A White Paper on the Determination and Methods for Thermal Conductivity Testing

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Relevant Acronyms:

ASHRAE - American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASTM - American Society for Testing Materials
CGD – Certified GeoExchange Designer
EWT – Entering Water Temperature
GHX – Ground Heat Exchanger
GSHP – Ground Source Heat Pump
IGSHPA – International Ground Source Heat Pump Association
WSHP – Water Source Heat Pump

Thermal Conductivity Testing

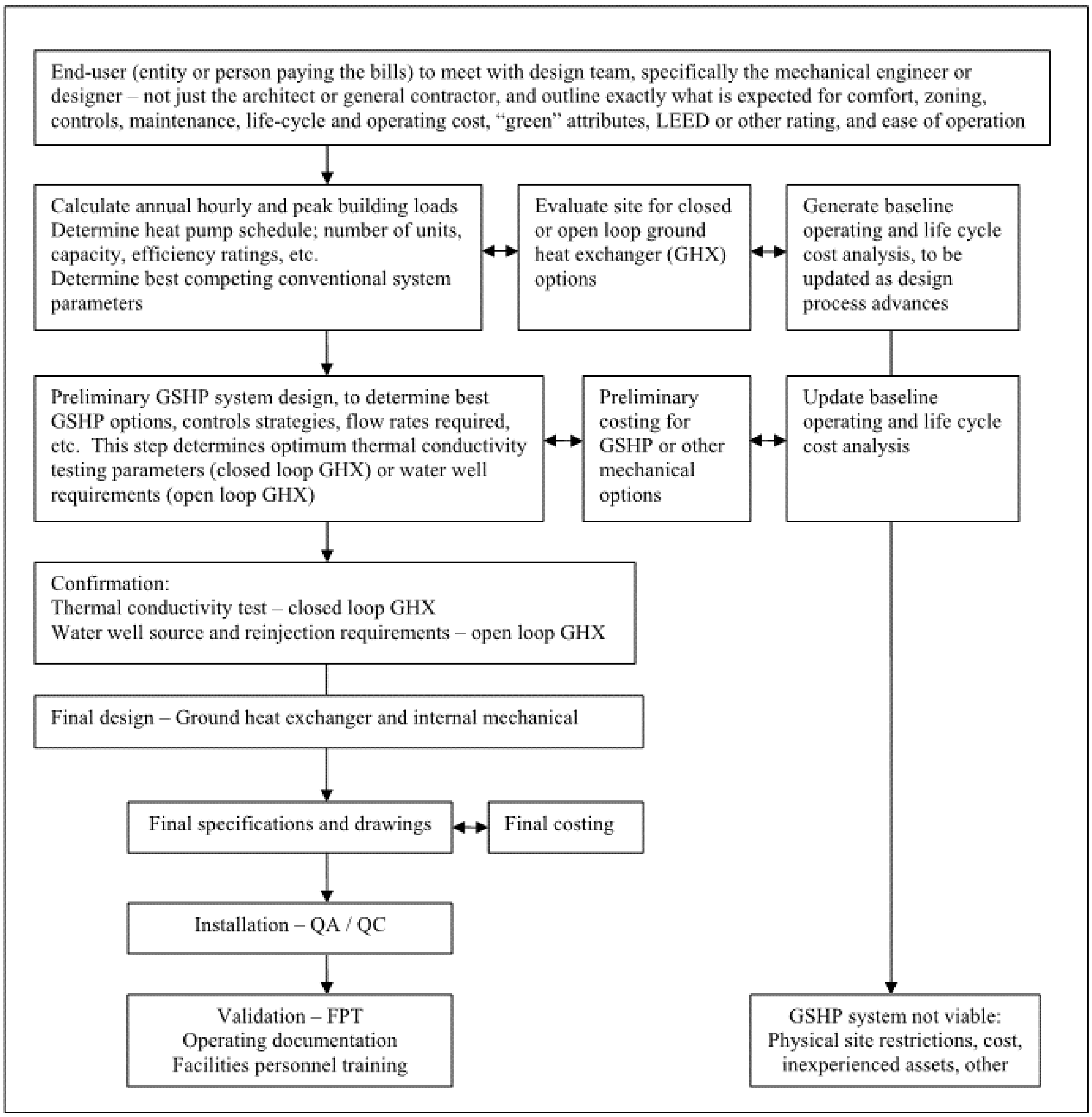
The design of a closed loop ground heat exchanger (GHX) intended to service a ground source heat pump system must account for total cooling and heating load duration on the GHX, the efficiency of the heat pumps to be used at different entering water temperatures and the flow rates required to service the heat pumps, and geologic conditions hosting the GHX. The latter is generically referred to as thermal conductivity but in reality must account for not only thermal conductance of the geology but also the undisturbed temperature and a value referred to as diffusivity. The objective is to design a GHX that will maintain an entering water temperature range that the heat pump system is compatible with.

