The Groundwork for Sustainability: Geothermal

Development of a Web-based Screening Tool for Ground Source Heat Pump Applications

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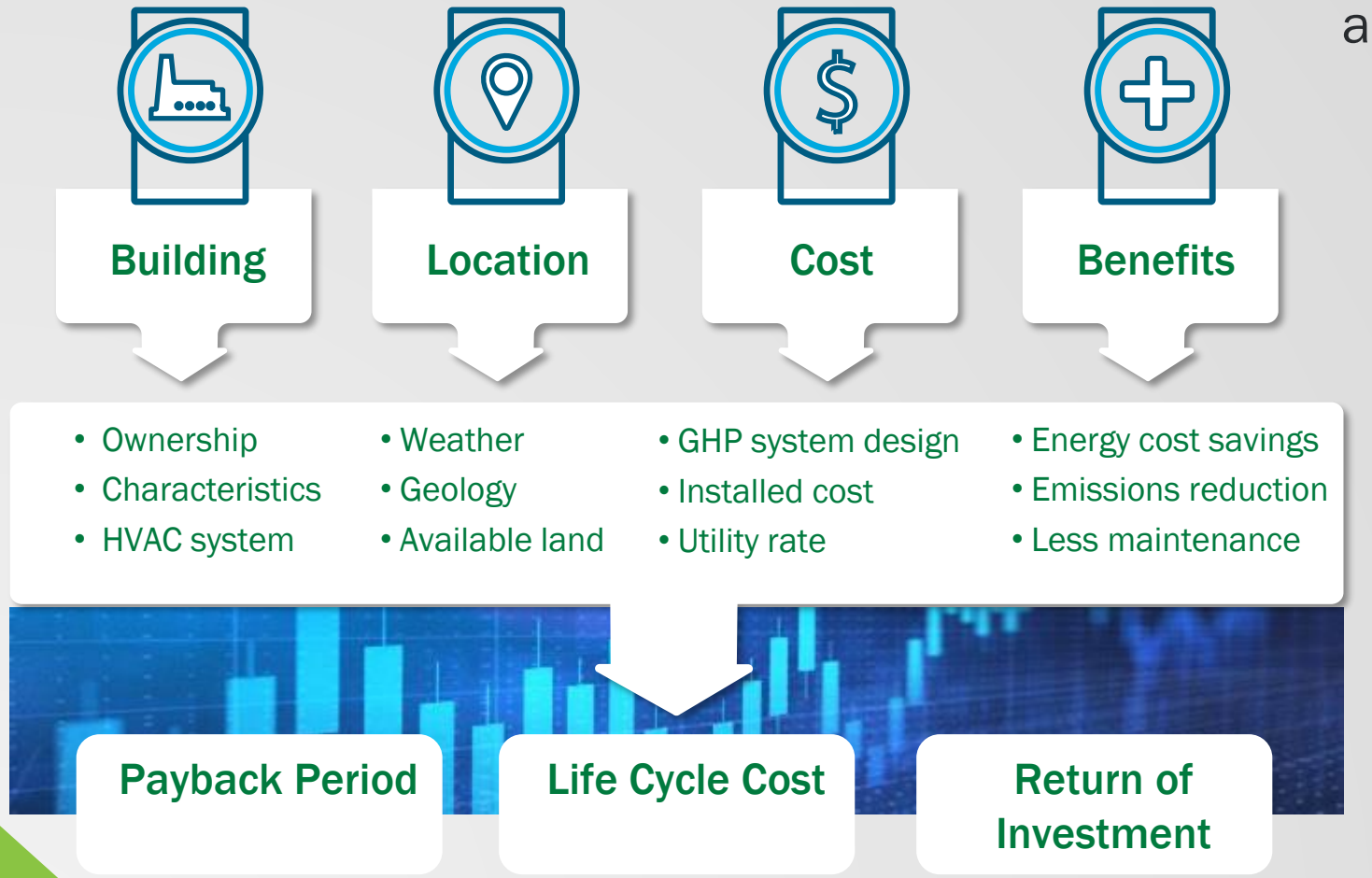
Annual Conference, December 6 - 8, 2022 – Las Vegas, NV

Agenda

- Background and goal
- Methodology
- Overview and demonstration
- Results and discussions
- Summary and future work

Background and Goal

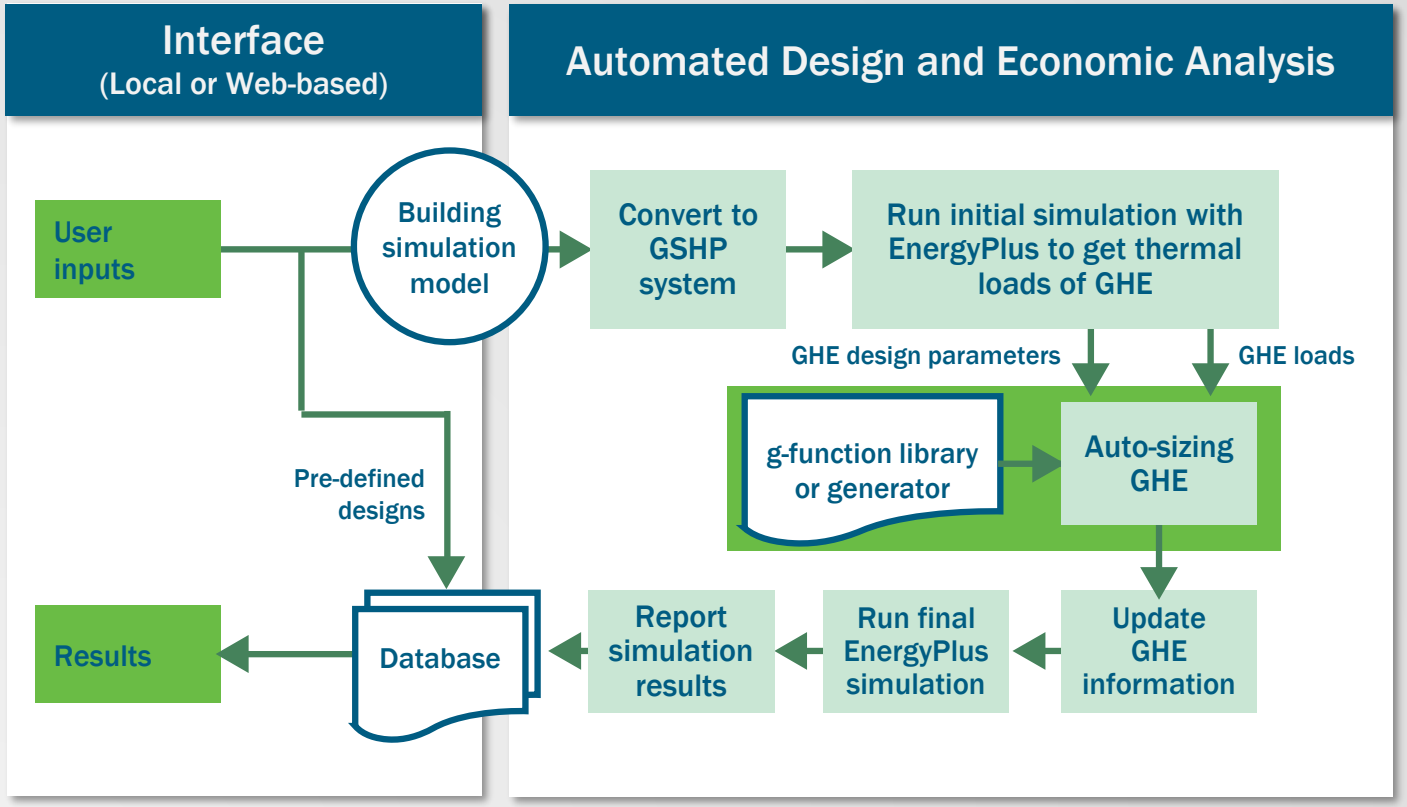


The economic viability of a ground source heat pump (GSHP) system is affected by many factors, which current design and analysis methods do not fully examine

