INTERNATIONAL GROUND SOURCE HEAT PUMP ASSOCIATION

2015 IGSHPA Product Showcase

Optimizing ground heat exchanger length with GeoperformX pipe

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Université du Québec

INRS Overview

- A university dedicated to research only
- Water, Earth and Environment Center based in Quebec City, Canada
- Lab facilities heated and cooled with a ground source heat pump (GSHP) system
- Operates a test site with a pilot ground heat exchanger (GHE) and monitoring boreholes

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Collaborations with Versaprofiles to develop GHE pipes

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RESEARCH ARTICLE Open Access

Designing coaxial ground heat exchangers with a thermally enhanced outer pipe

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Abstract

Background: Ground heat exchangers installed in boreholes are an expensive component of a ground-coupled heat pump system, where minimizing the borehole length with appropriate materials and configuration can reduce the overall cost of the system.

Methods: Design calculations performed analytically indicate that the coaxial pipe configuration can be more advantageous than the single U-pipe configuration to reduce the total borehole length of a system.

Results: A decrease of the borehole thermal resistance and an increase of the thermal mass of water contained in the coaxial exchanger helped to reduce borehole length by up to 23% for a synthetic building load profile dominated by cooling. The decrease of the borehole thermal resistance was achieved with an outer pipe made of thermally enhanced high-density polyethylene, where the thermal conductivity is 0.7 W m^{-1} K^{-1}.

Conclusions: The coaxial configuration requires further investigations of the technical barriers related to the installation of ground heat exchangers in the field.

Keywords: Geothermal; Heat pump; Ground heat exchanger; Borehole; Coaxial; Concentric; Pipe; Thermally enhanced

Background

Ground-coupled heat pump systems used for heating and cooling buildings are a highly efficient technology that takes advantage of the Earth's subsurface acting as a heat source or heat sink. The operation of heat pumps reduces the need for conventional energy. However, the systems are expensive because of the drilling or trenching required for installation of the ground heat exchangers (GHEs). Technological innovations can help reduce the length of GHEs for building energy needs to be fulfilled at lower installation cost. Reducing installation costs is particularly important for vertical systems with boreholes that tend to be more expensive than horizontal systems (Canadian GeoExchange Coalition 2010). Significant advances in addressing this market barrier can reduce the payback period of geothermal systems and increase the shares of the geothermal sector on the global heating and cooling market.

To determine the required length of vertical GHEs, one of the various parameters considered in the equation is the borehole thermal resistance (Bernier 2000), which is the ability of the GHE to resist heat transfer. Selecting appropriate materials and

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- 2015 – Geothermal energy
  www.geothermal-energy-journal.com/content/3/1/7
- 2011 – ASHRAE Transactions
- 2011 – Ground Water
- 2011 – GeoConneXion Magazine

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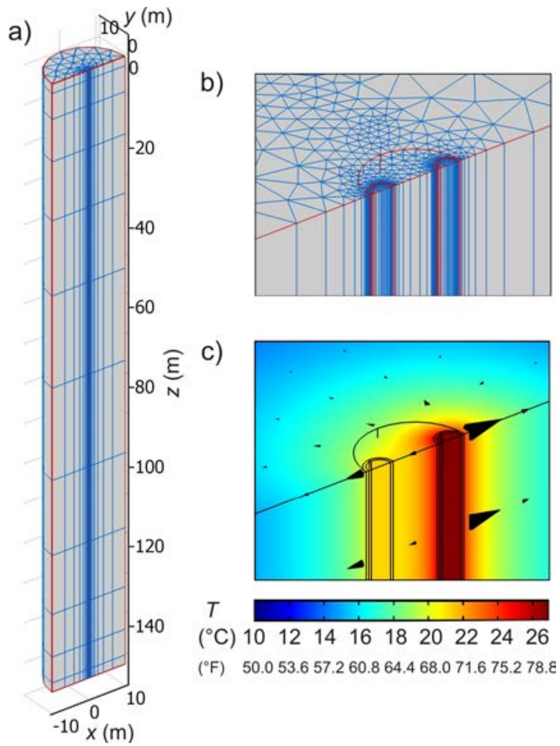
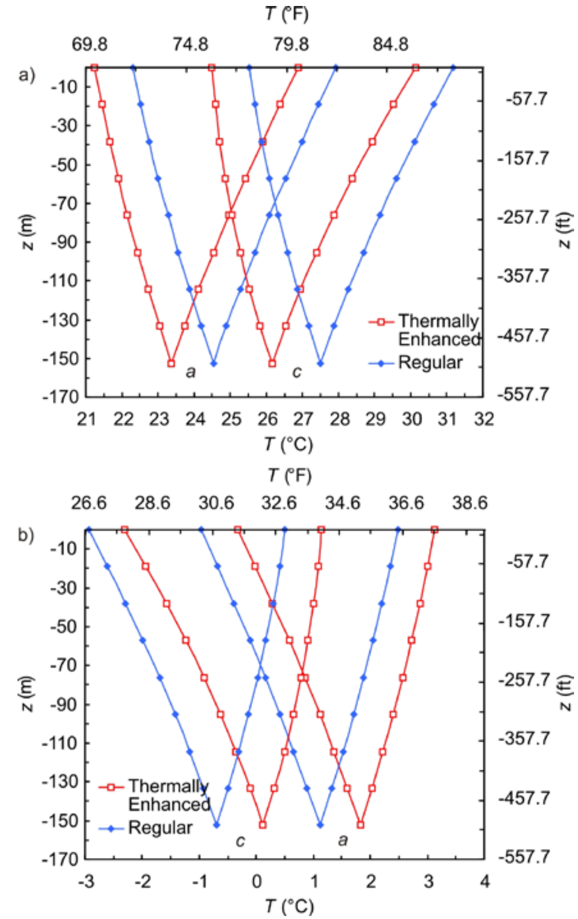
Numerical evaluation of GeoperformX pipe performances



2011 – ASHRAE Transactions

- 2D and 3D numerical simulations of 1U-pipe GHEs
- Evaluated operating temperatures – 0.6 to 1 ºC (1.1 to 1.8ºF) better
- Up to 24 % borehole thermal resistance reduction and 9 % bore length decrease



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Verification of the GeoperformX pipe performances with thermal response tests

2011 – Ground Water

- TRT-1 : GeoperformX

-TC 3.0 W/m K (1.73 Btu/h ft ºF)

