GEOTHERMAL TEST BORES & TC TESTING

Moderator: **Aeowyn Kendall / *Aztech Geothermal***

Speakers: **Kortney Lull / *Midwest Geothermal***

Dan Sergison / *Salas O'Brien*

Dr. Jeffrey Spitler / *Oklahoma State University*

Garen Ewbank / *Ewbank Testing*

Geothermal Drilling Track – Northside Ballroom – 11:45-12:45

About the Speaker: Kortney Lull

- Worked with Midwest Geothermal since 2008
- IGSHPA Accredited Installer
- IGSHPA Board of Directors (2020 – current)
- MGEA Board of Directors

GEOTHERMAL
IGSHPA Certified Installers

We need to drill a test bore – who does what?

- When hiring a test bore, you might need a few people involved:
  - Drilling contractor
  - Geologist
  - Testing Agency
- What to look for:
  - Testing company that calibrates & reviews their equipment.
  - A driller that is capable of drilling productively to design depth.

GEOTHERMAL
IGSHPA Certified Installers

Importance of a Test Bore: Drilling Technology

- What do we mean when we say drilling productively to the design depth?
  1. Capable of drilling to the design depth.
  2. Capable of drilling to the design depth.
  3. Capable of drilling to the design depth.
- Look for contractors familiar with the area and that utilize more common drilling methods.
  - Air or mud rotary and air hammer are the most common drilling techniques.

GEOTHERMAL
IGSHPA Certified Installers

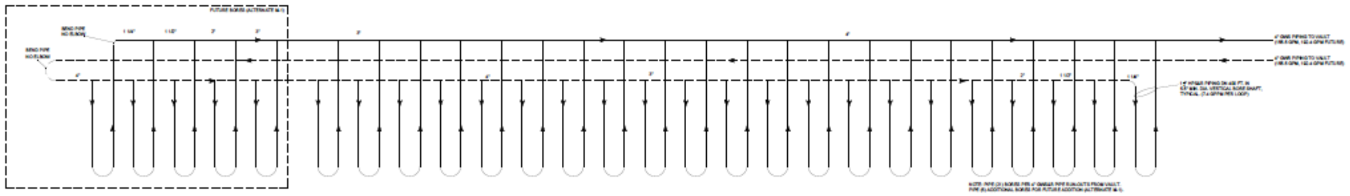
Importance of a Test Bore: Drill Log

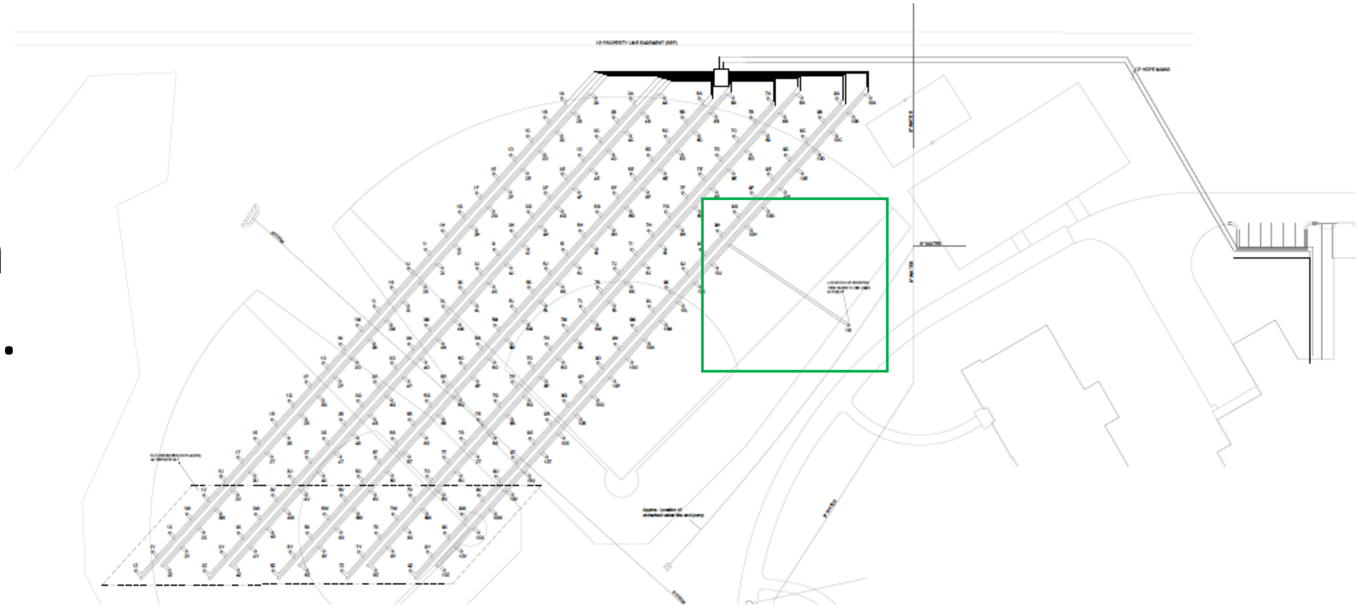
- Thermal conductivity, diffusivity and undisturbed ground temperature are key components to provide to the design team.
- For drillers bidding on the work, a drill log is the crucial piece of information to fill them in on how these holes will go.
  - Accurate reporting of what's existing.
  - Borehole description, including any water encountered or other subsurface challenges.
  - Drilling method.

GEOTHERMAL
IGSHPA Certified Installers

Importance of a Test Bore: Location, Location, Location

- Ideally, the test bore will be drilled in a location that will be used in the future borefield.
- If the test bore cannot be used, show that in the design documents and outline that the unused bore needs to be abandoned.
- On larger projects, more than one test bore may be needed.





GEOTHERMAL

IGSHPA Certified Installers

Importance of a Test Bore: Closeouts

- Often, a test bore is drilled well before the field is ready to go in, or full project construction starts.
- Remember, the test bore is an investment in the geothermal field – protect that investment!
- When a test bore has been completed, request a GPS coordinate for the completed bore(s) and photographs of the installed bore.
- Require a pressure test of the completed bore, after grouting has occurred.

GEOTHERMAL
IGSHPA Certified Installers

Importance of a Test Bore: Basis of Design

- When changing the depth of the bore, be aware of the impact on the project.
  - If going deeper, remember that deeper than the bore drilled during the test is an unknown.
  - Formation could change dramatically, even in just an additional 20', let alone even deeper than that.
  - Conductivity and diffusivity may change – if you decide to change the design depth, an additional test may be required even to validate your design.

GEOTHERMAL
IGSHPA Certified Installers

Dan Sergison

Salas O'Brien™

Decarbonization • Electrification • Energy Master Planning

Geothermal Test Bores & TC Testing

Designer’s Perspective

October 23, 2024

Why do we do it?

- The obvious: to confirm and quantify the thermal properties of the subgrade, most often in the form of **three (3) geothermal software inputs, to support design:**
  - Thermal Conductivity - BTU/(hour*foot*°F)
  - Thermal Diffusivity – square foot/day
  - Average Ground Temperature – range in °F
- The less obvious: to confirm and characterize the subgrade
  - Observe and document drilling conditions closely (**driller's logs can vary**)
    - Water production
    - Casing requirements
- Much less obvious: measure **speed**, identification of the best **drilling method**
  - Penetration rate (PR)
  - Mud versus air rotary

How many for a project?

- Old IGSHPA guideline – 1 test loop per 100 tons of load
- Highly site-specific. Usually, we'll specify quantity.
  - **Obama Public Library, Chicago, Illinois**
    - Four (4) test bores completed for **~240 bores** (19-acre site)
  - **Epic Systems Geothermal, Verona, Wisconsin**
    - Four (4) test bores completed for over **6,200 bores** (1,100-acre site)

TC	**2.17 – 2.22**	**BTU/(hour*foot*°F)**
TD	**1.47 - 1.53**	**square foot/day**
Ground Temp	**54.3 – 54.7**	**°F**

- **Hoboken, NJ**
  - Geotechnical report – Weathered bedrock at **155'** below grade (terminal depth of boring)
  - One (1) test bore – competent bedrock discovered at **300'** below grade (2-acre site)
- **Jersey City, NJ**
  - Geotechnical report – Competent bedrock at **75'** below grade, becomes denser after 100' (2-acre site)
  - One (1) test bore – competent bedrock discovered at **80'** below grade

1 mile away from each other!