Because conventional water source heat pumps have a much narrower operating range of supply water temperatures, typically between 50°F to 80°F, if a GHX were designed to stay within this much narrower temperature range, the loopfield would be substantially larger, require more land and have a much higher installation cost. True extended range WSHP equipment, referred to as ground source heat pumps (GSHP), can tolerate a much wider range of EWT. This is what allows the industry to design much smaller ground heat exchangers that in most cases can be cost-justified.

For example an engineer might determine that the GHX for a specific application should be able to maintain a maximum EWT range of between 35°F to 95°F (actual target EWT design ranges will vary depending on the specific needs of each project), even though most modern GSHP equipment is designed to tolerate a EWT range of 20°F to 120°F. The reason for this is that load calculations and GHX designs are still estimates and it makes no sense to design a loopfield to these maximum supply water temperature limits, leaving no room for unforeseen issues. This may also be thought of as having an automobile capable of driving at over 100 mph because the speedometer is rated that high – it can be done but at far less efficiency (higher fuel consumption) and reliability will certainly suffer.

Developers, general contractors, architects and mechanical engineers need to keep in mind that while TC testing is a relatively simple process, the test parameters must be determined first from an evaluation of the building's mechanical requirements, comprehension of available area to install the GHX, type of GHX configuration considered and other variables. An experienced GHX design mechanical engineer and/or CGD (Certified GeoExchange Designer) should be consulted before proceeding with any commercial scope closed loop ground heat exchanger design and installation.

Figure 1. Summarized GSHP design flow chart.



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Loads

Typically for any commercial scope project where internal gains from lighting, occupancy, outside air management, etc., are significant a detailed hourly load is required accounting for the peak cooling and heating load of the facility for every hour of the year. Industry informally refers to this kind of load calculation as an ‘8760’ load, derived from 24 hours x 365 days.

Heat Pumps

The efficiency of the heat pumps at differing EWT ranges must be known as the compressor heat from the mechanical equipment must be added for cooling and deducted for heating relative to the building’s 8760 hourly load. The parameters of the heat pump schedule must be accounted for in the GHX design simulation. The flow rates required by all of the heat pumps must also be known as this is accounted for to determine the number of individual circuits, pipe sizes for the ground loop and other considerations.

Thermal Conductivity Values

The designer must account for three key geologic values when integrating the hourly loads and variables derived from the intended heat pump schedule to design a GHX. These values are as follows:

1. Thermal conductivity (TC) – the rate at which energy can move through the host geology, either absorbed (heating) or rejected (cooling), typically defined as how much btuh energy per linear foot of borehole it takes to make one degree F change in temperature. This value is usually defined as btuh/ft/°F or by the symbol *k*.