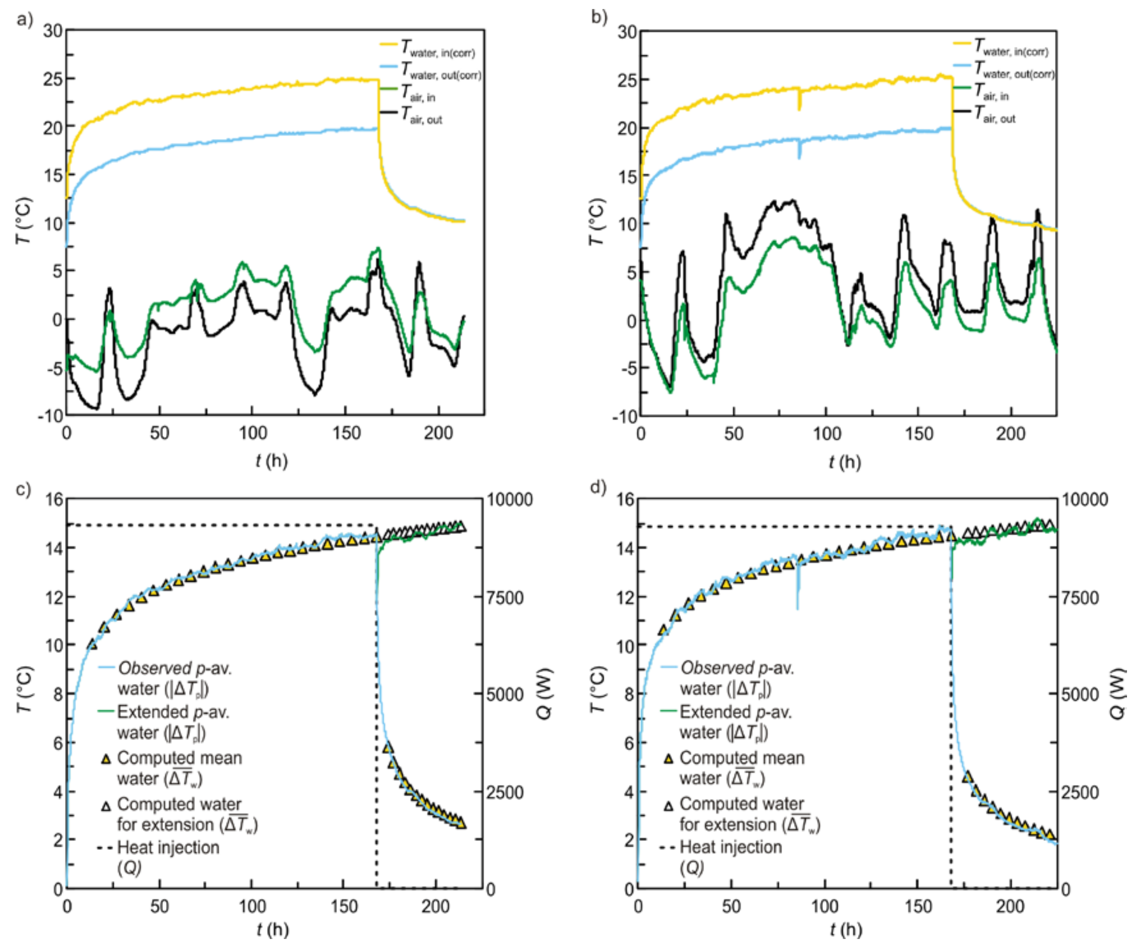
-R_b 0.065 m K/W (0.112 h ft ºF/Btu)

- TRT-2 : Versapipe

-TC 3.4 W/m K (1.97 Btu/h ft ºF)

-R_b 0.081 m K/W (0.140 h ft ºF/Btu)

- 20 % less R_b with 1U-pipe GeoperformX



- Test performed by Golder Associates (Groleau and Pasquier, 2009)

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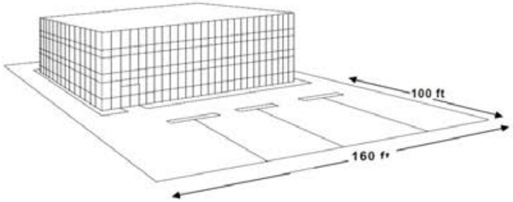
Sizing GSHP systems with GeoperformX pipe

2011 – GeoConneXion Magazine

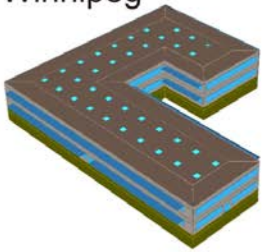
- Demonstrated how to size GSHP systems with GeoperformX pipe using commercial design programs (EED, eQUEST, GeoAnalyser, GLD, GLHEPro, GS2000)
- Showed 6 to 11 % bore length reduction for three buildings using different sizing approaches (ASHRAE, Sweden) for 1U-pipe configurations

a) Montreal

b) Ottawa



c) Winnipeg



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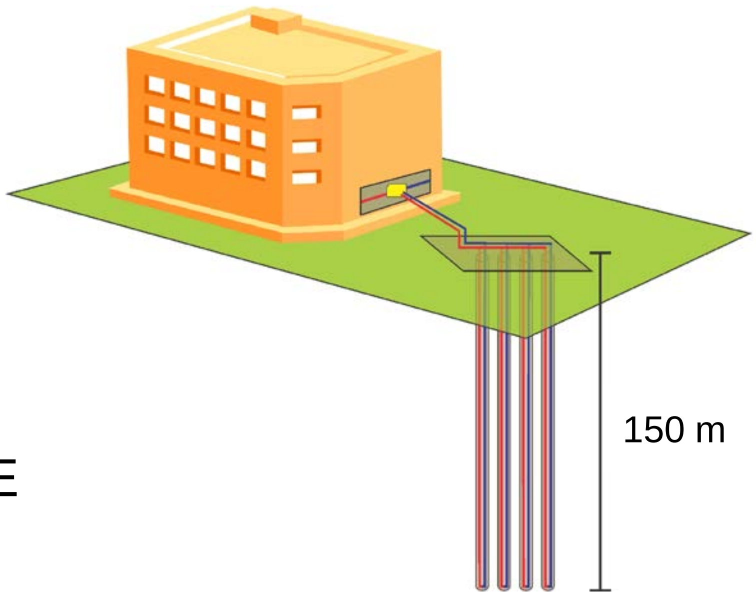
Designing GHEs to reduce borehole length

- Objective : decrease the installation cost and reduce the pay back period
- How : optimize the GHE heat transfer performances to decrease its total length
- In most GSHP design programs, the GHE performances are described by the borehole thermal resistance