How do we do it?

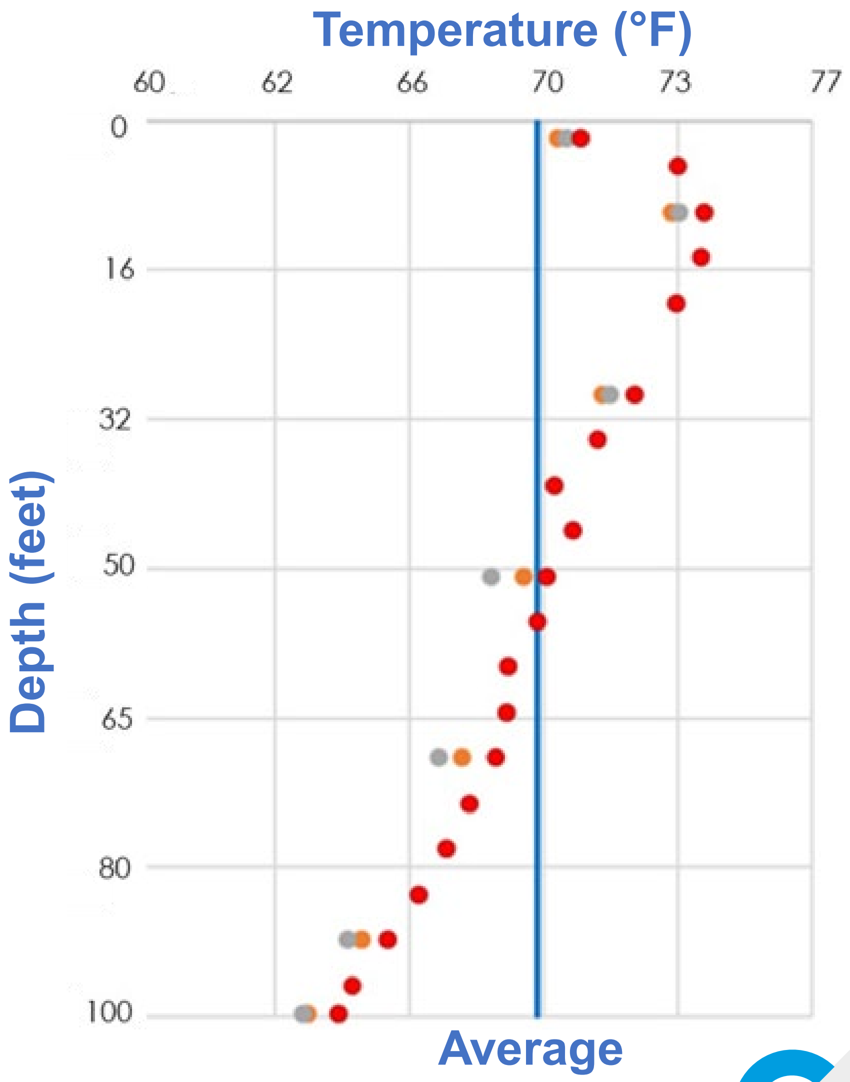
- Consult known information from federal, state and local resources
  - States maintain geologic records differently – highly variable state-to-state
  - United States Geological Survey (**USGS**) resources are helpful, database continually refined/expanded
    - Where possible, invite USGS to log test bores - **mutually beneficial and helpful to our industry**
  - **Local knowledge is valuable**, whether drillers or geologists
- Specify test bore RFP packages with testing procedure outlined
  - Most often, a 40 to 48-hour Thermal Conductivity Test (TCT), for a vertical HDPE U-bend loop
    - Only adds heat to the loop
  - **Different approaches for different GHX's**
    - Coaxial (Rygan) – longer-duration test
    - Open loop and non-grouted closed loop – pumping tests (water quantity), water quality tests
    - Analytical versus line-source methods – I'll leave that to Garen
- **Do not** specify borefield depth deeper than test bore depth

What if we’re not present during test drilling and testing?

- **Try to avoid this at all costs**, but it happens. Doing so allows for:
  - Measurement of PR, quantify amount of time spent on non-drilling issues
  - Sampling and classification of drill cuttings
  - Observation of equipment behavior
  - Quantification of **groundwater**, possible water quality sampling
  - Measurement of time to pull drill rids, “**trip-out**”
  - Confirmation of: **drilling location, utility markout**, drill bits, quantity of drill bit change-outs drilling, casing quantity, borehole drift survey (if applicable), drill depth, loop functionality, loop insertion depth (2’ marks on piping), tremie depth, grout mixture, TCT procedure (piping insulation, proper voltage)
- What do we want drillers to call about? In addition to providing above:
  - If target depth cannot be reached, and the issues experienced leading up to it
  - Unexpected’s (when possible) – ex. high groundwater production, large subgrade voids, etc.
  - When they are tripping out and preparing to **set casing** (if applicable)

What about temperature?

- Ground temperature with depth
  - In NYC, observed the urban heat island effect in densely built-up areas
    - Must be **100’** below grade to reach temperatures below **60°F**
  - Often not worth measuring beyond what is already provided as part of the TCT data
- Ground temperature over time
  - Not a major consideration for the test bore
  - Dedicated temperature monitoring wells - typically, only provided if requested by the client
  - Often not worth measuring beyond what is already provided by the final system’s control system and trended data
    - Control system must be **designed to prevent thermal degradation** over the system’s long lifespan