- Rule of thumb
  - Simple but rough approximation
  - Lack of differentiation for buildings and ground formations
  - Often oversized and result in poor economics
- Detailed simulation
  - More accurate but requires hundreds of inputs
  - Time-consuming and expensive
  - Cannot auto-size ground heat exchangers (GHE)
  - Not common because of the cost and expertise required

Goal: Provide the GSHP industry with a tool for (1) easily assessing the economic viability of GSHP applications and (2) optimizing borehole field design

Methodology



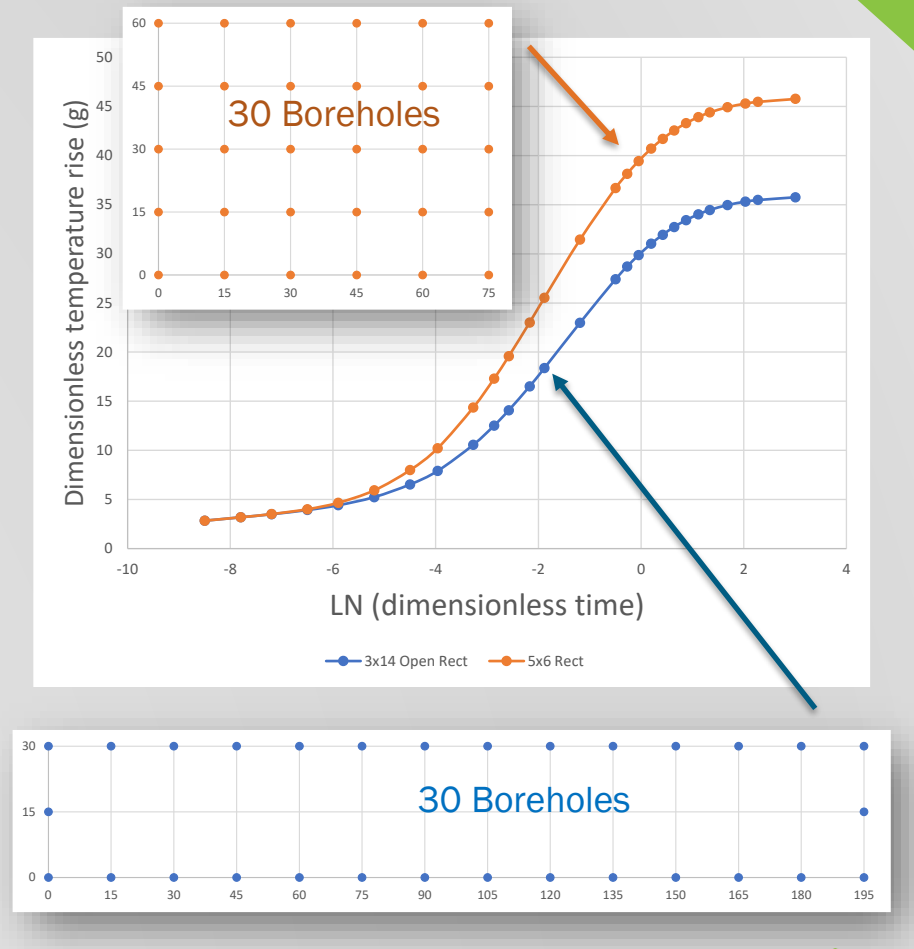
- Utilize the state-of-the-art building energy simulation programs: OpenStudio and EnergyPlus
- Integrated with the latest development in GHE modeling to increase flexibility, speed, and accuracy
- Automatically create building energy models, size HVAC equipment and GHE, and evaluate the economics of GSHP retrofit for almost any existing building in the US

Simulation of GSHP Retrofits

- A new distributed GSHP system replaces the existing HVAC system of the simulated building to provide 100% space heating and cooling
  - Distributed configuration using multiple connected water-to-air heat pumps (WAHPs) to provide independent climate control in each thermal zone of the building
  - Rated heating and cooling coefficients of performance (COP) of WAHPs are 4.0 and 6.5, respectively. Operational efficiency and capacity are affected by the supply fluid temperature of the ground source
  - Vertical bore ground heat exchangers sized to maintain leaving fluid temperature between 1°C and 35°C year-round (square of near-square borehole field configuration with 6.1 m bore spacing)
  - Outdoor air ventilation is provided with a dedicated outdoor air system (DOAS)
- Energy savings are from not only the higher efficiency of GSHP equipment due to the stable ground temperature but also the improved outdoor air ventilation using DOAS, and individual zonal climate control through the distributed configuration, which avoids simultaneous heating and cooling of conventional variable air volume (VAV) systems

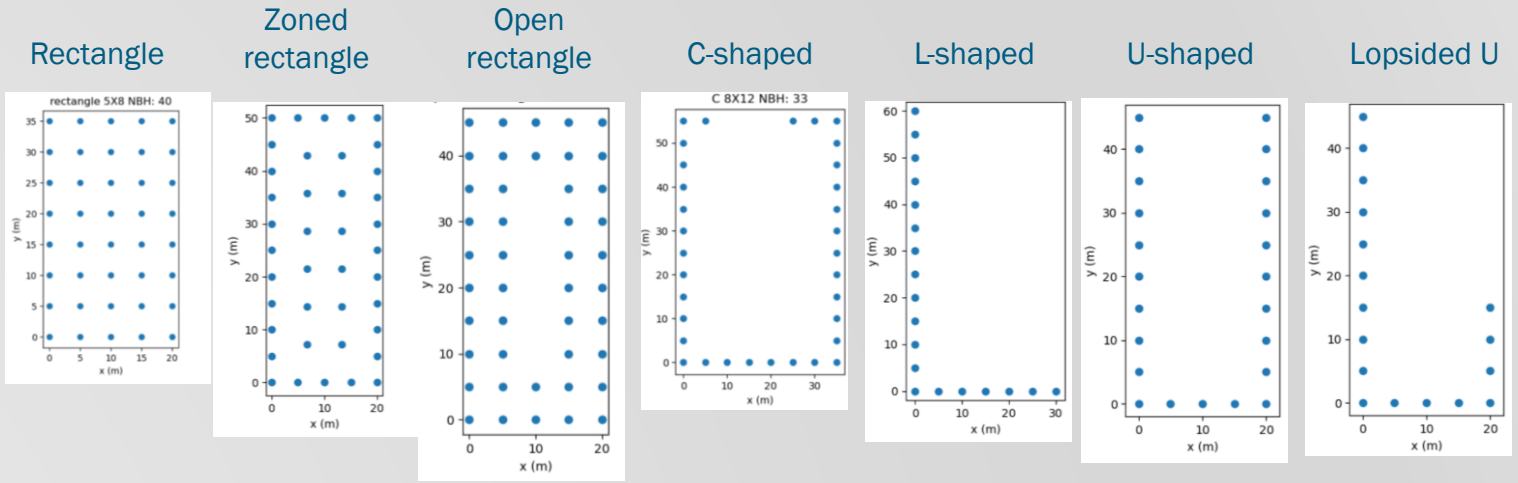
g-functions

- Precomputed thermal response factors of borehole fields
- A practical and accurate method to simulate both short- and long-term performance of vertical bore GHEs
  - 30+ year simulations with g-functions are fast (≈ 1 to 2 s per simulation)
- Calculating g-functions has been slow for large fields (20 min to 1+ h)
  - Precomputed libraries with limited configurations
- Recent developments enable “on-the-fly” fast calculation of g-functions for customized borehole fields



Expanded g-function Library

Borehole field configuration	Number of g-functions
Rectangle	1,651
Zoned rectangle	12,615
Open rectangle	2,332
C-shaped	4,525
L-shaped	495
U-shaped	3,248
Lopsided U	9,455
Total	**34,321**