  R_b (m K/W – h ft ºF/Btu)
- With given subsurface conditions, optimizing the GHE implies reducing R_b



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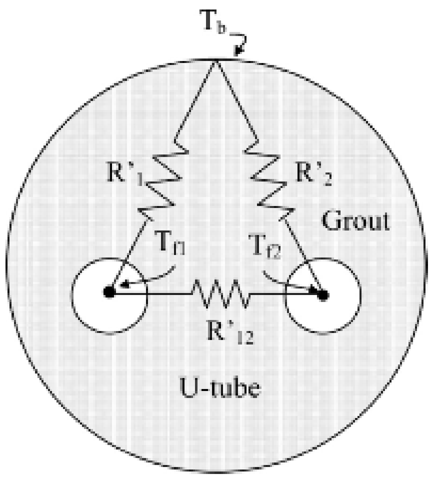
The borehole thermal resistance

- Describes the opposition to the passage of heat between the GHE fluid to the subsurface at the borehole wall

- Enclose the thermal resistances caused by fluid flow as well as the properties and configuration of the GHE materials

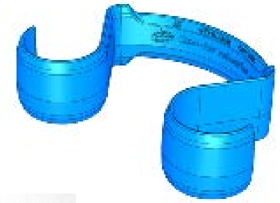
- Most commercial design programs use a 2D approach's to calculate the borehole thermal resistance (GLHEPro, LoopLink, GLD)

- A 3D approach including an internal resistance is sometime used (EED)

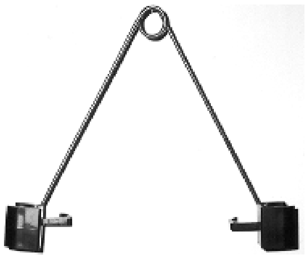


Lamarche et al., 2010

The borehole thermal resistance



- Varies between 0.05 to 0.35 m K/W
  (0.09 – 0.61 h ft ºF/Btu)



- Can be reduced by:
  - Increasing the pipe spacing
  - Increasing the grout thermal conductivity
  - Reducing the borehole radius
  - Improving the pipe
    - Thermal conductivity (TC)
    - Thickness
    - Configuration

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Versaprofiles 2nd generation of GeoperformX pipe

- Launched in 2015
- Version 2 made with thermally conductive nanoparticles and PE4710
- Can be heat fused with regular HDPE
- Meets minimum requirements for geothermal pipes, including IGSHPA guidelines (slow crack growth, PENT, Hydrostatic, etc.)
- Available in many diameters (> ½") and dimensions (> SDR-9)
- 75 % increase in thermal conductivity

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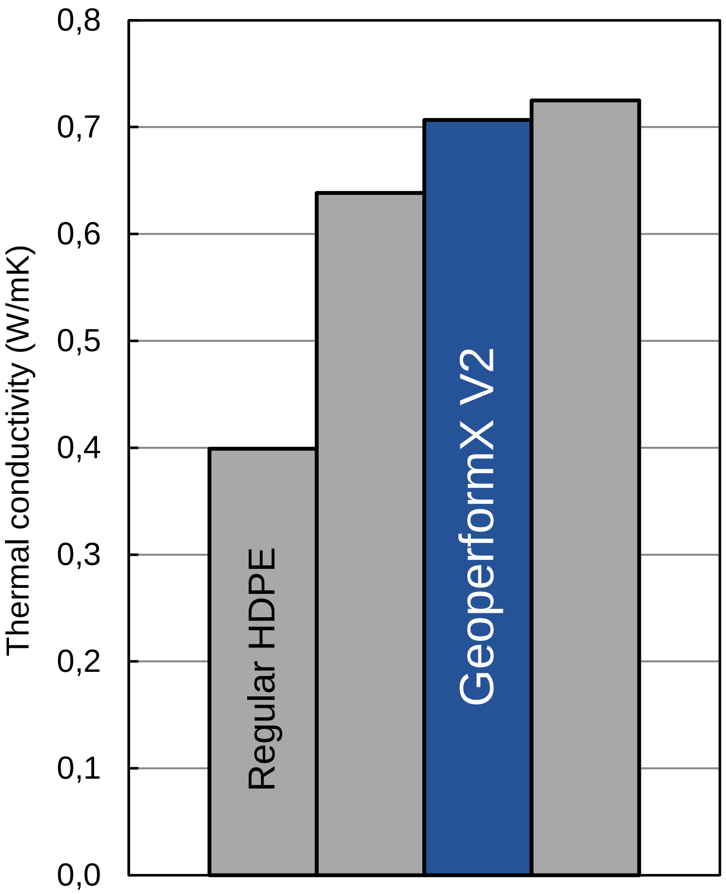
Thermal conductivity of the GeoperformX pipe

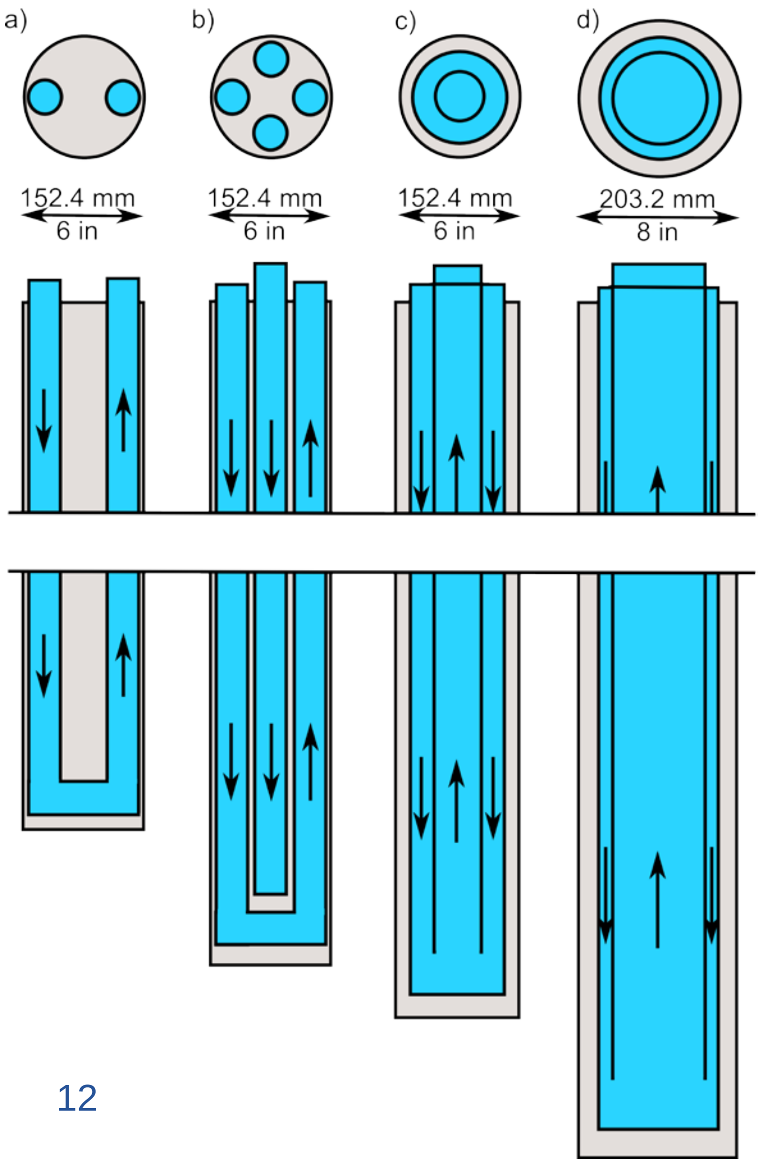
- Regular HDPE 0.4 W/m K
  (0.23 Btu/h ft ºF)