Thermal Response Testing for Ground Thermal Properties – History and Basics

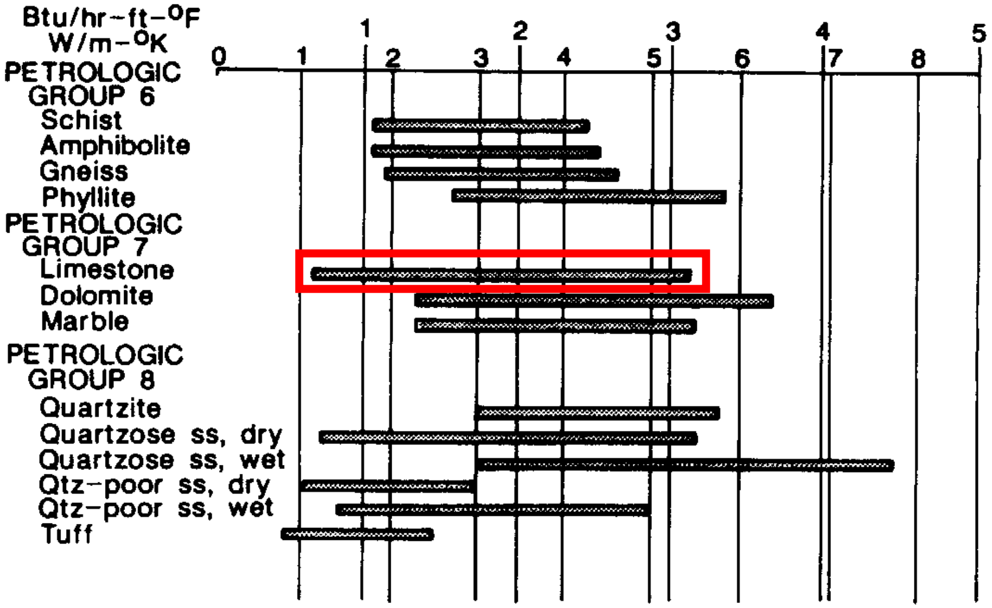
Speaker: **Jeffrey D. Spitler**

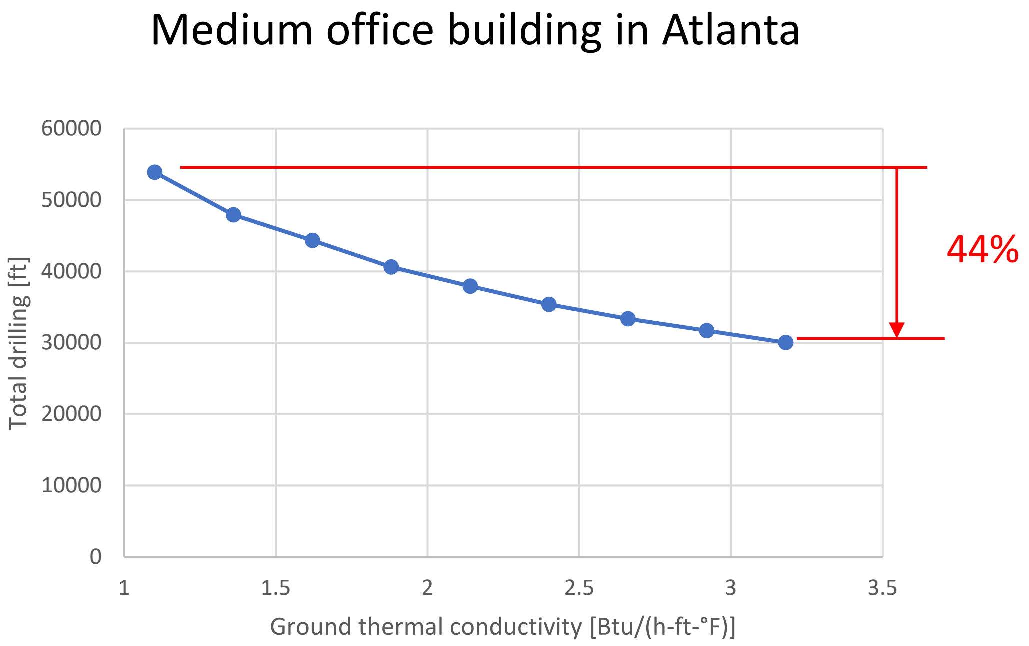
School of Mechanical and Aerospace Engineering

Oklahoma State University

Geothermal Drilling, 11:45 am, 10/23

Why?





From: Bose, J. E., Ed. 1989. Soil and Rock Classification for the Design of Ground-Coupled Heat Pump Systems—Field Manual, Electric Power Research Institute.

Needle Probe - 1931

TEKNISK TIDSKRIFT

HÄFT. 28 | UTGIVEN AV SVENSKA TEKNOLOGFÖRENINGEN | 11 JULI

ÅRG. 61 | *HUVUDREDAKTÖR CARL KLEMAN* | 1 9 3 1

NY METOD FÖR BESTÄMNING AV VÄRMELEDNINGS-KOEFFICIENTER.*

Av fil. lic. BERTIL STÅLHANE och civilingenjör SVEN PYK.

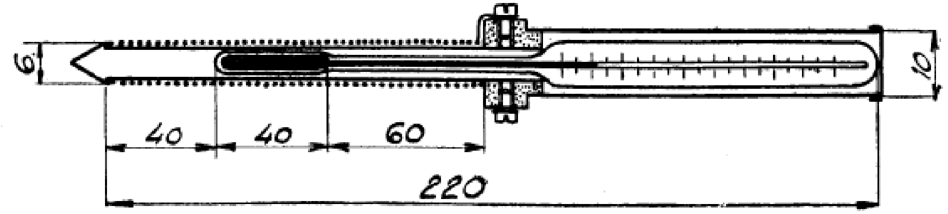


Fig. 6.

1980s – 1990s

- Palne Mogensen (1983) proposed method for measuring borehole thermal resistance.

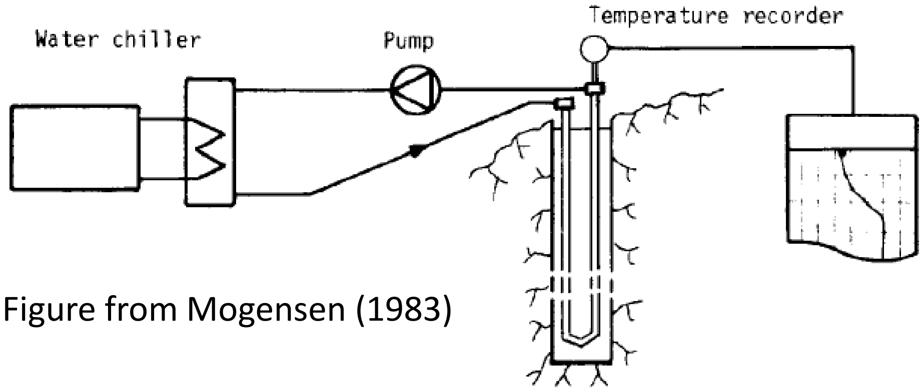


Figure from Mogensen (1983)

- 1994 – work on mobile thermal response testing units began in Oklahoma and Luleå