100 times larger than the existing g-function library

- A new g-function library was created with cpgfunction program at OSU (Spitler et al. 2022)
  - Uses less memory than pygfunction and significantly faster than pygfunction for borehole fields with low similarity
- G-functions generated with cpgfunction are nearly identical to those generated with pygfunction or the original methods developed by Claesson and Eskilson (1987)
- The new g-function library available at Geothermal Data Repository (GDR) since Sept. 2021

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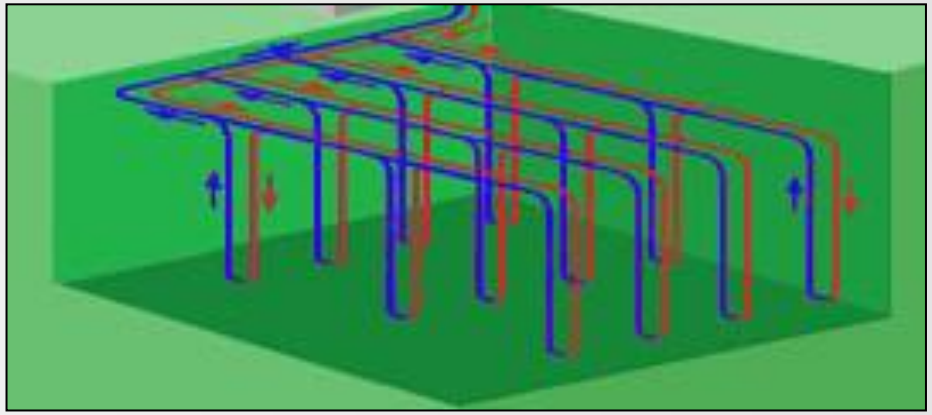
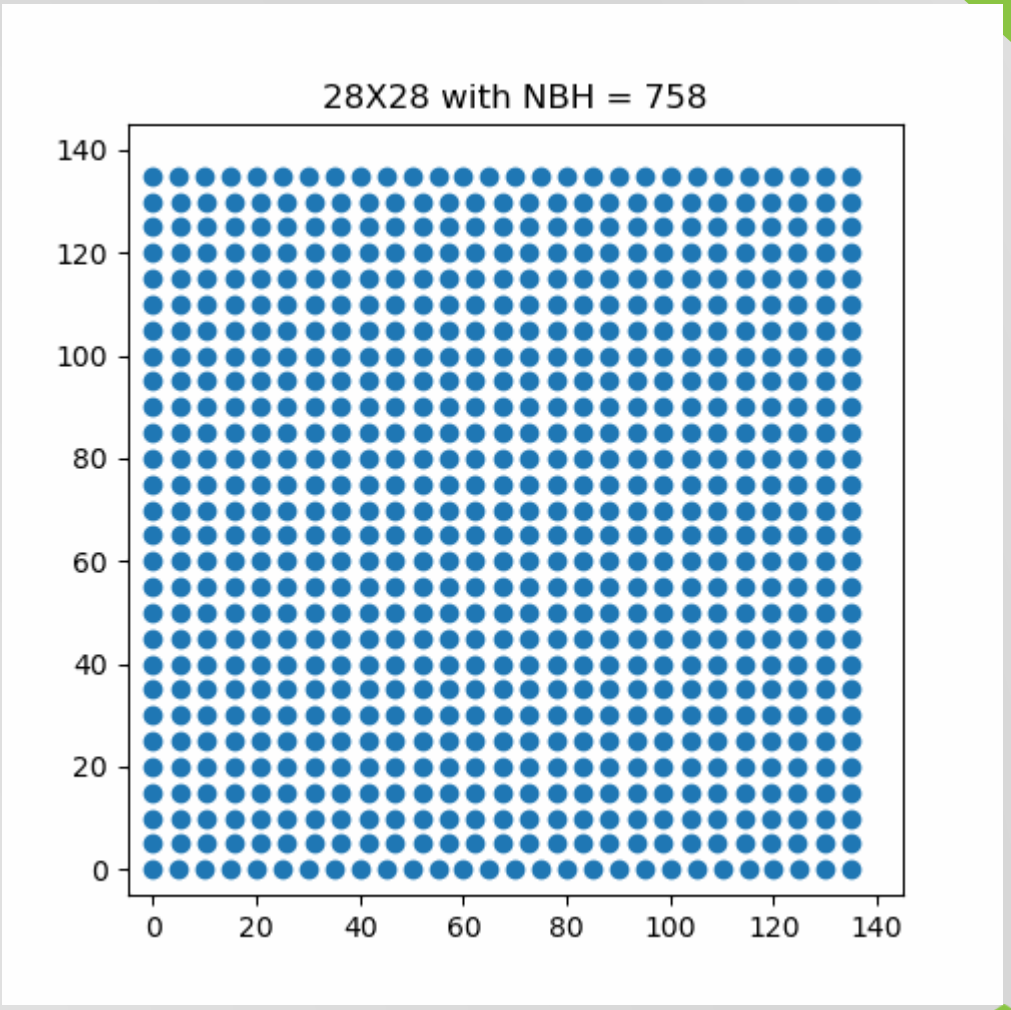
Auto-Sizing GHE

- Size vertical bore GHE based on simulation results of GHE using library g-functions or new g-functions calculated “on-the-fly”
- Auto-search available borehole field configurations to find the near-optimal borehole field layout and borehole depth for meeting the thermal loads and constraints of GHE supply temperatures
- Can auto-place boreholes within the allowable land area that may have complex geometry





Example of auto-searching the entire domain of available borehole field configurations. An actual design would only need to evaluate a few of these configurations.

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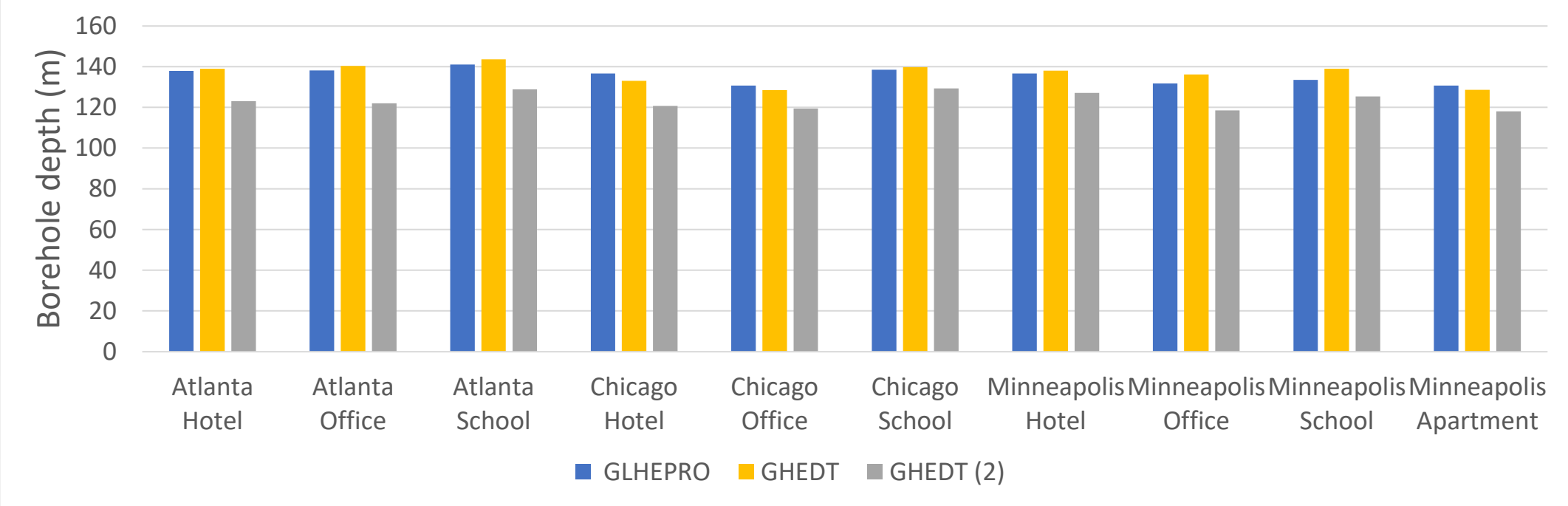
Validation of the New GHE Design Tool (GHEDT)