- GeoperformX 0.7 W/m K
  (0.40 Btu/h ft ºF)

- Was verified on samples with a needle probe



Borehole thermal resistance of GHEs



- To determine the performance of the GeoperformX pipe
- Verified various pipe configurations including coaxial
- Calculated with the 3D model of EED
- Used the multipole (Claesson and Hellström, 2011) and the concentric methods
- Accounted for internal heat transfer (Hellström, 1991)

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Assumptions made to calculate the borehole thermal resistance of GHEs

- Borehole length 150 m (492 ft)
- Grout thermal conductivity 1.7 W/m K (1.0 Btu/h ft ºF)
- Subsurface thermal conductivity 2.5 W/m K (1.44 Btu/h ft ºF)
- Pipe dimension SDR-11 1¼" except for coaxial GHE
- High flow rate to ensure turbulence

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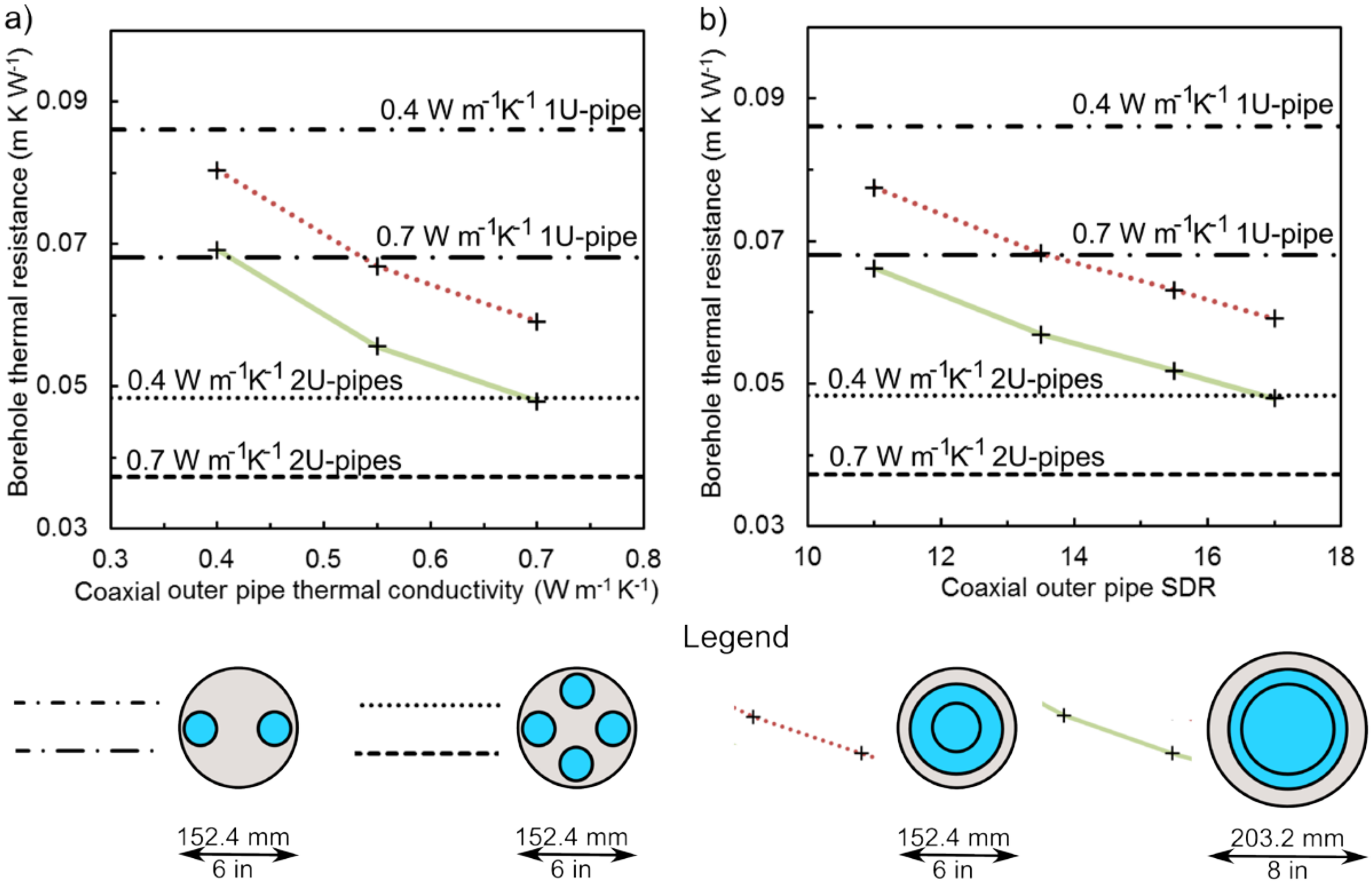
Borehole thermal resistance of GHEs



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Key results to minimize the borehole thermal resistance

- When comparing similar configurations, the GeoperformX pipe can reduce R_b by up to 31 %
- Highest R_b differences for GHE with conventional and GeoperformX pipes are for coaxial configurations with a thick outer pipe
- 2U-pipe with GeoperformX has the lowest R_b
- The thermal mass of water, which will affect GHE length, is not taken into account when determining R_b