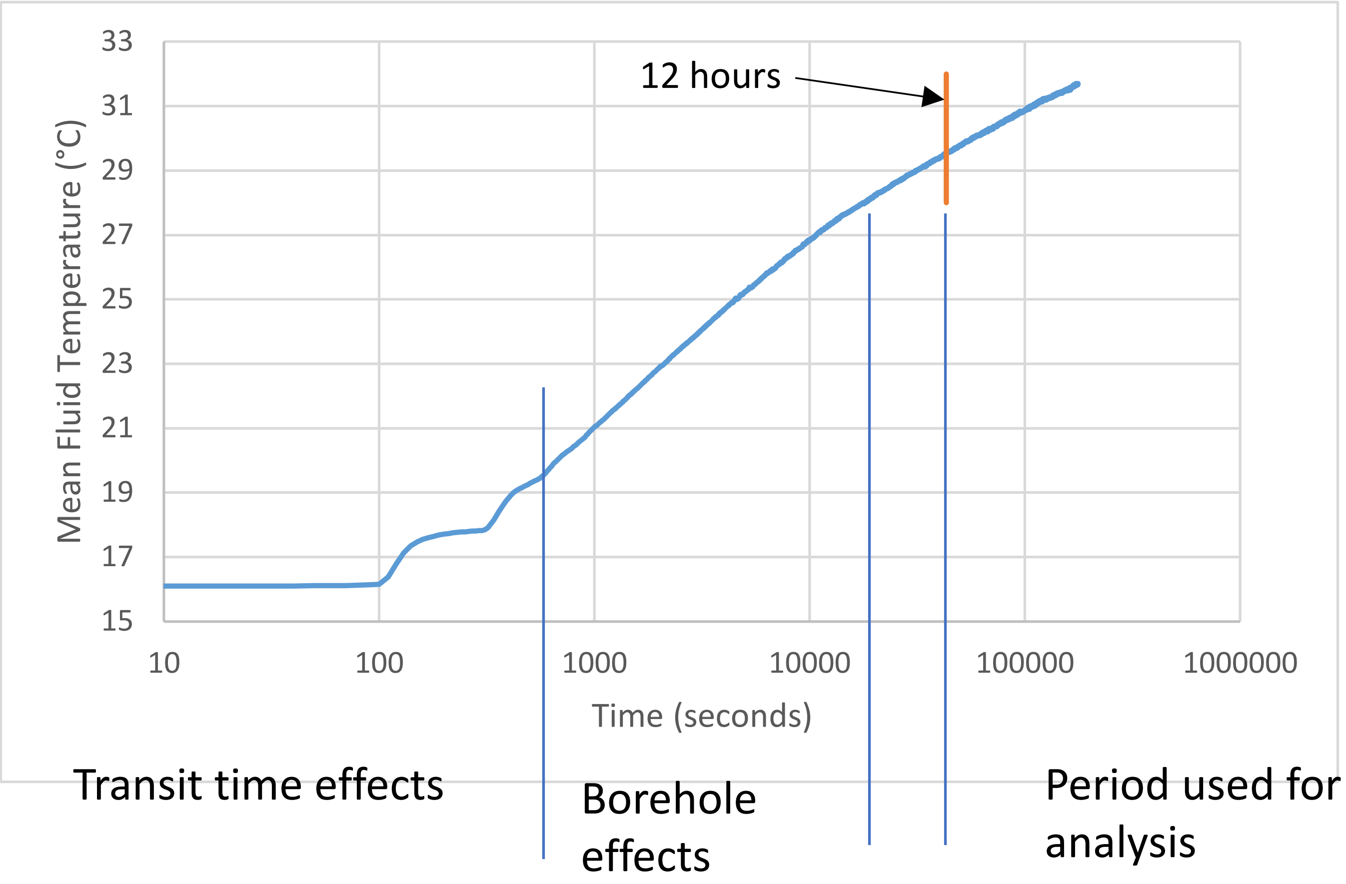
Bottom photo: Signhild Gehlin

Jeff Spitler, Palne Mogensen, Signhild Gehlin
2009

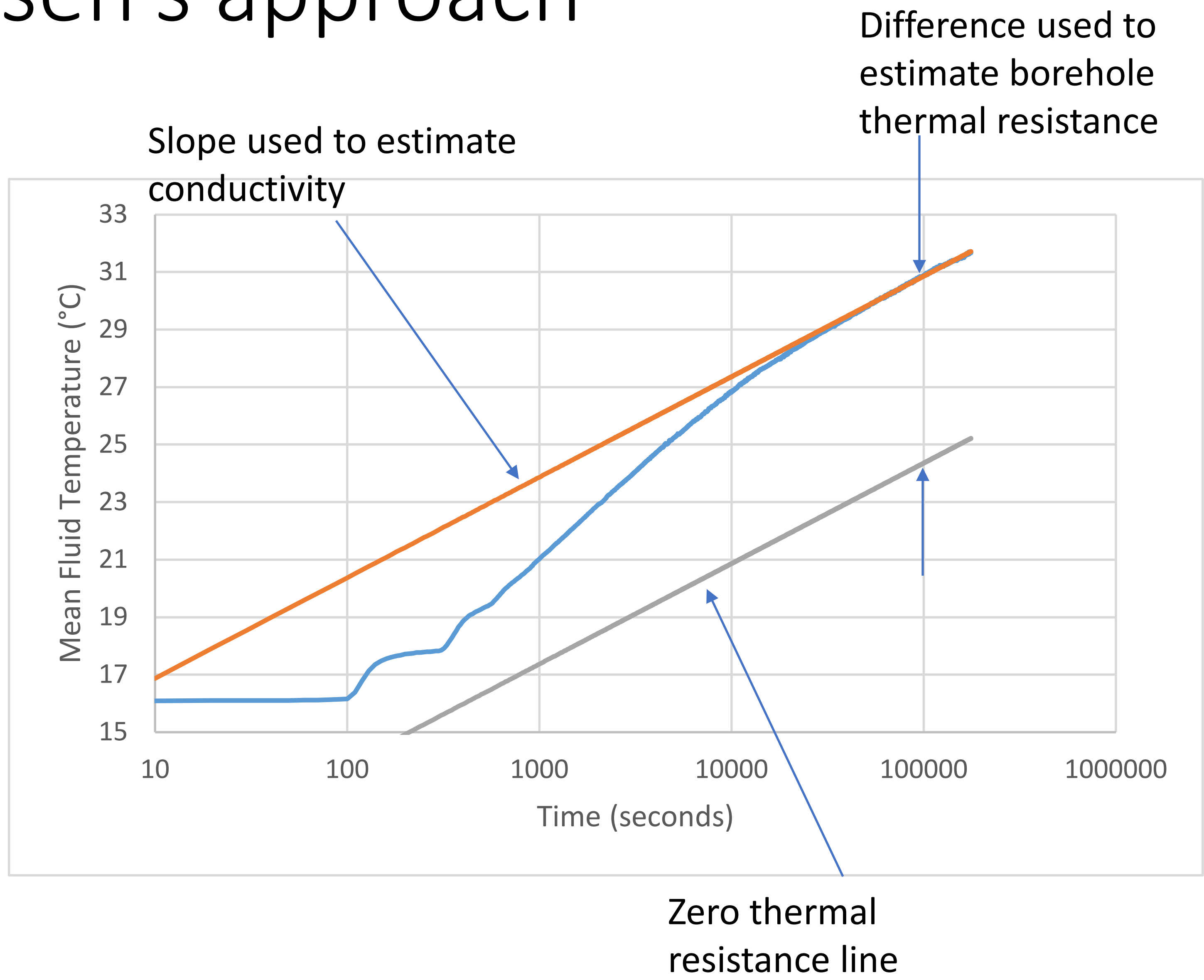
Concept

- Utilize test borehole.
- Insert and grout a U-tube.
- Put a **constant** heat flux on the borehole.
- Temperature response can be used to estimate thermal conductivity.
- Line source (Ingersoll & Plass 1948) can be approximated to give:

$$k^* = \frac{q}{4\pi}\left(\frac{dT_f}{d(\ln(t))}\right)^{-1}$$

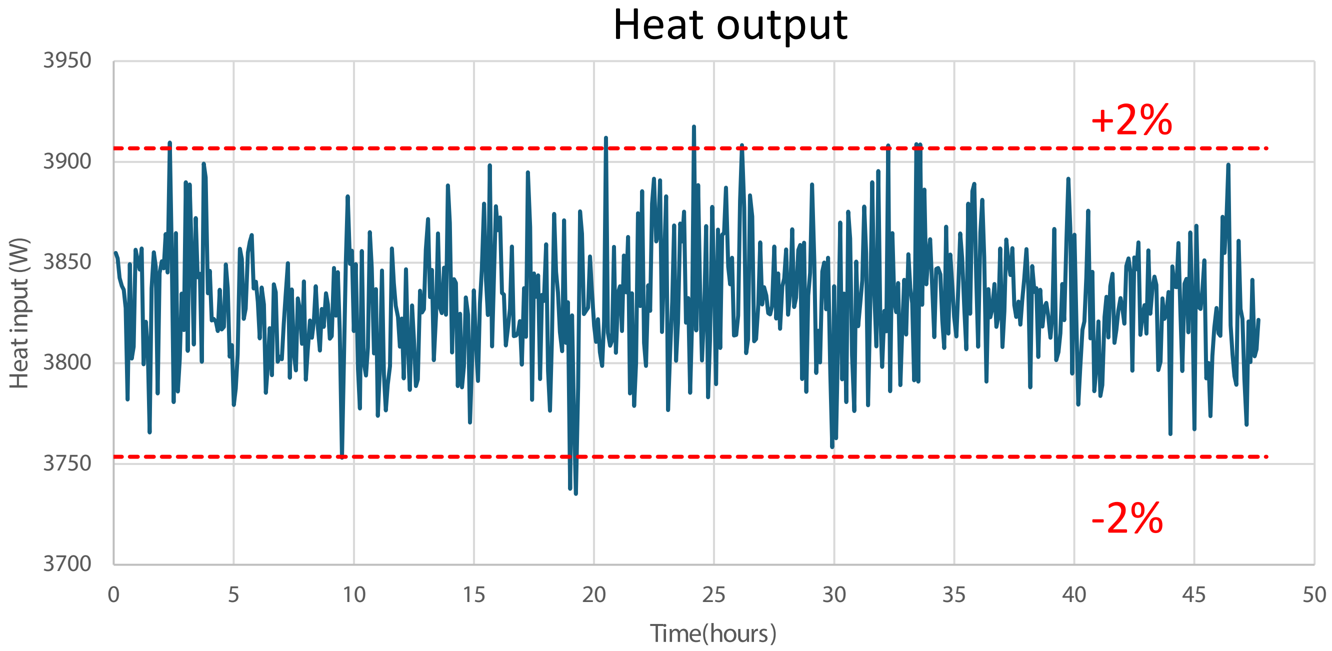


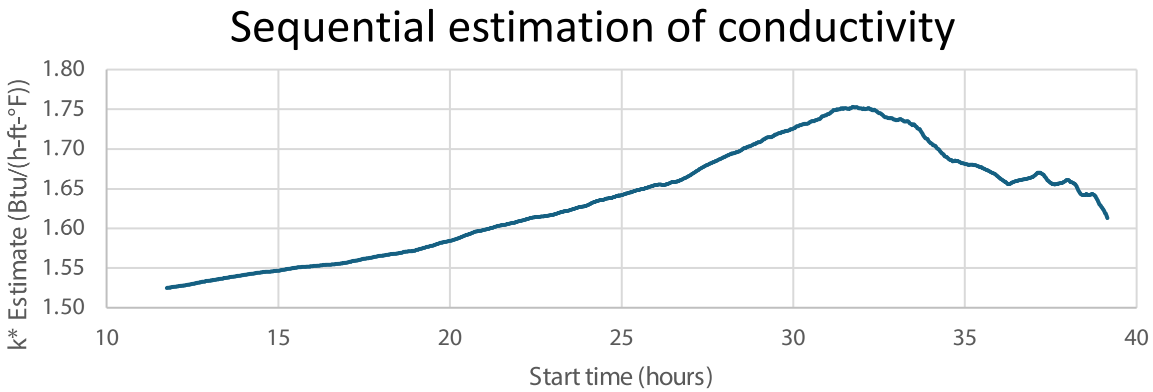
Mogensen’s approach



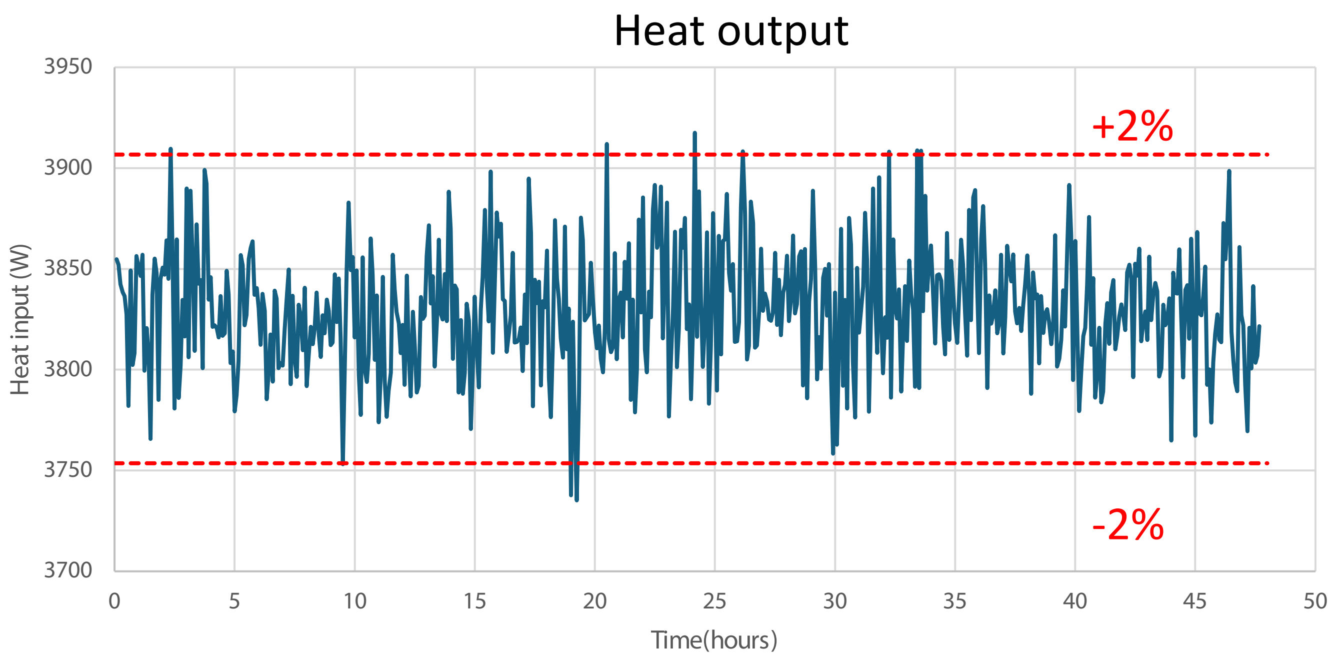
Line source and parameter estimation

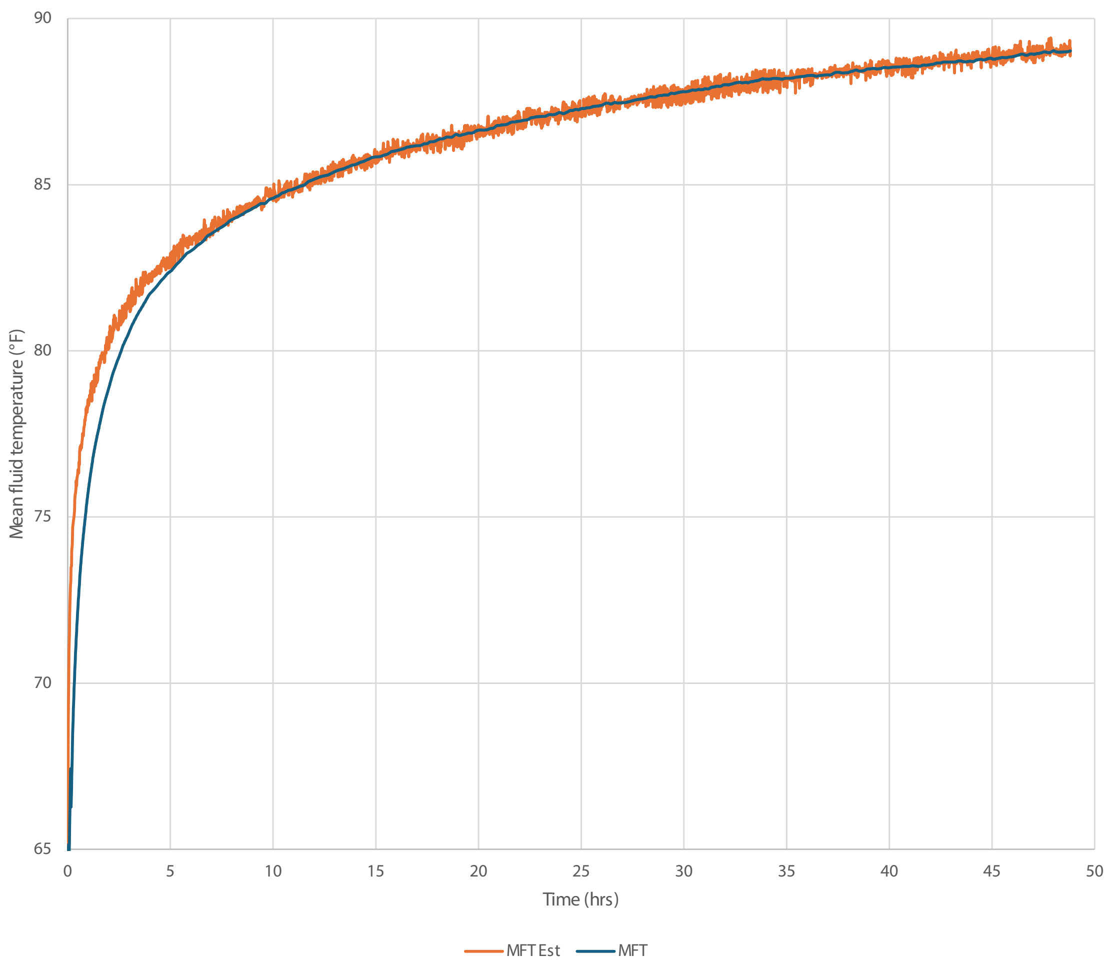
- Early test rigs suffered from transients in heat output due to:
  - Environmental effects on generators and incidental heat losses.
  - Or utility voltage fluctuations
- Even later test rigs with minor variations (right)
- Parameter estimation
- First estimates of uncertainty ~±10% under field conditions (Austin, et al. 2000)



