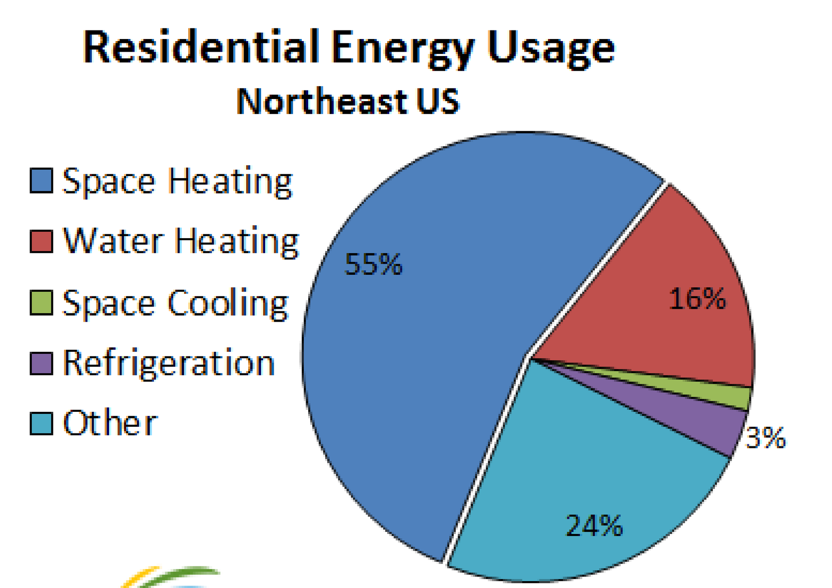
UNH P.I. J. Matthew Davis GES P.O. Robert Sullivan

Project Participants: Wheeler Ruml, Max Miller, Tom Clancy

Project Summary

Problem

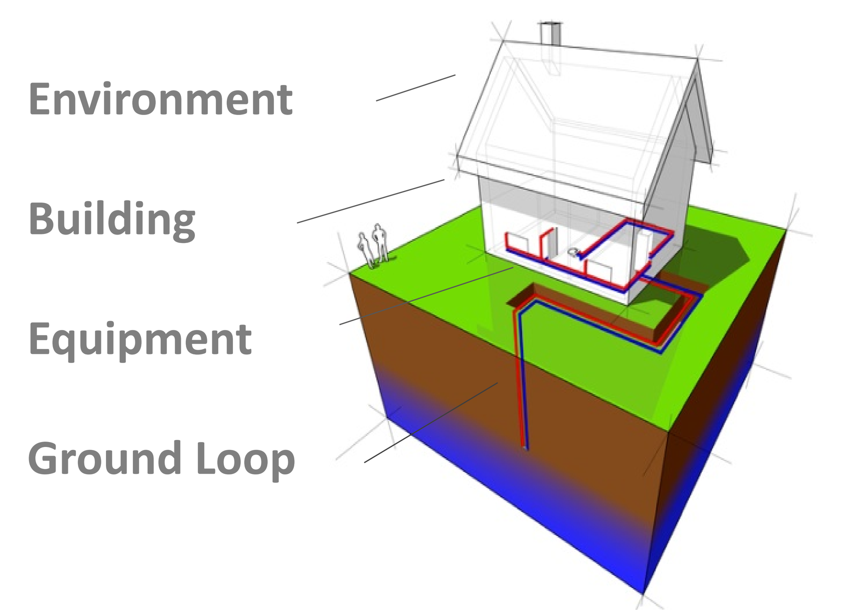
- US Northeast relies heavily on fossil fuels for space and water heating.



- Geothermal heat pumps (GHP) have potential to provide an alternative source of clean renewable energy.
- Market penetration is limited by lack of confidence in technology among consumers, policy makers, and investors.
- $10 billion annual expenditures on fuel oil in Northeast.

Recognized Needs

- Objective, scalable, and actionable evaluation, measurement, and verification (EM&V) of actual systems.
- Quantify performance and risk with attention to each system component.



- Utilize readily available but imprecise information.
- Off-the-shelf heat meters are not a viable stand-alone solution.