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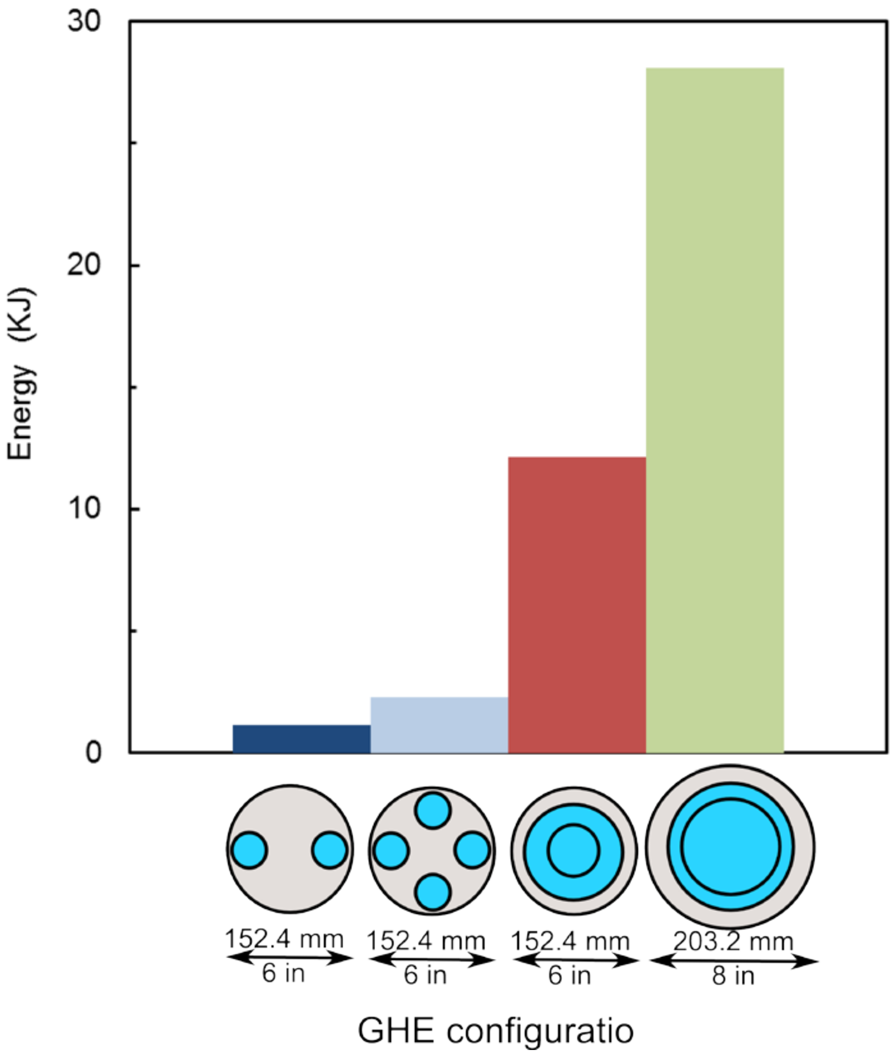
Energy needed to increase the water temperature in the GHE by 1 ºC (1.8 ºF)

- 6 to 28 times higher for coaxial GHEs when compared to 1U-pipe
- Can damp short-term peak loads and have a positive impact on GHE length reduction



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Sizing calculations to determine GHE length reduction

- Calculated with GLHEPro using R_b determined with EED
- Thermal short circuiting is taken into account with the 3D approach for R_b with EED (Hellström, 1991)
- The *g*-function used for simulations with GLHEPro considers the thermal mass of water (Xu and Spitler, 2006)
- Synthetic cooling dominated building loads were assumed

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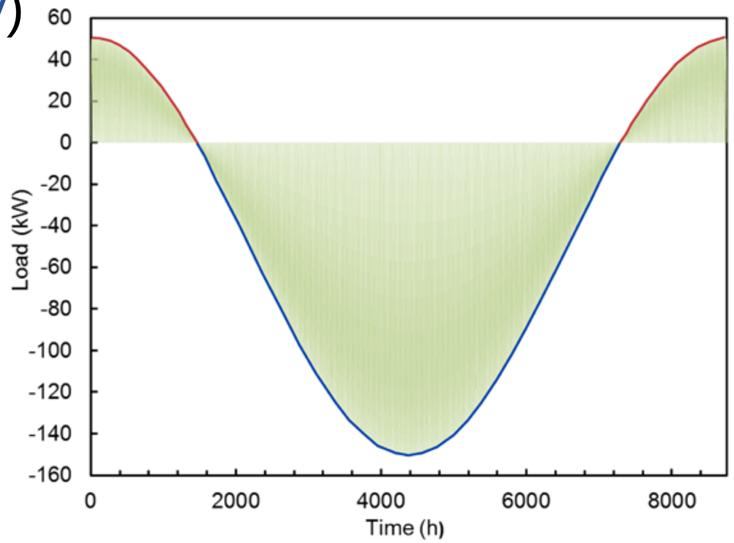
Assumptions for sizing calculations

- Peak heating : 50 kW (171 kBtu/h - January)
- Peak cooling : -150 kW (-512 kBtu/h – July)
- Heat carrier fluid is pure water
- SDR-11 1¼" pipes except for coax (17 out)



- Grout thermal conductivity 1.7 W/m K (1.0 Btu/h ft ºF)
- Subsurface thermal conductivity 2.5 W/m K (1.44 Btu/h ft ºF)
- Subsurface temperature 10 ºC (50 ºF)

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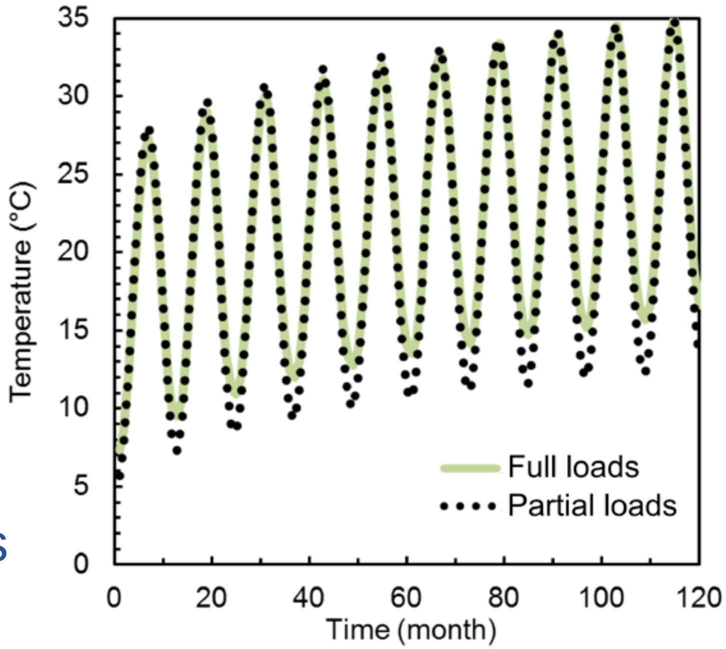
Assumptions for sizing calculations