2. Undisturbed temperature (UT) – The native temperature of the geology, in °F.

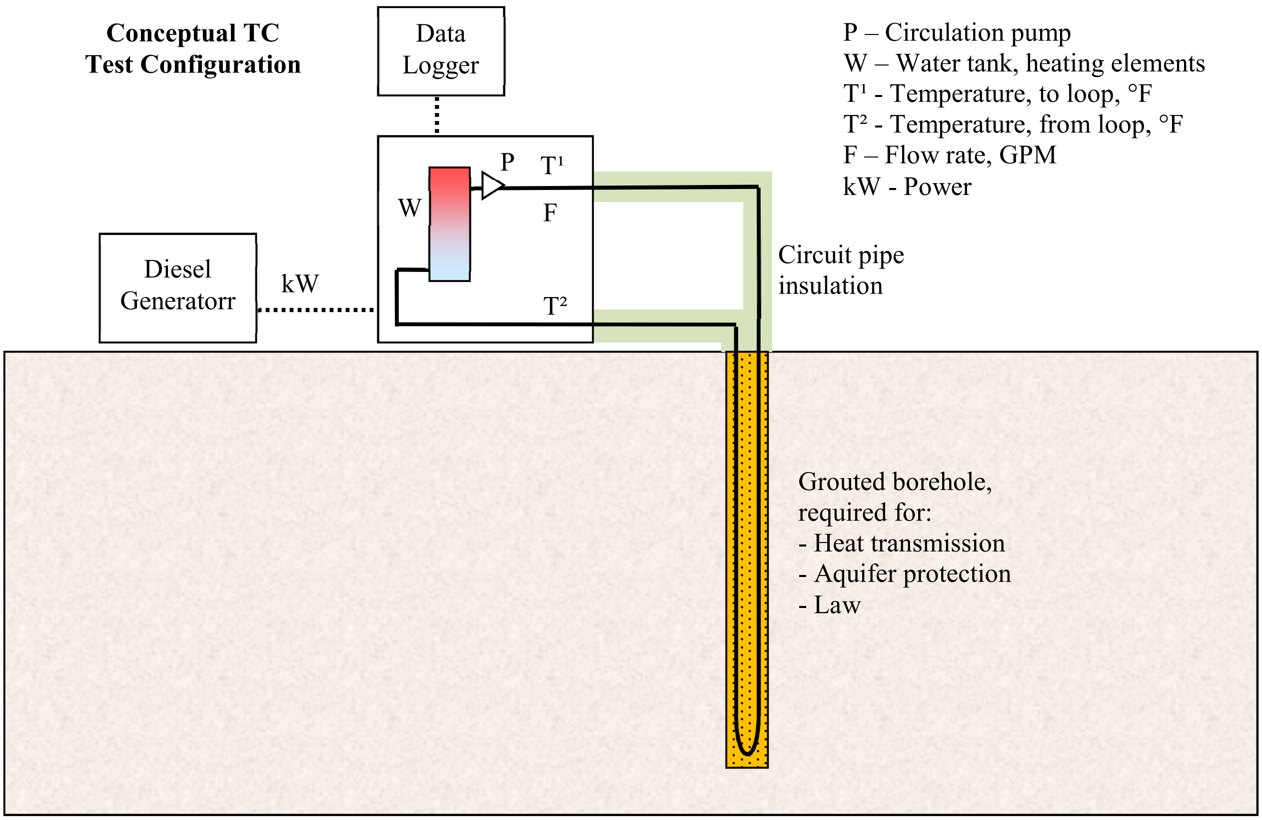
3. Diffusivity (D) – the impact of heat migration away from the point source of energy, so for a borehole heat exchanger this is usually expressed in temperature migration away from the bore per day. This gives a value to the designer at how fast heat can radiate away from the ground loop. This value is usually defined as ft^2/day or by the symbol α.

In Europe and other countries where the metric system is used these values are referred to in these respective units:

Thermal conductivity: W/(mK)
Undisturbed temperature: °C
Diffusivity: m^2/day

These three key values are determined from in-situ testing by two different types of TC testing that account for overburden pressure and other host condition influences.

Figure 2. Borehole thermal conductivity test apparatus and configuration.



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The first type of test is based on what is called the 'line source' testing method that accounts for the average TC, UT and D values over the length of a borehole, either a vertical or horizontally drilled bore. The second type of test involves the use of a hand-held meter that samples these values directly from an excavated probe test, typically using a backhoe to get to the intended design depth, what we typically refer to as a point source or probe test. Since the UT is critical, the measurements must be taken immediately from a fresh excavated hole.

For a vertical borehole test, the test values will likely vary with depth at even the same location; i.e., a TC test for a 300' borehole may yield different values than a 500' hole for the same location. Same with a probe point test, a TC value at 5' may be different than that at say 8' depth. For these reasons no thermal conductivity testing should be programmed until compatible test parameters are determined through preliminary GHX simulations to select the optimum test parameters.

Myth: Some perceive that a TC test either confirms or kills a GSHP option. Nothing could be further from the truth. The TC test is just another piece of the design puzzle to properly design a GHX. It is no different than doing standard geotechnical evaluations or other construction-related testing for civil and structural design considerations to determine parameters for other construction efforts.