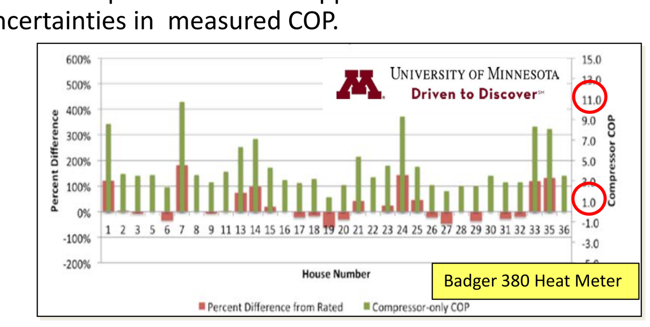
The Problem with COP

- The Coefficient of Performance (COP) provides just a single metric of performance and is prone to large uncertainties.

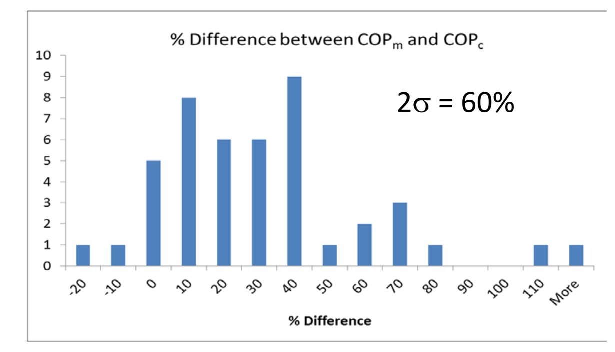
$$COP = \frac{c_f \cdot \dot{m}_f \cdot \Delta T + 3.412 \cdot kW_{consumed}}{3.412 \cdot kW_{consumed}}$$

- Results from recent studies using COP as primary performance metric illustrate the impact of measurement error.

Huelman et al (2016) completed a study for the Minnesota Department of Commerce. Use of Badger 380 heat meter with Class B temperature sensors appears to have contributed to large uncertainties in measured COP.

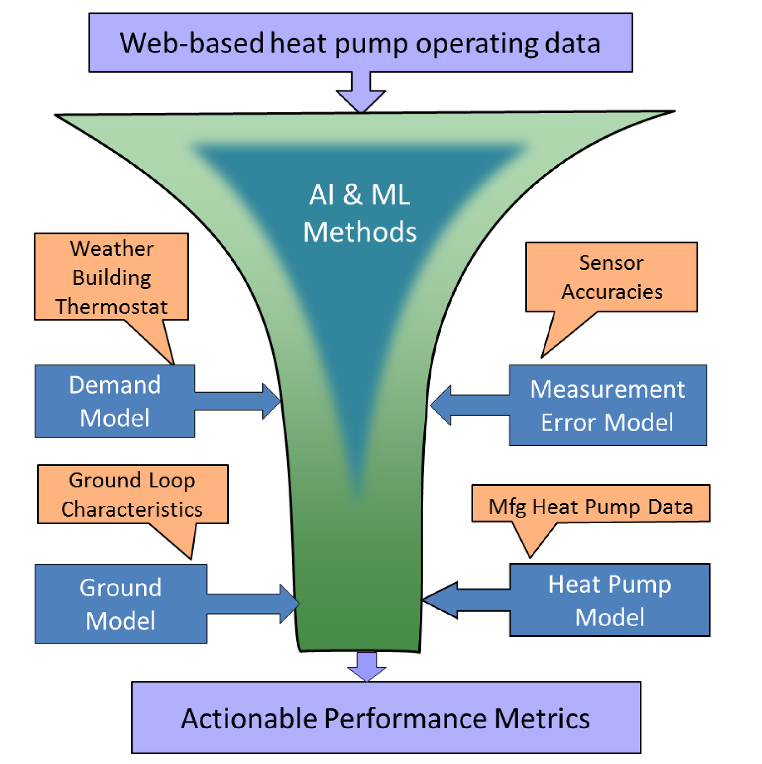


CDH Energy (2017) recently completed a study for New York State Energy Research & Development Authority. They attributed discrepancies between measured and expected COPs (COP_m and COP_c, respectively) to measurement errors. The resulting measured COP_m is both biased and has a large standard error.



Proposed Solution

- Apply methods of artificial intelligence (AI) and machine learning (ML) to synthesize multiple sources of data into 'smart' GHP system meter.