- Greater depth targeted for 2U-pipe and coaxial GHEs to balance flowrates
- Borehole spacing is 10 m (32,8 ft) to minimize thermal interactions
- System sized for a maximum operating temperature of 35 ºC (95 ºF) after 10 years
- Full GSHP and hybrid systems with a 55 kW (188 kBtu/h) cooling tower were considered



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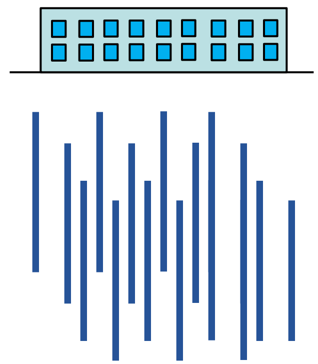
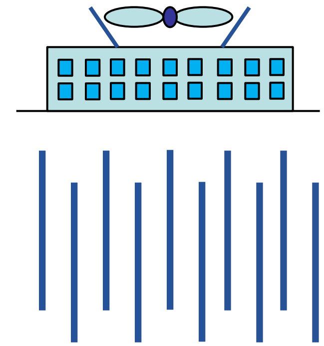
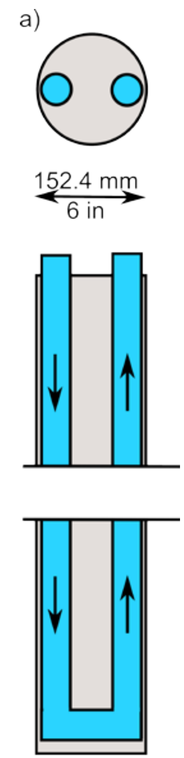
Sizing calculation results for 1U-pipe GHEs

Pipe TC – W/m K	0.4	0.7	0.4	0.7
Total flow rate – L/s	7	7	4.6	4.6
R_b – m K/W	0.0955	0.0777	0.0948	0.0768
GHE grid	4 × 4	4 × 4	2 × 5	2 × 5
Water volume – m^3	4.62	4.39	2.65	2.49
Individual GHE length – m	159	151	146	137
Total GHE length – m	2544	2416	1460	1370
GHE length reduction – %	---	5	---	6



SDR-11 1¼"

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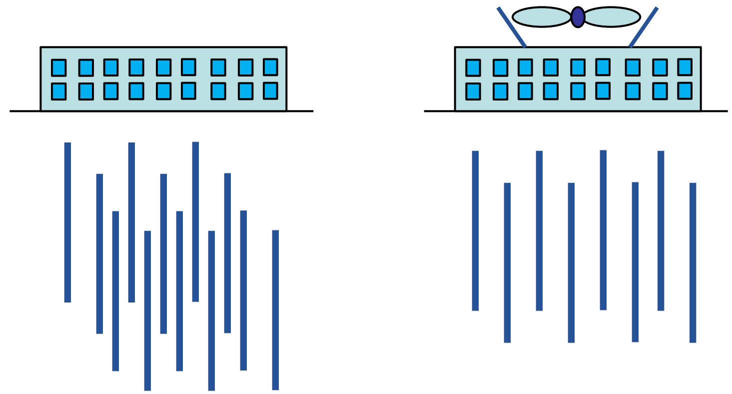
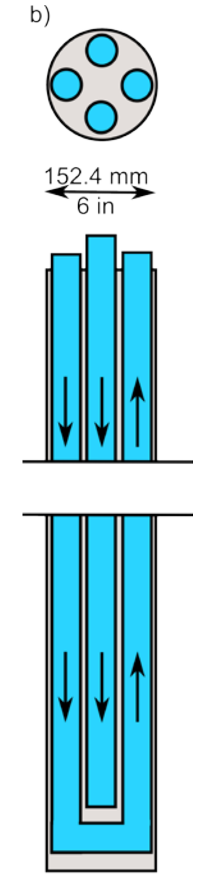
Sizing calculation results for 2U-pipe GHEs





SDR-11 1¼"

Pipe TC – W/m K	0.4	0.7	0.4	0.7
Total flow rate – L/s	7	7	4.6	4.6
R_b – m K/W	0.0563	0.0443	0.0547	0.0442
GHE grid	3 × 4	2 × 5	2 × 4	2 × 3
Water volume – m³	7.89	7.37	4.59	4.37
Individual GHE length – m	181	203	158	199
Total GHE length – m	2172	2030	1264	1194
GHE length reduction – %	15	20	13	18

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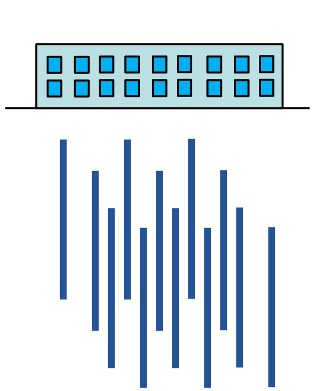
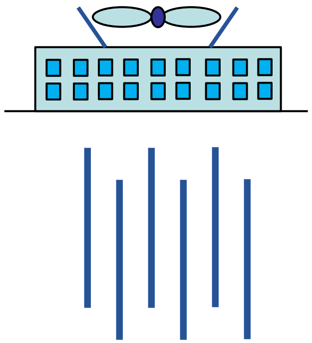
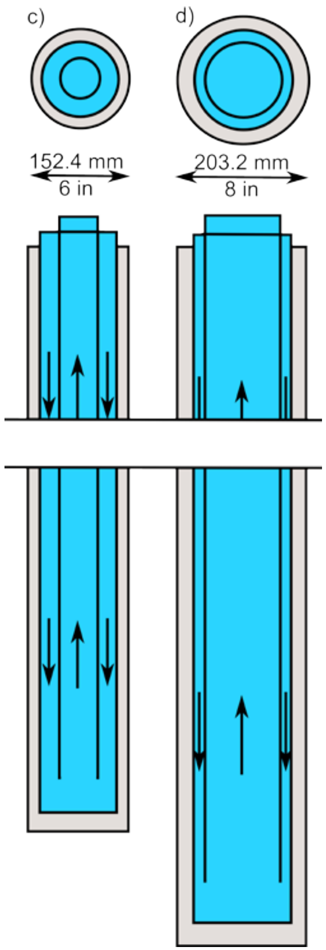
Sizing calculation results for coaxial GHEs





Outer pipe diameter – mm	152	203	152	203
Total flow rate – L/s	9.6	8	6	6
R_b – m K/W	0.0734	0.0630	0.0701	0.0587
GHE grid	3 × 4	2 × 4	2 × 3	2 × 3
Water volume – m^3	16.43	27.48	9.40	16.59
Individual GHE length – m	194	246	222	198
Total GHE length – m	2328	1968	1332	1188
GHE length reduction – %	9	23	9	19



SDR-11 in
SDR-17 out

The outer pipe TC is 0.7 W/m K for all cases.