An experienced ground loop designer can typically pre-design a GHX to within 5% to 10% of the final size based upon preliminary field simulations. The TC values determined from testing will certainly *influence the final size and scope of the GHX but the dominant determination of field size, number of circuits and other specifics will be the total annual cooling and heating loads, not the TC test results. For this reason accurate load calculations are necessary for the most cost-effective GHX design.*

Figure 3. Probe thermal conductivity test apparatus.

Example photos of probe testing (Windsor Middle school, Weld County, CO).
***Courtesy Major Geothermal*, *Wheat Ridge, CO*.**

Preliminary GHX Simulations

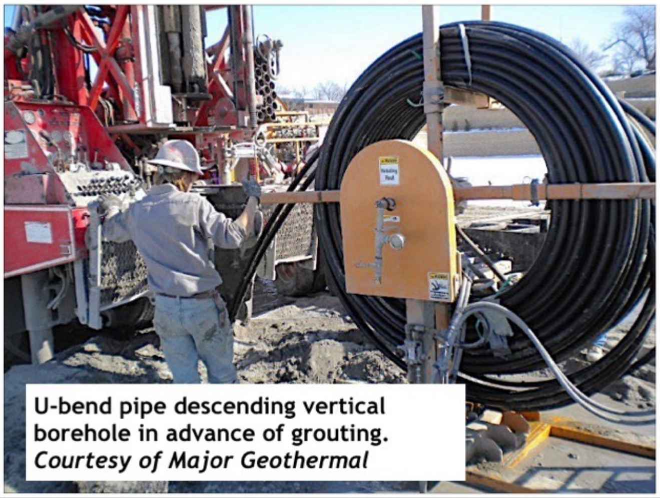
So how is the TC data used in the design of a ground loop? It is integrated with the annual cooling and heating load calculations for the project, along with consideration of the type of heat pumps to be used, and anticipated water flow rates required to feed the heat pumps. All of these bits of information go into a calculation to run ground loop simulations to determine the appropriate depth of the GHX, number of circuits (boreholes, slinkies, etc.), spacing between circuits and other criteria. This is why no TC test should be done until preliminary GHX simulations are done, which requires knowledge of the building's mechanical needs first.

A flow chart that describes when TC testing should be done is described in Figure 1 as a Confirmation step. This flow chart has been modified and summarized from the ASHRAE commercial GSHP design manual (*Geothermal Heating and Cooling: Design of Ground-Source Heat Pump System, Kavanagh & Rafferty, ASHRAE*).

Additional photos are included describing the drilling processes to install GHX's (Ground Heat Exchangers.

Generator and data logging unit for borehole thermal conductivity testing (Denver Water Campus, Denver, CO).
Courtesy of Major Geothermal

Examples of drilling rigs used for horizontal borehole closed loop installation and loading of u-bend ground loop assembly (Delta Americas headquarters, Fremont, CA).



U-bend pipe descending vertical borehole in advance of grouting.
Courtesy of Major Geothermal

Two horizontal drilling rigs punching lateral loops after completing those ready for headering.
Courtesy of Major Geothermal

Examples of drilling rigs used for vertical borehole closed loop installation and loading of u-bend ground loop assembly (IKEA retail store, Kansas City, KS).

This heavy-duty drill rig bores some of the 180 holes that went 600 feet deep by 6" wide to supply this 359,000 square foot store. They contain 36,000 gallons of fluid that interacts thermally between heat pumps and the earth. ***Courtesy of Major Geothermal***

TC Testing - Residential GSHP Closed Loop Ground Heat Exchangers

For small residential applications TC testing is rarely necessary. The reason for this is the cost difference between the worst and least case sizing of a GHX is often less than that of doing the test. This is a judgment call to be determined by an experienced loop designer.

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For more information on the technical aspects of thermal conductivity testing:

http://igshpa.okstate.edu/research/papers/tc_testing_copyright.pdf
http://grti.com/services/ftcOverview.htm
http://www.astm.org/Standards/D5334.htm

For additional information on geothermal heat pump technology and the case studies, policies, and efforts that support them, please go to:

www.CaliforniaGeo.org

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