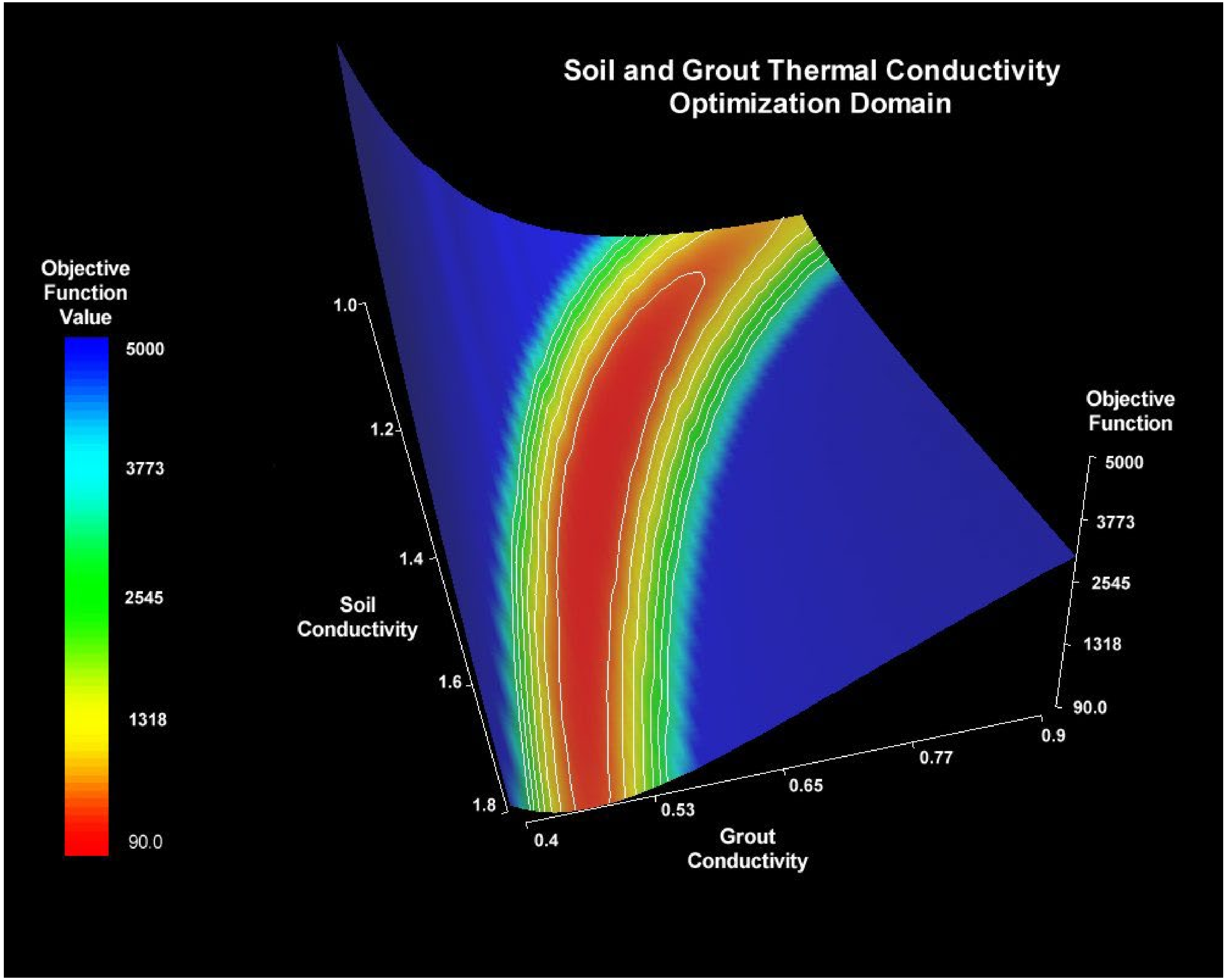


Parameter estimation

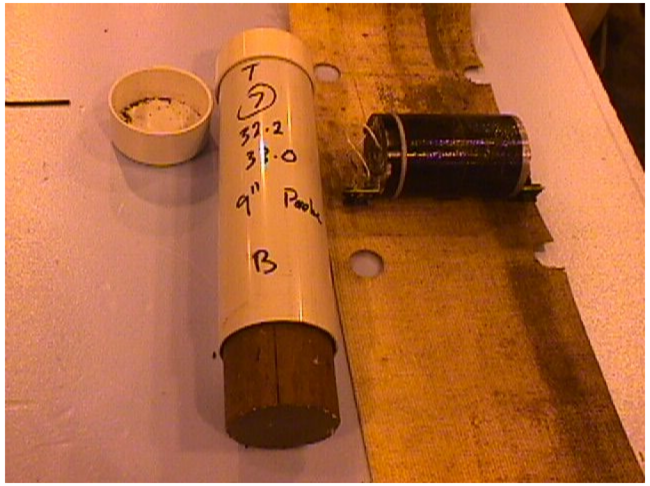




Parameter Estimation



Validation



Two approaches:

- Cored samples (left)
- Sandbox (right)
  Beier, et al. (2011)
- With careful control, TRT & parameter estimation gave ± 2.5%

Comments and further developments

- The TRT or TC test is well-established and reasonably accurate.
- Since the original development:
  - More compact test apparatus.
  - Lots of experience.
  - Distributed thermal response tests using fiber optic measurements can estimate conductivity = f(depth)
    (Acuña 2013; Monzó 2018)
    Oscillatory thermal response tests can estimate thermal diffusivity.
    (Lamarche, et al. 2024)

References

- Acuña, J. 2013. Distributed thermal response tests – New insights on U-pipe and Coaxial heat exchangers in groundwater-filled boreholes. PhD Thesis, KTH.
- Austin, W., C. Yavuzturk and J. D. Spitler. 2000. *Development of an In-Situ System and Analysis Procedure for Measuring Ground Thermal Properties*. ASHRAE Transactions 106(1): 365-379.
- Beier, R. A., M. D. Smith and J. D. Spitler. 2011. *Reference data sets for vertical borehole ground heat exchanger models and thermal response test analysis*. Geothermics 40(1): 79-85.
- Ingersoll, L. R. and H. J. Plass. 1948. *Theory of the Ground Pipe Heat Source for the Heat Pump.* ASHVE Transactions 54: 339-348
- Lamarche, L., J. Raymond and N. Giordano. 2024. *Oscillatory thermal response tests to estimate the ground thermal diffusivity.* Applied Energy 353: 122078.
- Mogensen, P. 1983. *Fluid to Duct Wall Heat Transfer in Duct System Heat Storages.* International Conference on Subsurface Heat Storage in Theory and Practice, Stockholm, Sweden, Swedish Council for Building Research. 652-657. June 6-8.
- Monzó, P. 2018. Modelling and monitoring thermal response of the ground in borehole fields. PhD Thesis, KTH.
- Spitler, J. D. and S. E. A. Gehlin. 2015. *Thermal response testing for ground source heat pump systems—An historical review. Renewable and Sustainable Energy Reviews 50(0): 1125-1137.* *http://dx.doi.org/10.1016/j.rser.2015.05.061*

Garen N. Ewbank

Ewbank Geo Testing, LLC, Owner, earth thermal properties

NexTEMP Solutions, Inc., Chair and Founder, polymodal, modulating/multisource heat transfer systems

The GreyEdge Group, LLC, Founding and Managing Member, pioneered ATL systems since 2002

Advanced Thermal Response Testing

The Numerical Analysis 'Digital Twin' Method

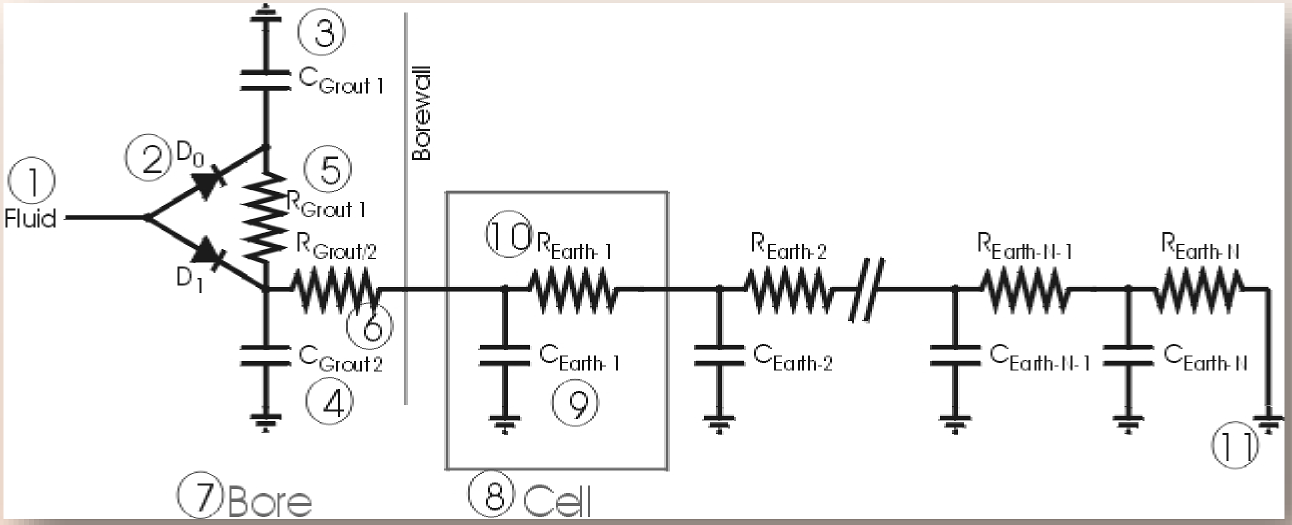
based on a Resistance/Capacitance understanding (i.e., Conduction/Storage)

U.S. and International Patents

Joint Venture of Geothermal Design Center and Ewbank Geo Testing

Rick Clemenzi and Garen Ewbank

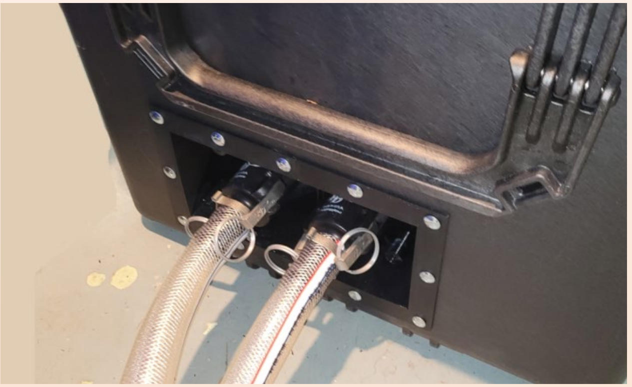
ORNL, SBIR, peer review, variance targets, and analysis (Xiaobing Liu, Ph.D.)