- GHEDT and GLHEPRO (the state-of-the-art GHE design tool) differ by less than 4% for the same burial depth (i.e., the depth of soil on top of the GHE) and load representation
- GHEDT (Version 2) gives shallower sizes for a more typical US burial depth (6 ft) and better load representation



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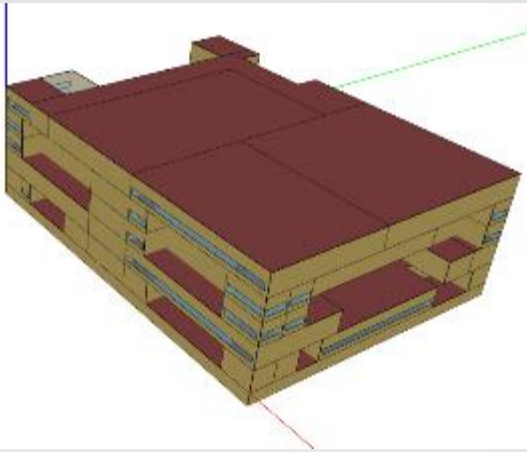
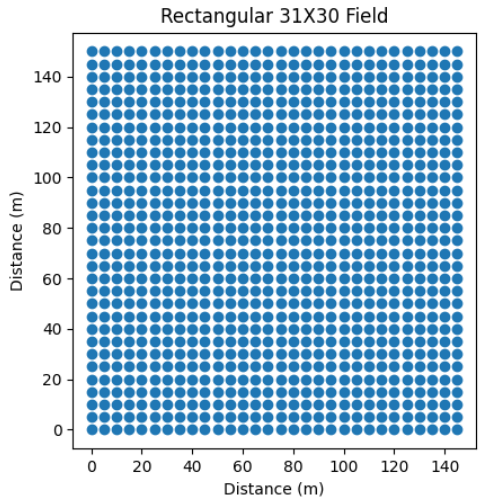
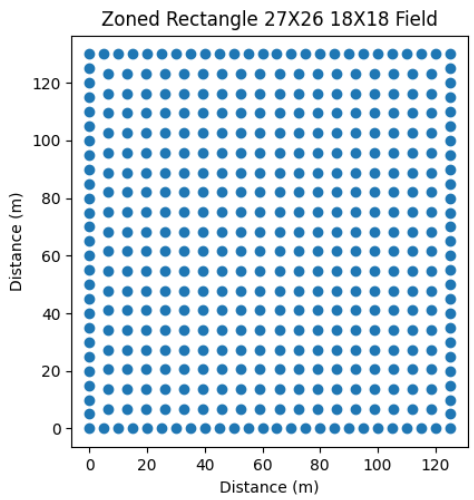
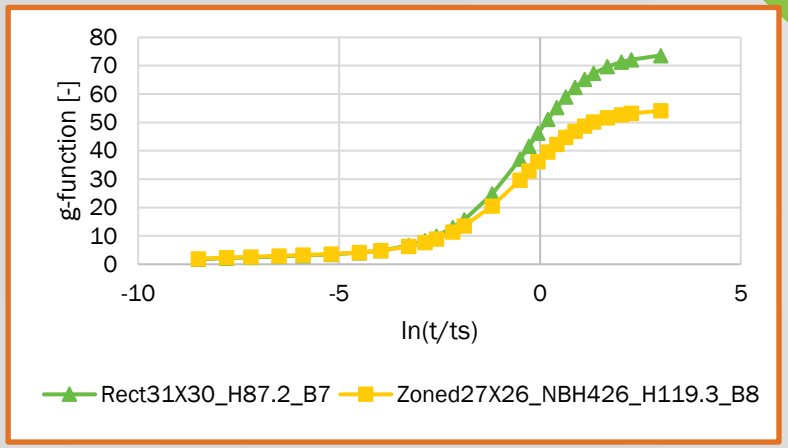
Case Study: Zoned-Rectangular Borehole

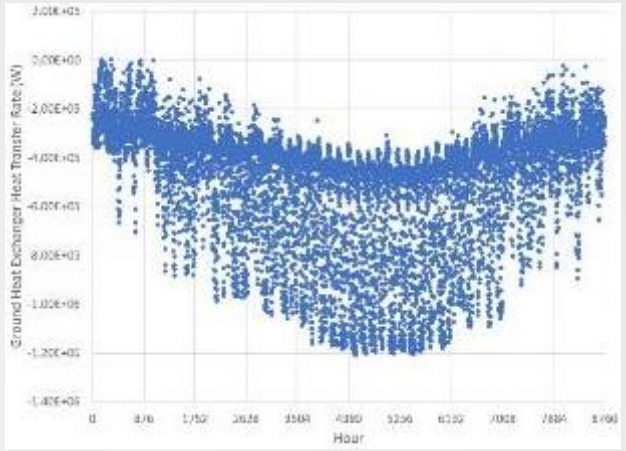


A hospital in Atlanta, GA

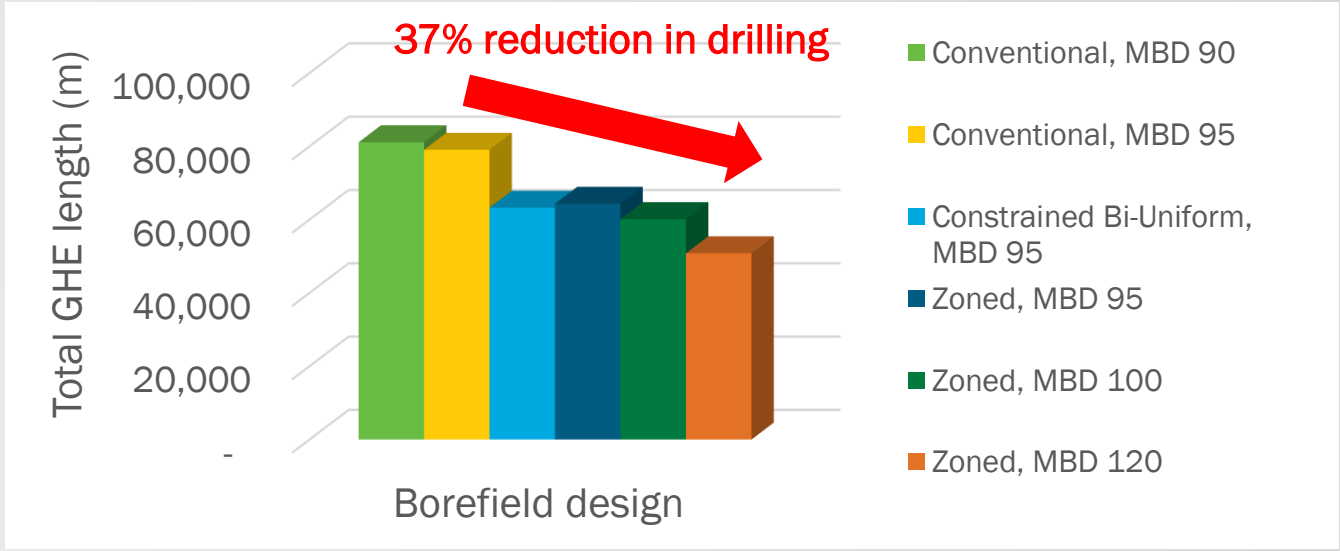








Hourly thermal loads of the GHE



With the same land area, using larger bore spacing inside a bore field and deeper boreholes can reduce thermal interference, and thus the required drilling for the GHE