- Provide Software as a Service to developers, utilities, policy makers to objectively assess performance of large numbers of GHP systems.

Progress to Date

(DoE Award Notification on June 20, 2017; DoE Award made on September 7, 2017)

Project Organization

Ground Energy Support LLC (GES) is working with the University of New Hampshire (UNH) to use data from actual GHP systems to develop and test new methods of assessing GHP performance.

Since 2012, GES has amassed over 1 million hours of 1-minute interval data from more than 50 GHP installations (residential and light commercial) in the eastern Unites States.

GES has licensed an anonymized subset of these data to UNH for the purpose of developing and testing new algorithms to quantify GHP system performance. Much of the research focuses on the close collaboration between GES and UNH.

GES will then connect these algorithms to the existing codebase for the GxTracker™ and other web-based monitoring systems making these methods available as a software product to utilities, developers, and third-party ground loop owners.

The project focuses on the development of four 'models' that utilized different combinations of information about the site, the equipment, the outdoor weather conditions, and the GHP system operating data.

- **Heat Pump Model** characterizes the heat pump operating conditions relative to manufacturer performance data.
- **Uncertainty Model** uses sensor measurement error data to quantify uncertainty in computed metrics.
- **Demand Model** assesses the observed GHP system demand on the ground loops, as measured by heat of extraction (HE) and heat of rejection (HR), relative to outdoor conditions and system design.
- **Ground Loop Model** uses measured HE and HR and corresponding measured ground loop temperature to estimate thermal conductivity of the ground and the thermal resistance of the borehole.

As part of the research effort (Phase I), the models will be used with existing GHP data to assess the range of observed operating conditions and the ability of the new algorithms to be combined with expert systems analysis and Bayesian statistical models and develop an actuarial database of GHP system performance. GES and UNH are working with the Renewable Thermal Alliance (http://bit.ly/2zbWzQV) to develop an open thermal database that will further expand opportunities for independent M&V.

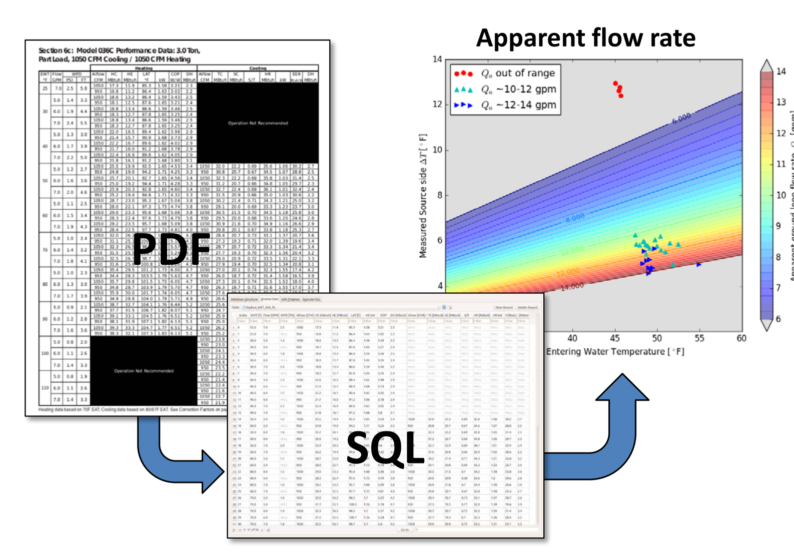
Preliminary Results

Heat Pump Model

The manufacturer performance data for heat pumps are translated into SQL database and used to assess whether heat pump operating conditions are within manufacturer specified ranges.

In the example to right, the source-side ΔT is plotted against the EWT to infer the ground loop flow rate. The ΔTs indicated by the red symbols suggest lower flow rates than expected.

Similar comparisons are made for observed and expected HE, HR, and kW.



Uncertainty Model

Comparison of uncertainties computed from measured EWT, LWT, Q_f, and kW. Uncertainties shown are computed using Monte Carlo simulations with 1000 realizations.