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Key results to minimize the GHE length

- For the given examples, the GeoperformX pipe allowed to reduce GHE length by up to 23 %
- Most GHE length reduction is obtained with the coaxial configuration and the GeoperformX for the outer pipe
- 2U-pipe with GeoperformX showed similar results, up to 20% GHE length reduction

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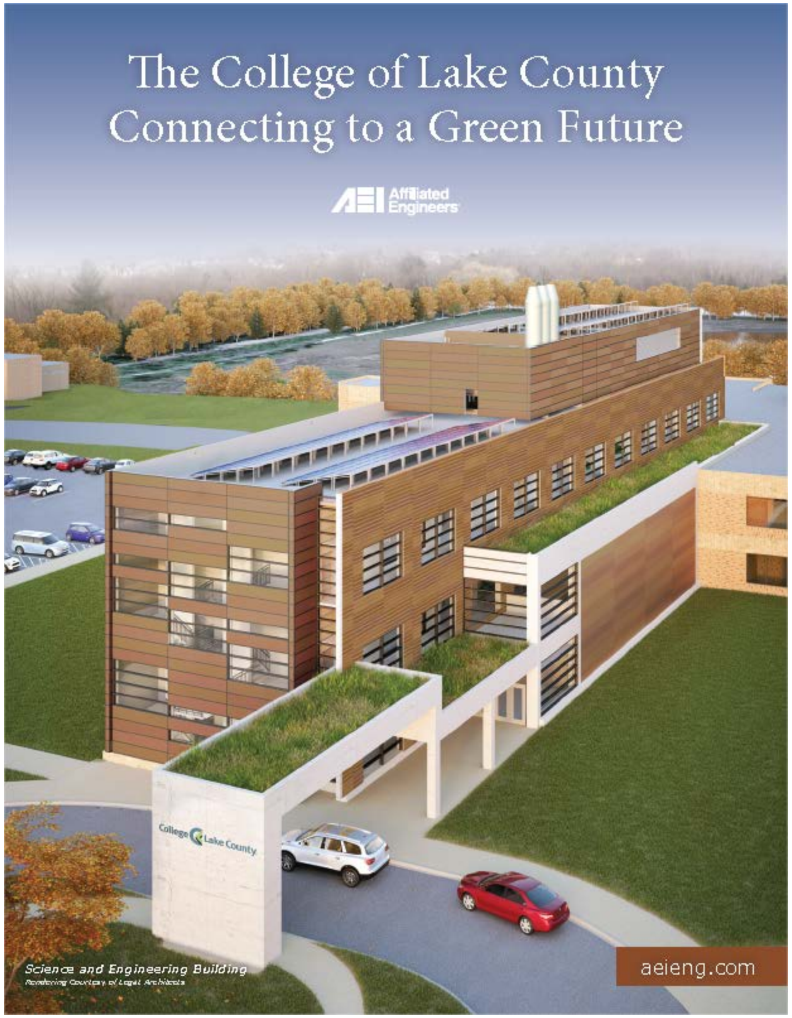
Real case example – Grayslake, IL

- A campus-wide GSHP system for the College of Lake County
- Variable pumping systems distribute the heat carrier fluid around the campus
- Heat exchange is achieved with a common GHE field
- Designed by Norbert Repka of Affiliated Engineers Inc.



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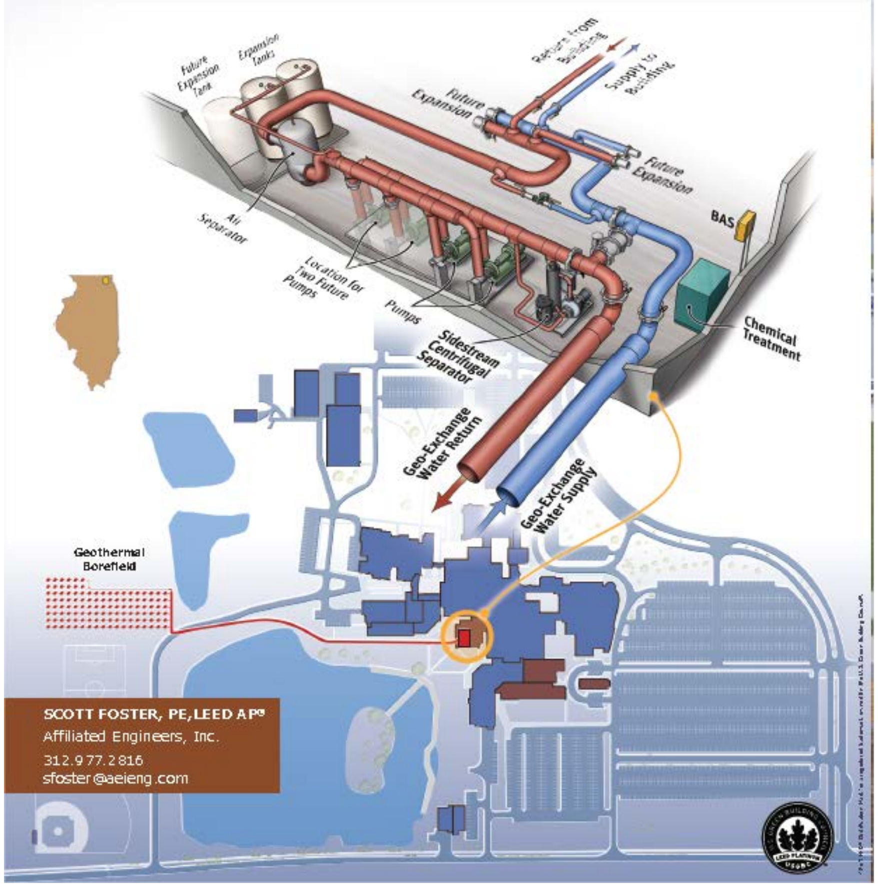
First phase – Grayslake, IL