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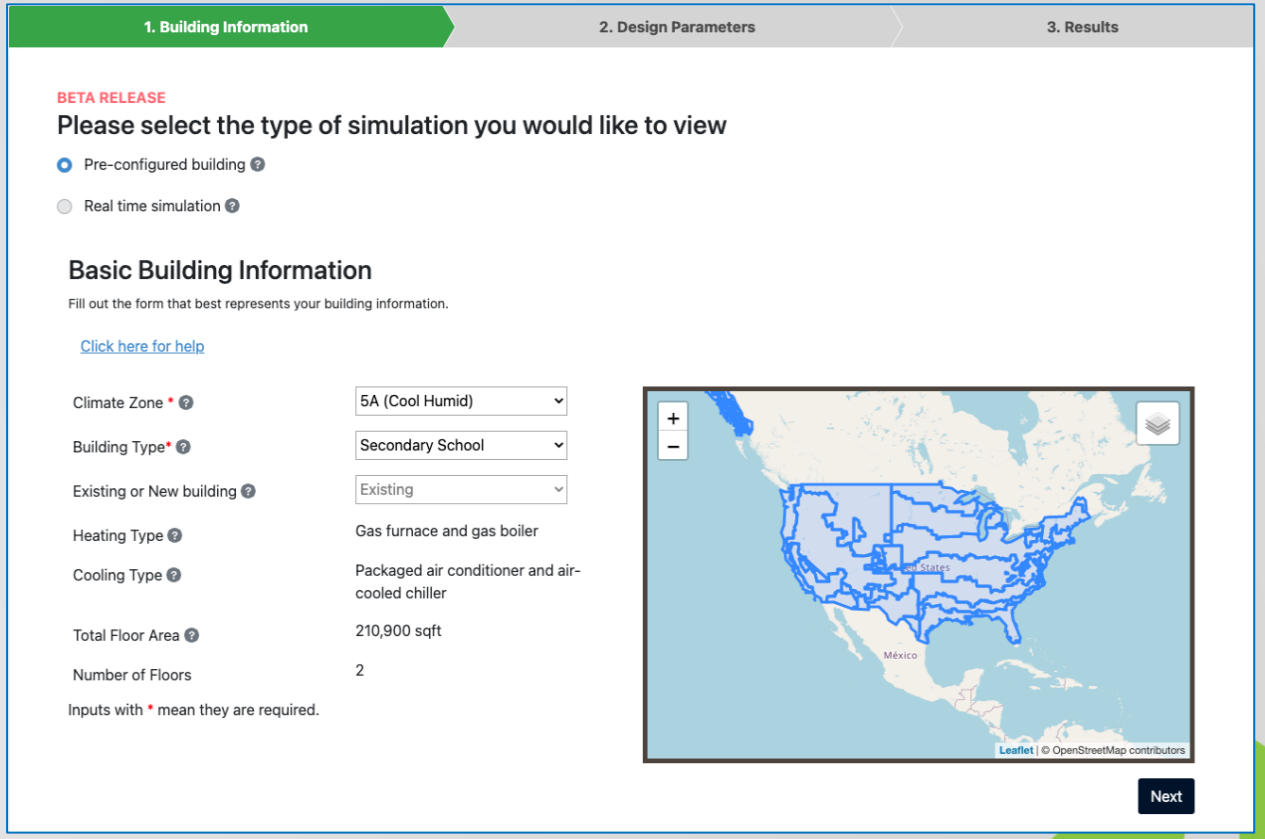
Web-based GHP Screening Tool

- Provide quick screening results based on users' inputs and pre-calculated simulation results using DOE's prototype building models
- Perform real-time simulations to conduct GSHP screening for 125 million existing buildings in the US
- Beta release is accessible via https://gshp.ornl.gov/screening-tool



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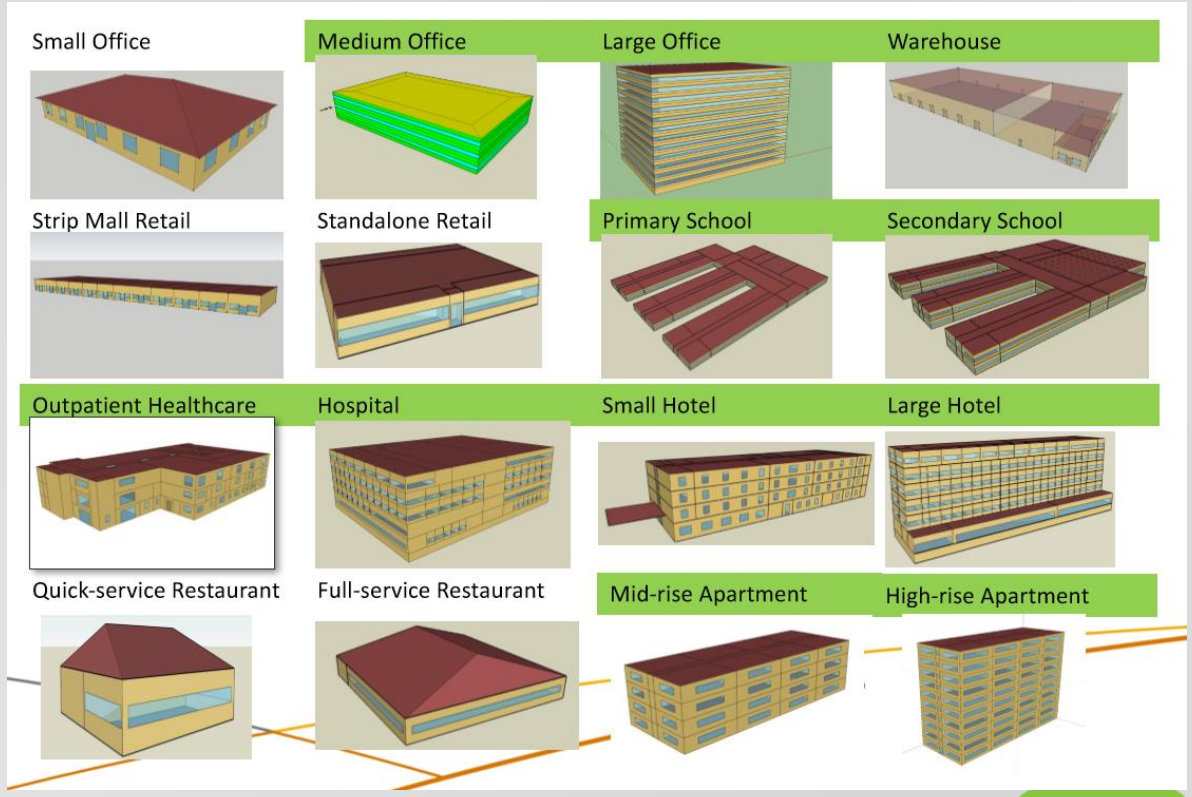
Web-based GHP Screening Tool

- Use DOE prototype building models and TMY3 weather data for predefined designs
- Integrated with AutoBEM to automatically create a building model based on simple user inputs
- Automated GHE design
  - Based on the extended g-function library
  - Multiple borehole field configurations based on land area constraints
    - Non-constrained: square or near-square
    - Constrained (basic): rectangles with bi-uniform spacing to fit available land (Not included in Beta release)
    - Constrained (advanced): least number of boreholes through an extensive search of uniform rectangles, zoned rectangles, open rectangles, U-shaped, L-shaped, line-shaped, and so on (Not included in Beta release)
- Economic analysis in real-time