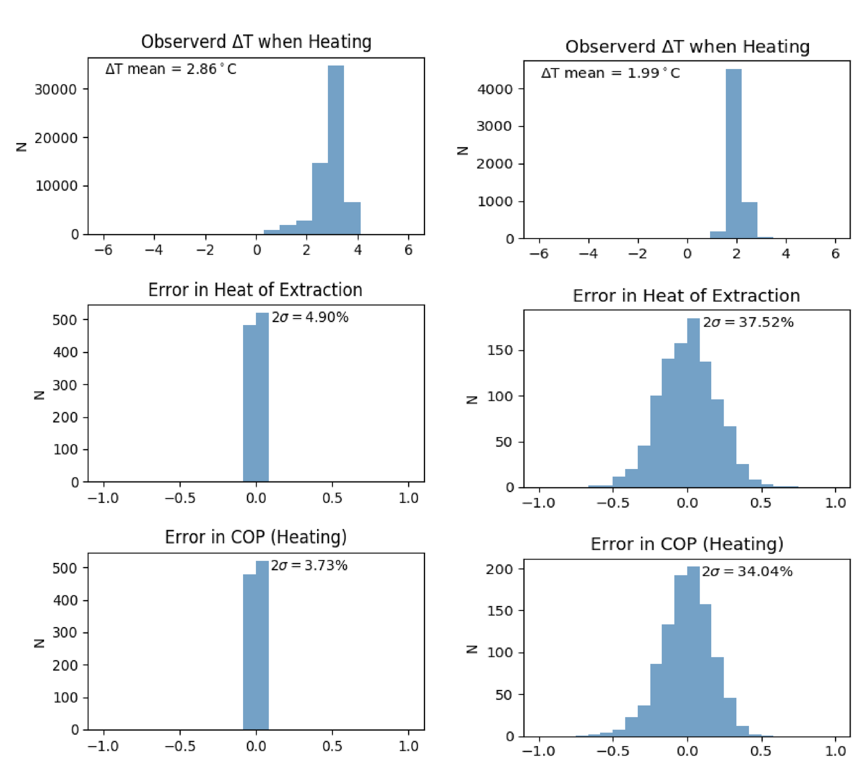
Analysis shown on the left is for system with higher average ΔT and the following measurement errors:

$$\sigma_T = 0.05\ [^\circ C] \quad \sigma_Q = 0.04\ [gpm] : kW_{err} = 0.5\%$$

Analysis shown on the right is for system with lower average ΔT and the following measurement errors:

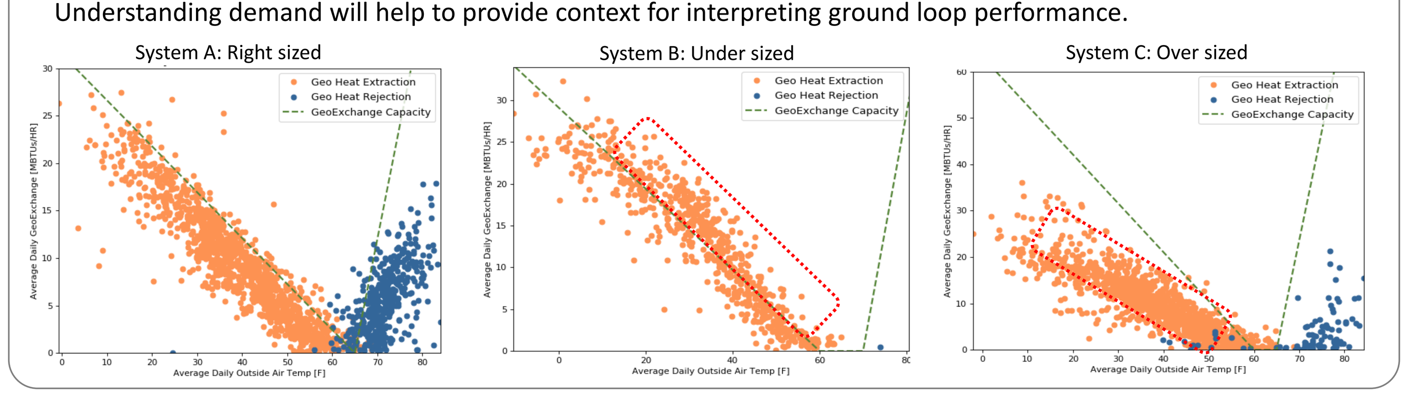
$$\sigma_T = 0.25\ [^\circ C] \quad \sigma_Q = 1.0\ [gpm] : kW_{err} = 10.0\%$$

The Uncertainty Model will be used to quantify uncertainty in performance metrics and conduct cost-benefit analysis on different measurement options with different accuracies.