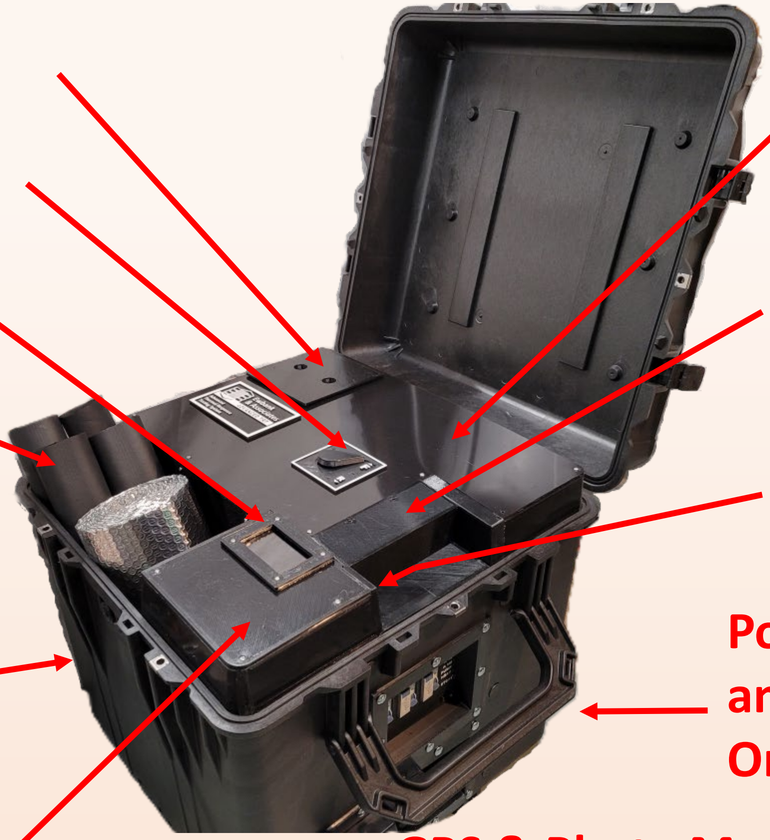
Advanced Thermal Response Testing
The Numerical Method Solution

- Single borehole testing
- Ground Heat Exchanger testing
- Cascading Heat Systems testing

Loop Connections



Example Testing System



Advanced Thermal Response Testing
The Numerical Method Solution

- Single borehole testing
  - No need for steady power
  - Power variations are okay
  - Flow variations are okay
  - Testing time on site can be greatly reduced using only the ATRT method and delivers better results
  - Third party verification
  - If required by EoR testing can meet the older ASHRAE/IGSHPA simple line source test standards using the first thirty-six (36) hours conventionally and the next twelve using the ATRT methodology

Advanced Thermal Response Testing
The Numerical Method Solution

- Ground Heat Exchanger Testing
  - New to the ground source industry!
  - Scale up the testing and analysis to confirm the operating ground heat exchanger thermal capacity and storage using the facility loads in real time
  - Quantify the thermal response and capacity of the GHEX for forecasting
- Forensic analysis of existing/operating ground heat exchangers to find:
    - Grout thermal properties
    - Boreholes installed not like the design or test borehole?
    - Is the GHEX operating like the sum of all the boreholes?
    - Are there flow/heat imbalances in each circuit?
    - Less than expected thermal performance?
    - Air purging necessary for the GHEX?

Advanced Thermal Response Testing The Numerical Method Solution

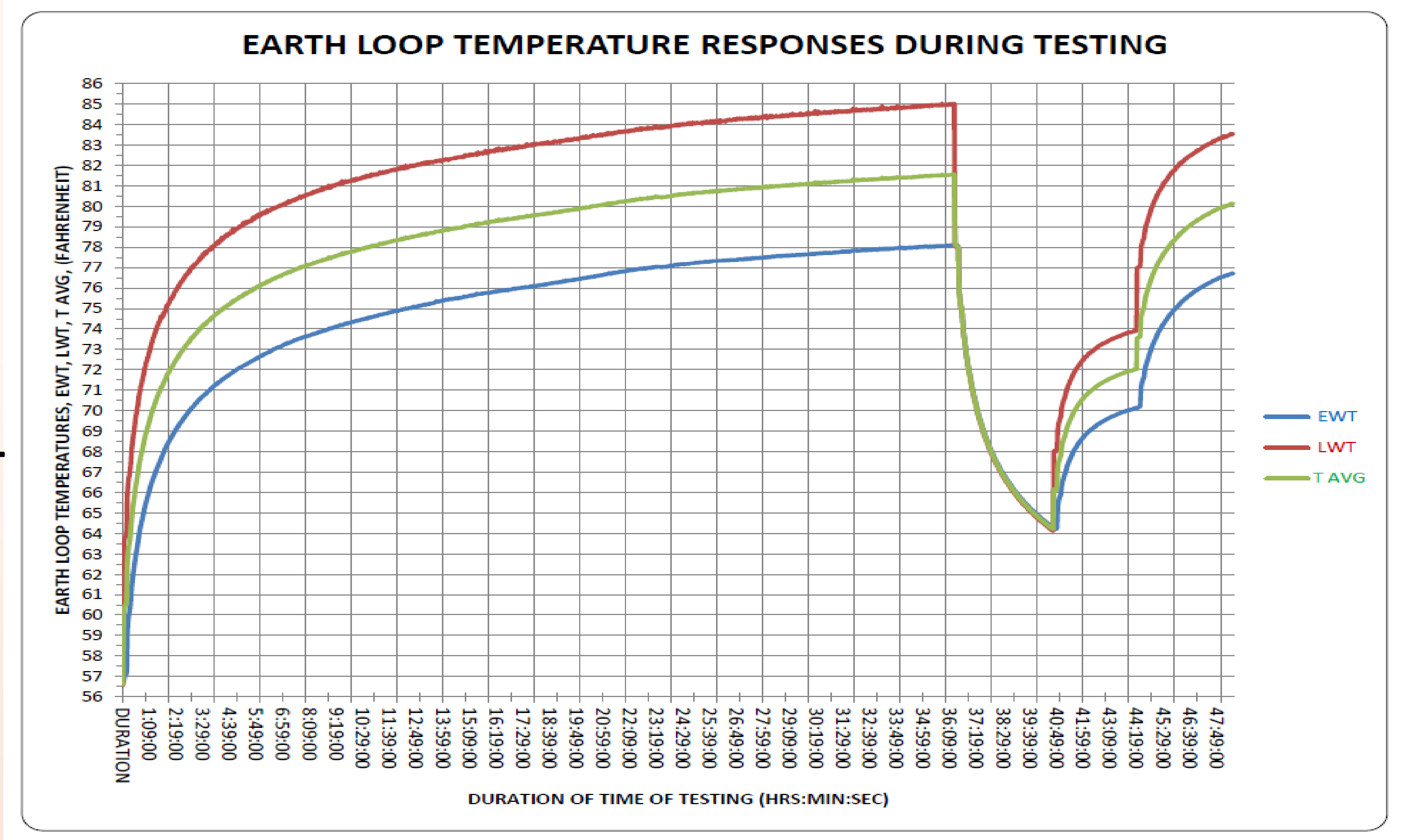
- Advanced Ground Heat Exchanger testing/digital-twin supports:
  - Hour-by-hour thermal response forecasting
  - Heat storage verification
  - Manage the GHEX hour-by-hour using:
    - Heat storage and discharge
    - Heat rejection with auxiliary devices
    - Full usage of a convective circulation circuit (Ambient Temperature Loop ATL)
  - Usage of an energy commons (a heat internet such as a district loop)
  - DER response