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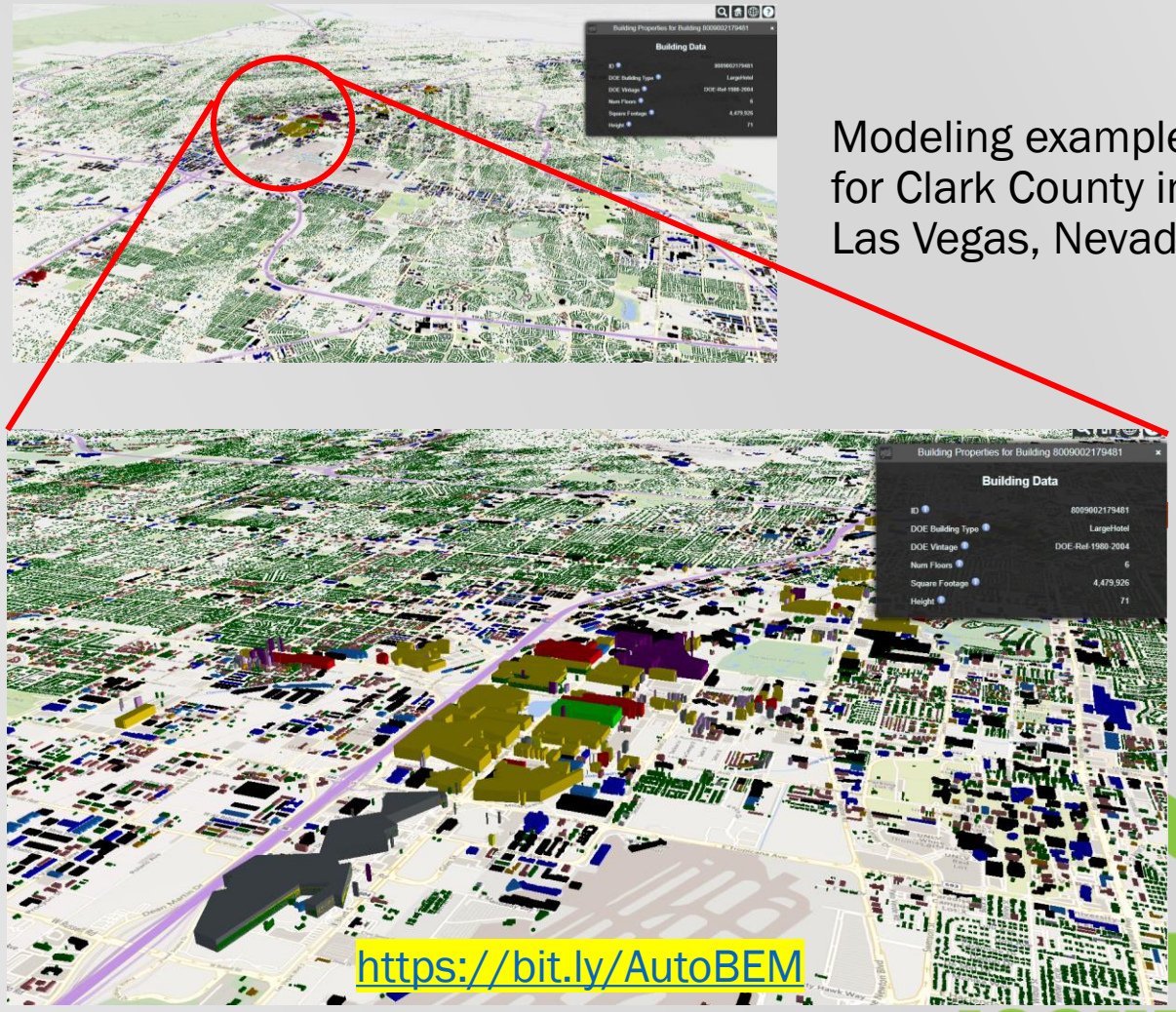
Use AutoBEM to Create Building Models

- Take a set of building properties as inputs, including footprint, height, function, and vintage
- Adopt internal characteristics and other building properties (e.g., occupancy, equipment, insulation) from DOE prototype buildings
- Develop building energy models using OpenStudio and run simulations using EnergyPlus



Modeling example for Clark County in Las Vegas, Nevada

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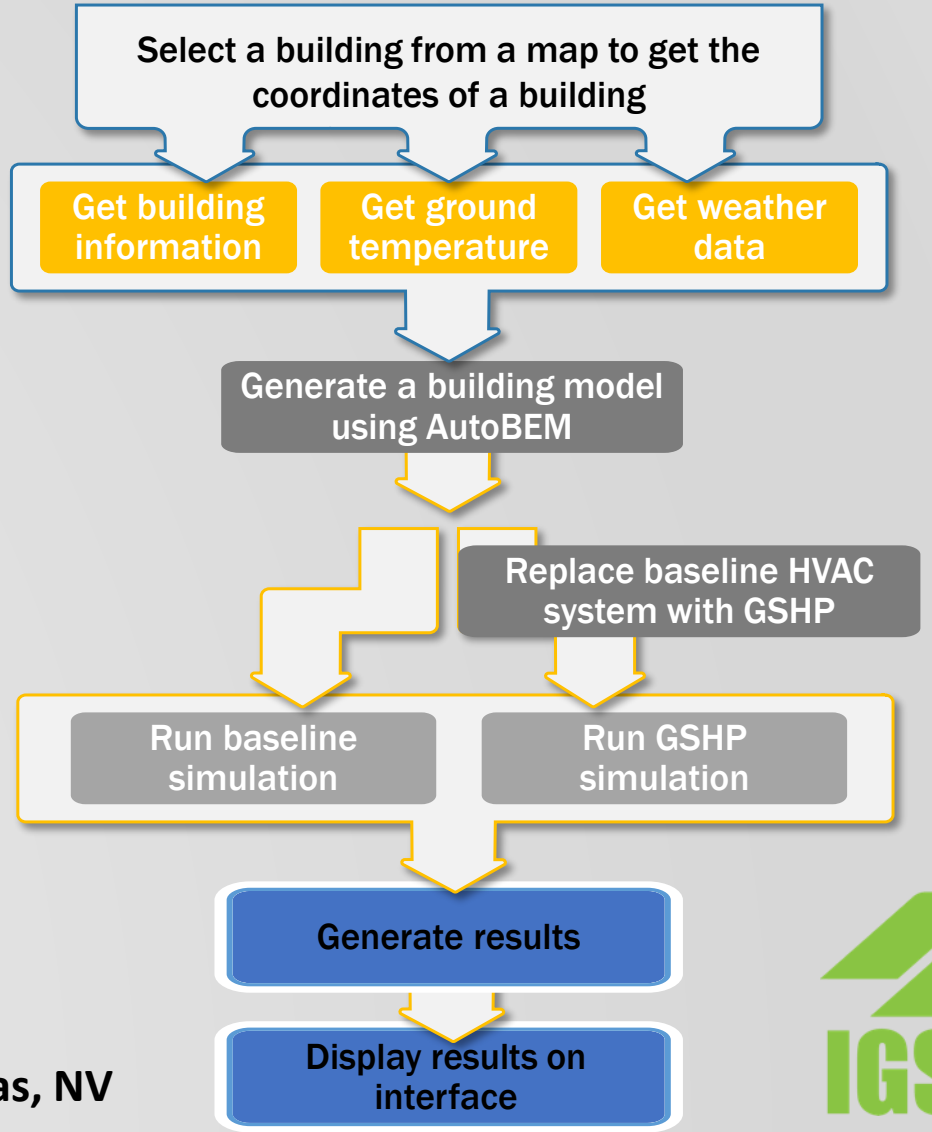
Integrate GSHP Screening Tool with AutoBEM

- Generating building energy models in real-time allows for model and data flexibility
  - Ability to update to the most recent version of AutoBEM to incorporate improvements
  - Ability to update building data to incorporate new and improved building data sources
  - Ability to take user input about a building to generate a more representative model