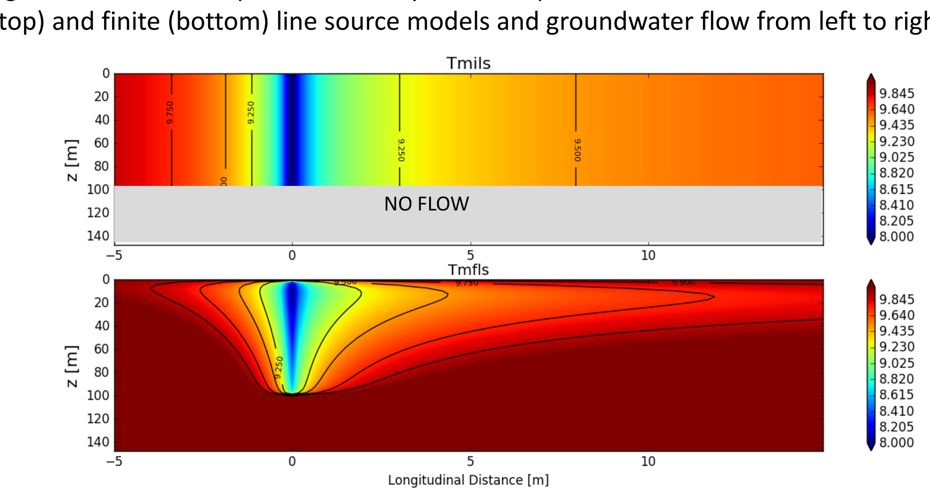
Demand Model

The Demand Model will quantify the demand on ground loop relative to system design (green dashed line). Understanding demand will help to provide context for interpreting ground loop performance.

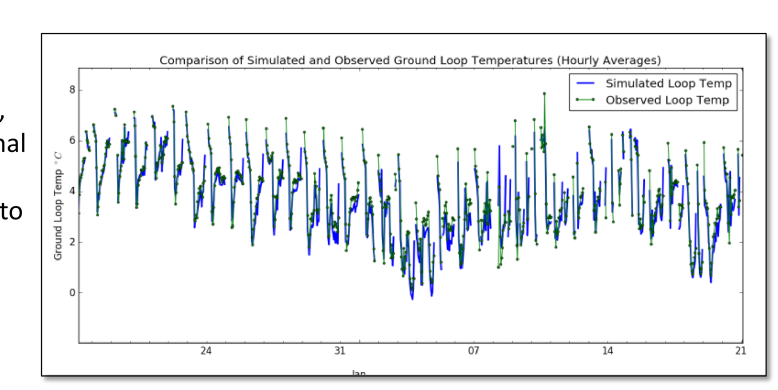


Ground Loop Model

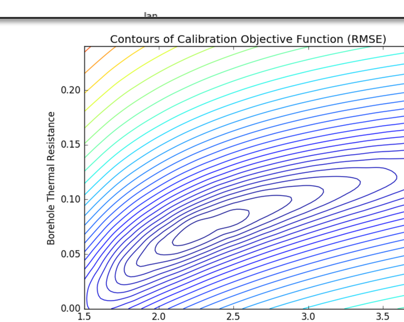
The Ground Loop Model will use heat pump operating data (EWT, LWT, HE, HR) to infer effective thermal properties of the ground loop. Getchell (2017) implemented the models of Sutton et al. (2003) and Molina-Giraldo (2011) to compute the thermal response for a range of subsurface conditions, including both the infinite and finite line source geometries as well as with and without groundwater flow. The figure below shows a profile of steady state temperature distribution for the infinite (top) and finite (bottom) line source models and groundwater flow from left to right.



Using superposition, we model the thermal response of the borehole subjected to a time-varying load.



Preliminary results suggest that the transient response is sensitive to both thermal conductivity and borehole resistance.



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