Advanced Thermal Response Testing
The Numerical Method Solution

- Management and Quantification of Heat Transfer in Cascading Heat Exchangers
  - Cascading heat exchangers are horizontal offshoots from vertical boreholes meant to introduce lower temperatures in one offshoot (zone) using “clean’ water and collecting higher temperature “clean” water or steam in a nearby parallel horizontal bore
  - Heat storage and transfer verification
  - Manage the heat hour-by-hour using:
    - Heat recovery to drive power generation systems
    - Heat storage
    - Heat rejection with auxiliary devices
    - Full usage of a convective circulation circuit
    - Usage of an energy commons (heat internet like a district loop)
    - Usage of “stacked” or “tiered” heat recovery systems

Example Test – Actual Temperature Measurements

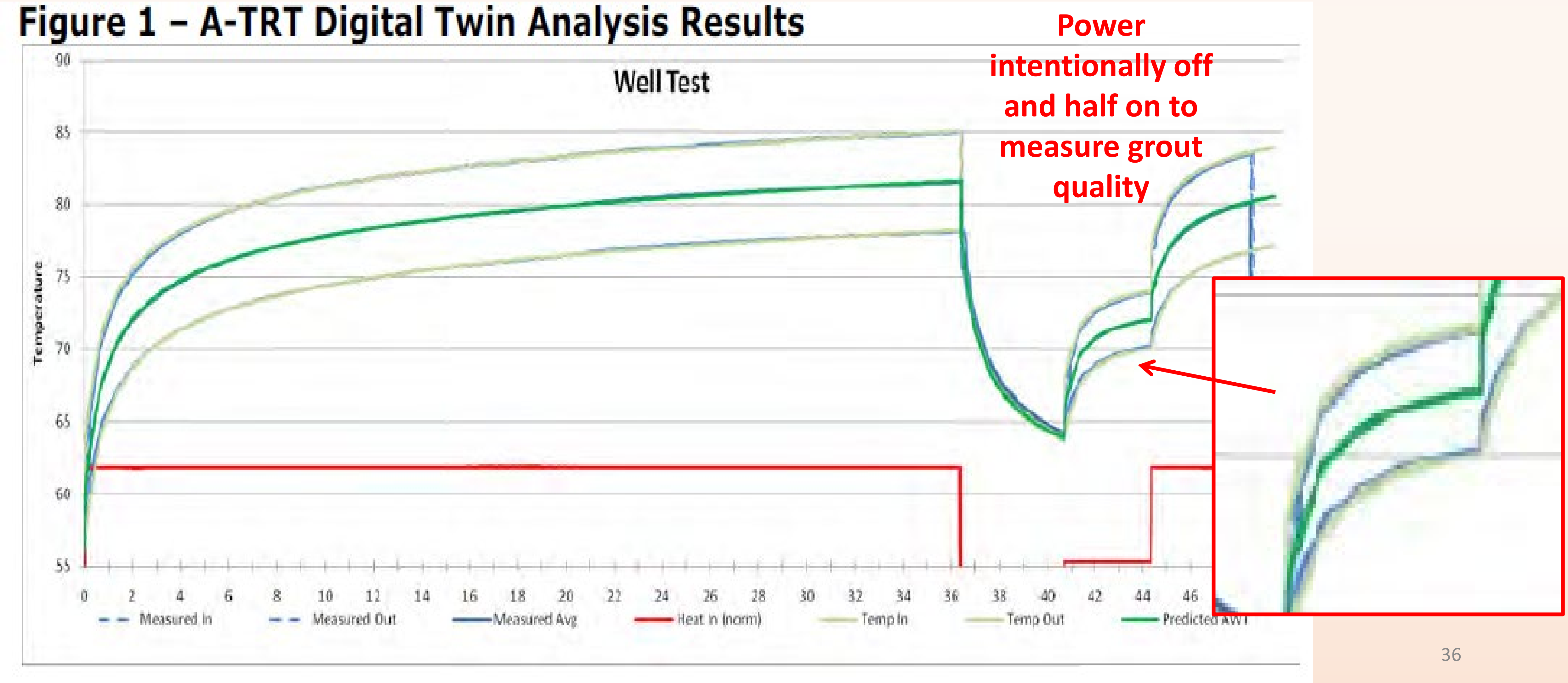
Temperature



Time

Digital Twin of the Example Test

Note how well the Blue (as measured) and Green (digital twin model) fit!



Comparison of TRT and A-TRT - December 30, 2023

- The average thermal conductivity **(k)** for the ground heat exchanger as installed was **1.69 Btu / (hr-ft-°F)**. This is an average conductivity per foot for the ground heat exchanger as constructed and tested. The thermal conductivity value represents the rate at which the ground heat exchanger and earth transfer heat. This value is required to determine the amount of ground heat exchanger for the design loads of the facility to transfer to or from the ground loads. The thermal diffusivity was estimated at **1.118 ft^2 per day** from the drilling log provided. The borehole resistance was estimated at 0.244 (hr-ft-°F) / Btu.
- This test data was acquired under the recommendations of the International Ground Source Heat Pump Association (IGSHPA) and the American Society of Heating, Refrigeration, and Air conditioning Engineers (ASHRAE). The line source method(s) was used to determine the above thermal conductivity.
- Additional numerical analysis was conducted using advanced thermal response testing (A-TRT) and digital twinning. This produced direct measurements of the volumetric heat capacity, grout thermal conductivity, and earth thermal conductivity. That report by Rick Clemenzi, P.E., follows and determined the earth thermal conductivity of **1.66**, earth volumetric heat capacity of 22.7, grout thermal conductivity of 1.30, grout volumetric heat capacity of 37 and thermal **diffusivity of 1.76**.
- The difference of the estimated and measured diffusivity (leading to volumetric heat capacity) is very important in designing an ambient temperature loop (ATL) connected to a ground heat exchanger as a thermal storage system rather than a heat sink and or source. It is recommended to use these values for design.

Advanced Thermal Response Testing
The Numerical Method Solution

Example A-TRT Results

Summary

The results of the A-TRT analyses are summarized as follows:

Description	**Ground**	**Grout**	**Units**
Thermal Conductivity	1.66	1.30	BTU/ft-hr-°F (TC or K)
Volumetric Heat Capacity	22.7	37.0	BTU/ft^3-°F (HC)
Deep Earth Temperature (avg)	56.8°F		
Calculated Diffusivity	1.76		ft^2/Day

Advanced Thermal Response Testing
The Numerical Method Solution

Additional Discussions:
Exploratory versus Developmental Drilling

- The TRT borehole is exploratory, defines the maximum depth for the project/location
- When drilling the GHEX do not drill deeper than the TRT test borehole to keep this as developmental drilling (think liability)
- Changes in design depth and or geology/lithology may require another TRT

Example error:
Test 300' – Spec 450'!

Advanced Thermal Response Testing
The Numerical Method Solution

Conclusion

- Base A-TRT test for 2/4 pipe and concentric
- Meets IGSHPA/CSA/ASHRAE requirements
- The following will require changes to the testing procedure
  - Twister
  - Additional water storage, such as thermal piles
  - Integration of Thermal Batteries

Summary of session, closing questions:

Who – Every Commercial GHEX

What – Advanced Thermal Response Testing

When – Before GHEX design!

Why – Proper sizing and cost

Where – On-site testing with remote monitoring

Garen N. Ewbank

gewbank@geotctest.com

gewbank@nextempsolutions.com

gewbank@greyedgegroup.com

Thanks!

GEOTHERMAL TEST BORES & TC TESTING

Moderator: **Aeowyn Kendall / *Aztech Geothermal***

Speakers: **Kortney Lull / *Midwest Geothermal***
Dan Sergison / *Salas O'Brien*
Dr. Jeffrey Spitler / *Oklahoma State University*
Garen Ewbank / *Ewbank Testing*