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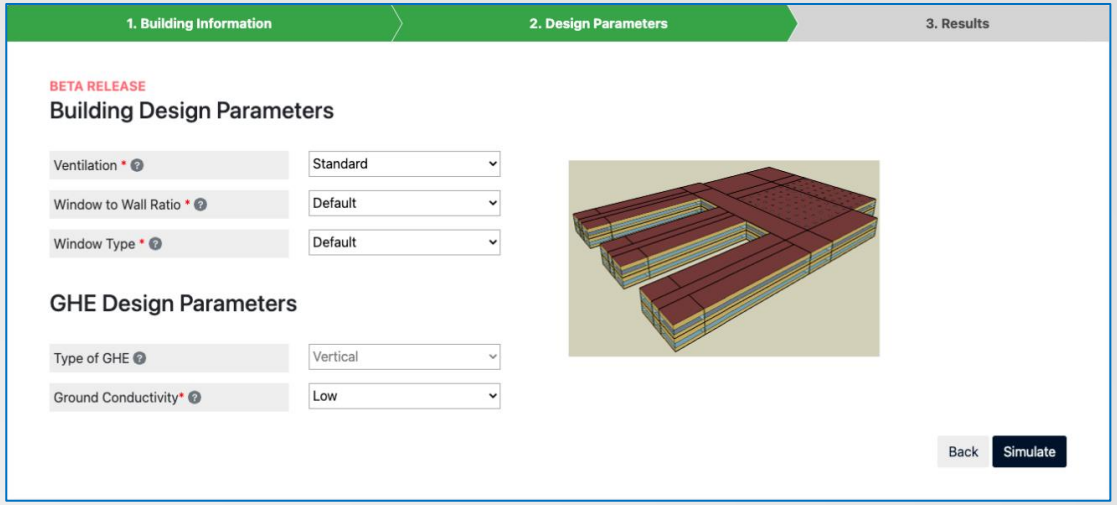
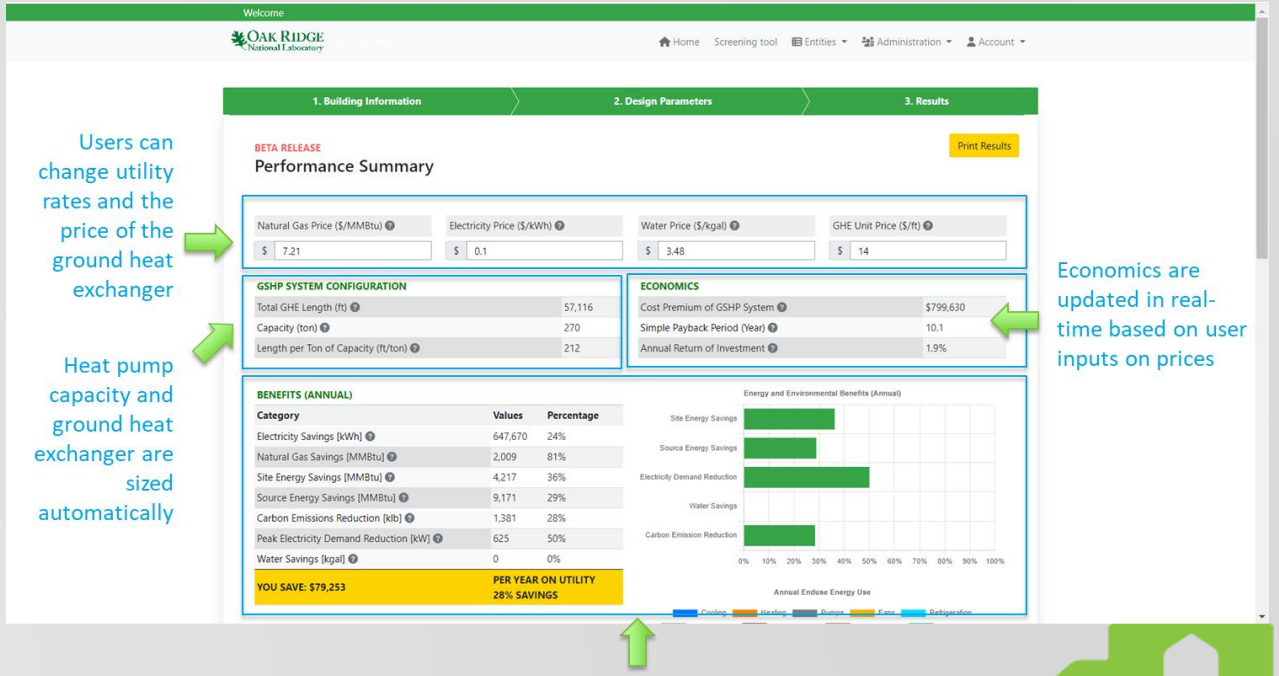
Web-based GHP Screening Tool

- For pre-simulated prototype buildings





Users can change utility rates and the price of the ground heat exchanger

Heat pump capacity and ground heat exchanger are sized automatically

Economics are updated in real-time based on user inputs on prices

The benefits of using GSHP instead of a conventional HVAC system are presented in tables and graphs.

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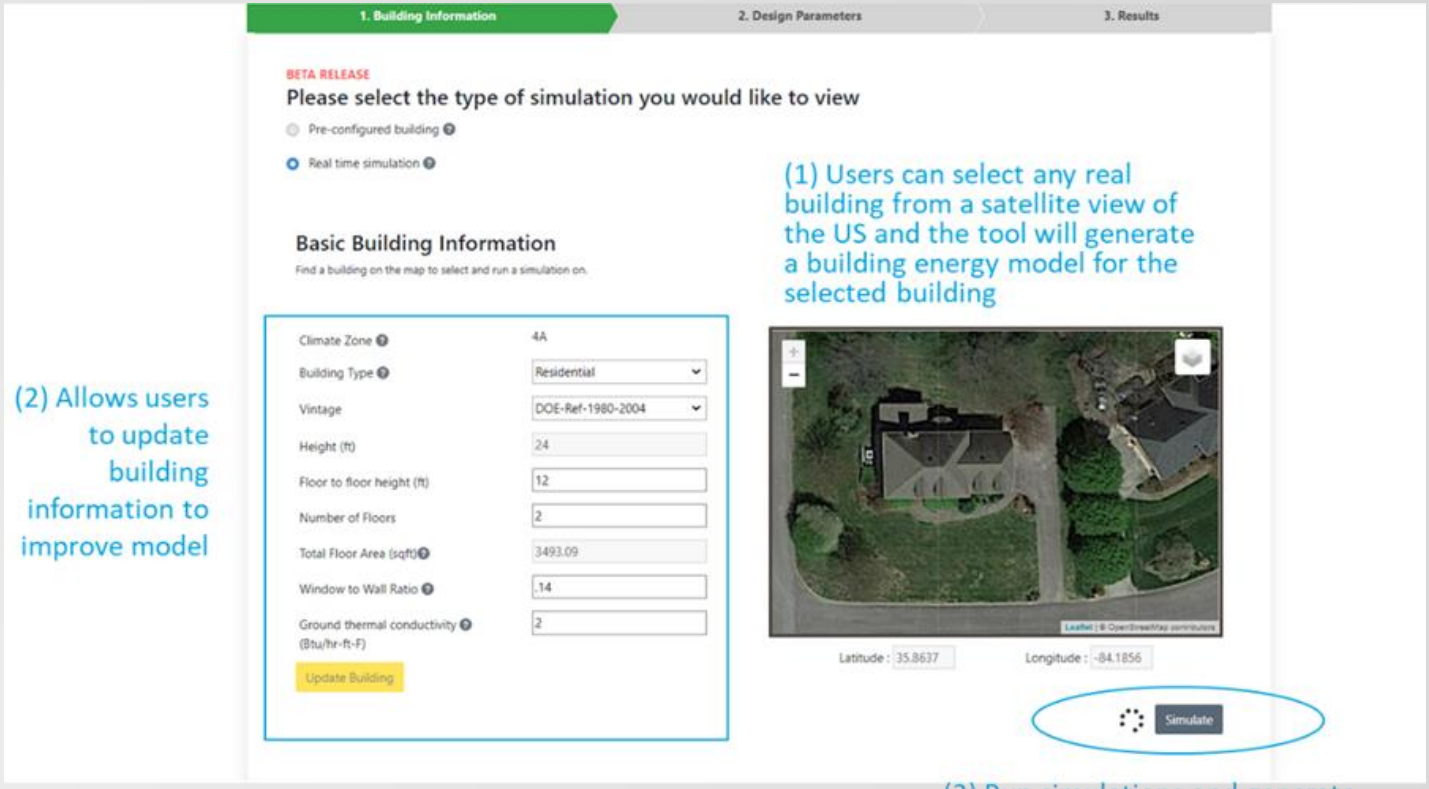
Web-based GHP Screening Tool