GHE field

- •81 boreholes expendable to 480
- •500 ft deep
- •1U-pipe SDR-9 GeoperformX
- •Expansion tanks

•1500+ tons of heating and cooling capacity with extension

•800 to 1000 boreholes needed for the full campus



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TC test results – Grayslake, IL

GHE	Conventional	GeoperformX
Configuration	1U	1U
Borehole diameter – in	7.8	6.6
GHE length - ft	500	503
Pipe SDR	?	9
Subsurface temperature – ºF	53.6	52.3
Grout TC – Btu/h ft °F	1	1
R_b – h ft °F/Btu	0.221	0.174
Subsurface TC – Btu/h ft °F	1.64	1.79

Test carried out by Galen Streich of GRTI

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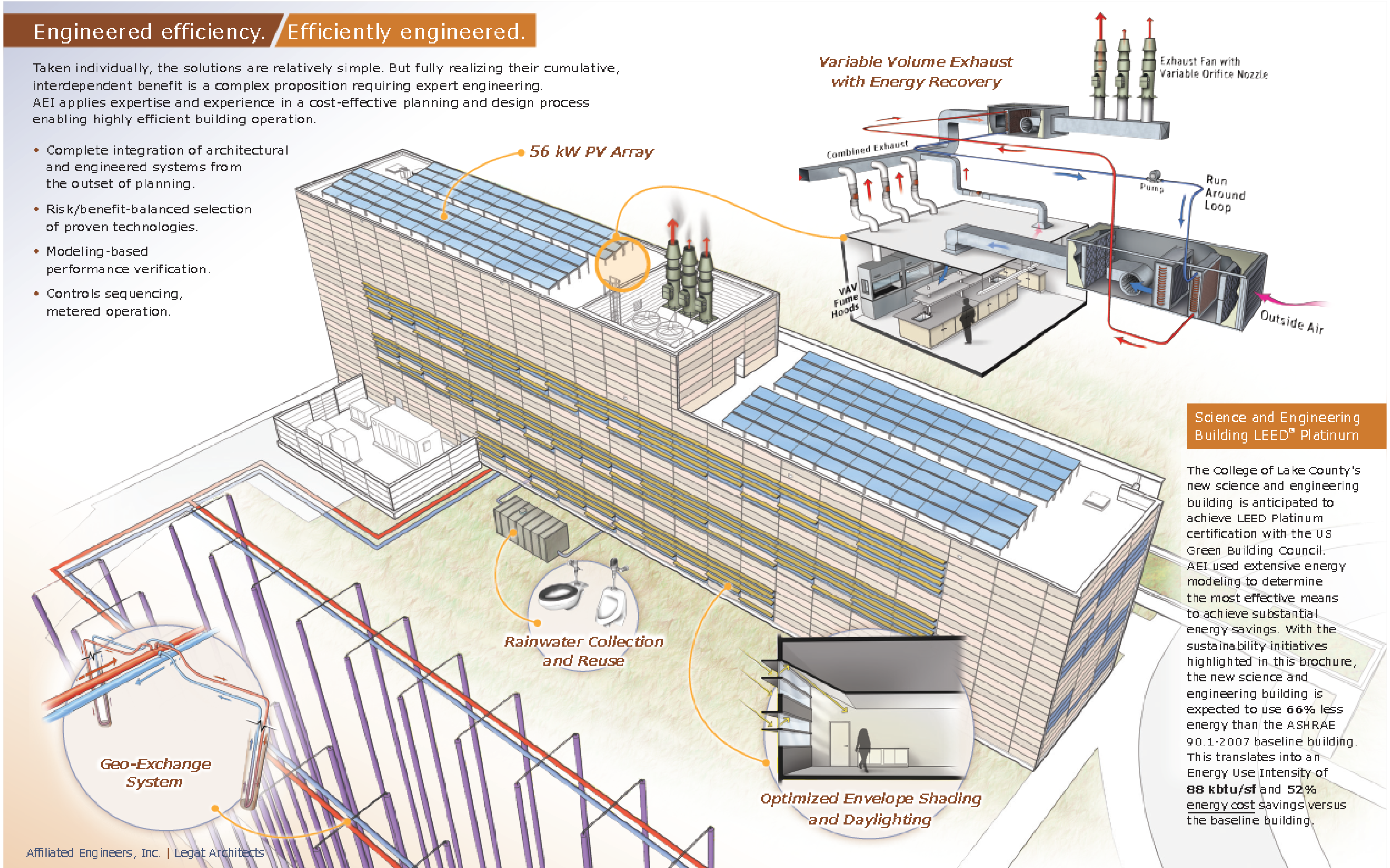
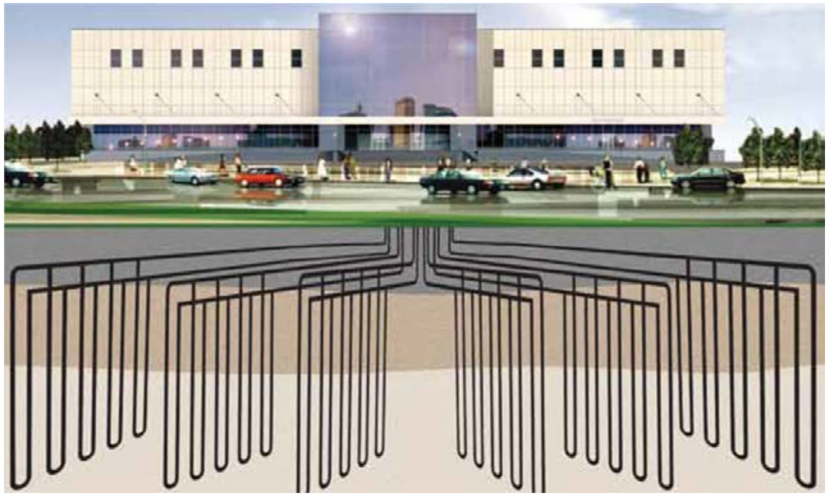
First phase – Grayslake, IL

25 ft bore length reduction per GHE with GeoperformX



Conclusions

- Reducing R_b is a key to optimize GHE length to decrease installation cost and improve the pay back period of GSHP
- The GeoperformX pipe with its 75 % higher thermal conductivity is a unique product to achieve bore length reduction



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Conclusions

- Using the GeoperfomX pipe with 1U, 2U and coaxial configurations typically results in 5 to 25 % bore length reduction

- Performances have been proven in the lab, in the field and with simulations of systems

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