- For real-time simulation of real existing buildings



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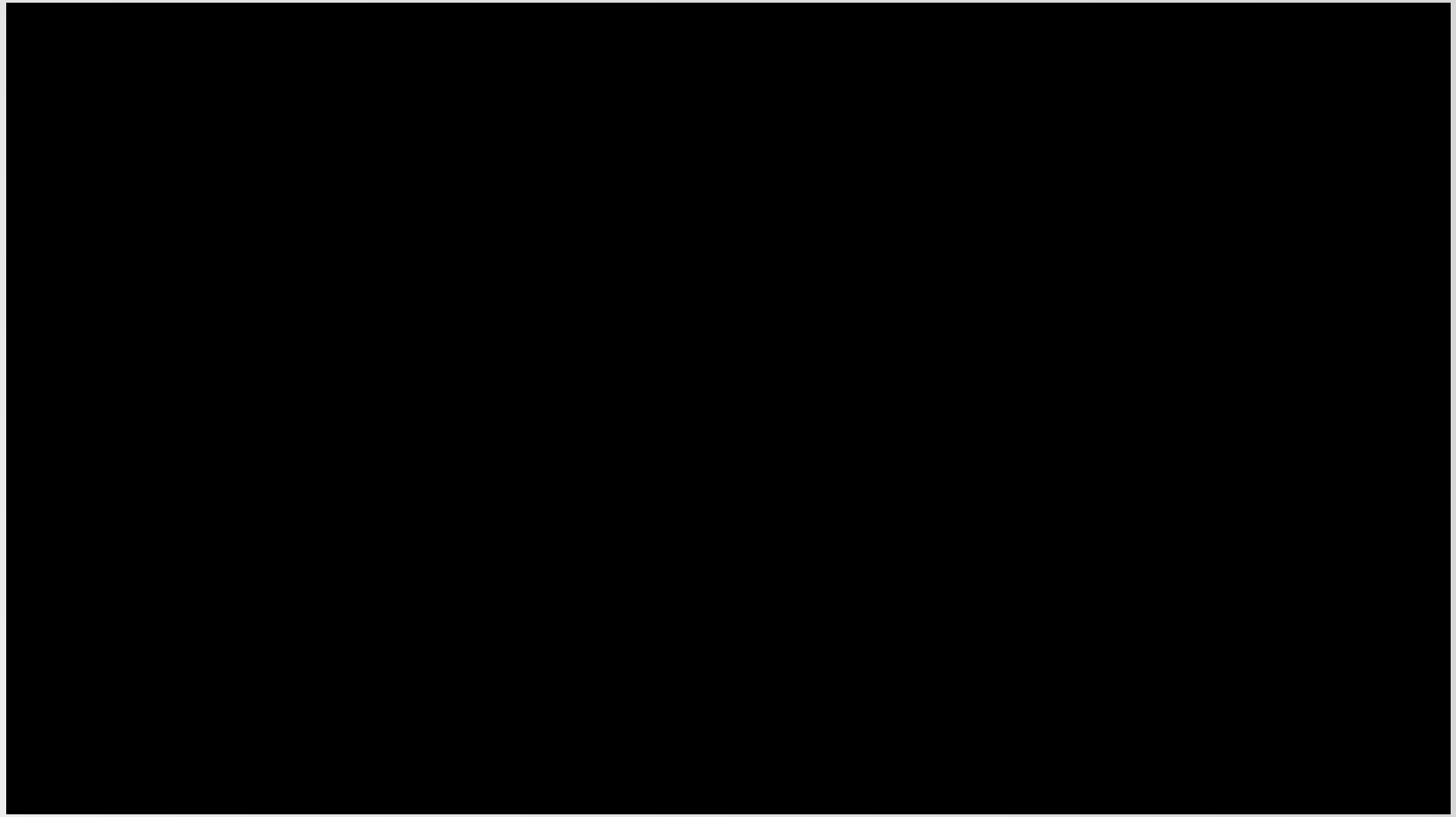
Demo of Web-based GSHP Screening Tool



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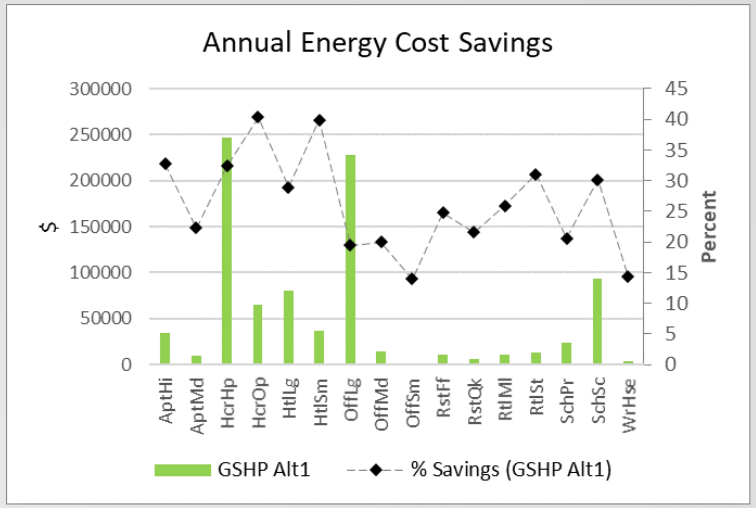
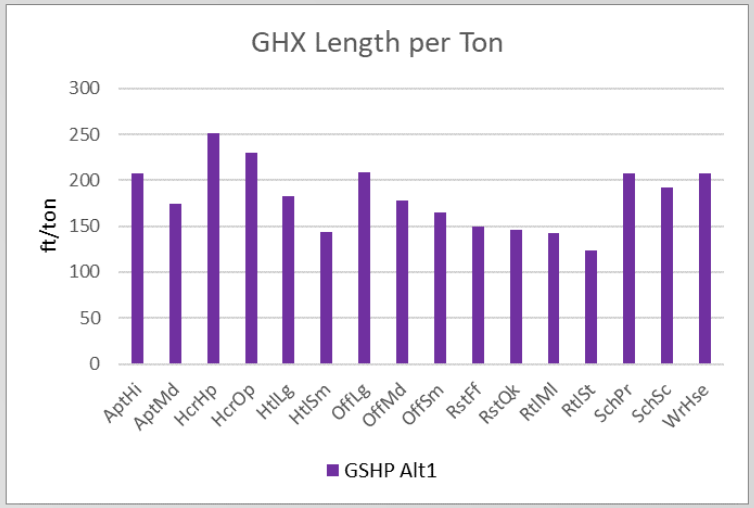
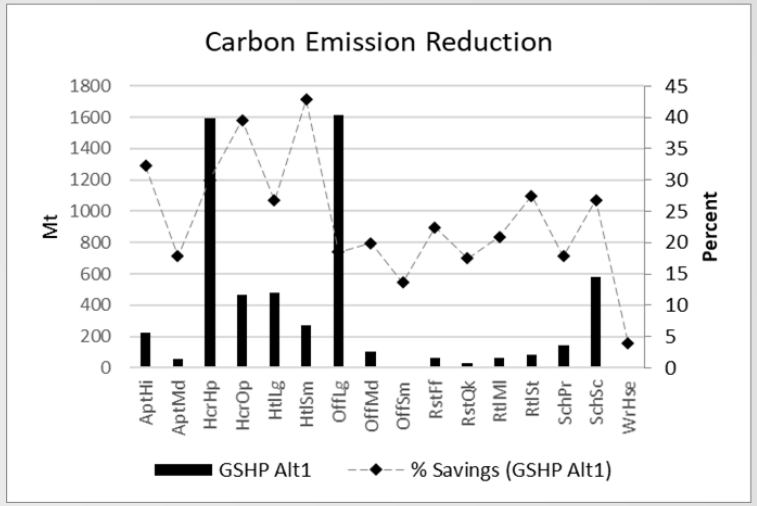
Web-based GHP Screening Tool: Example Results

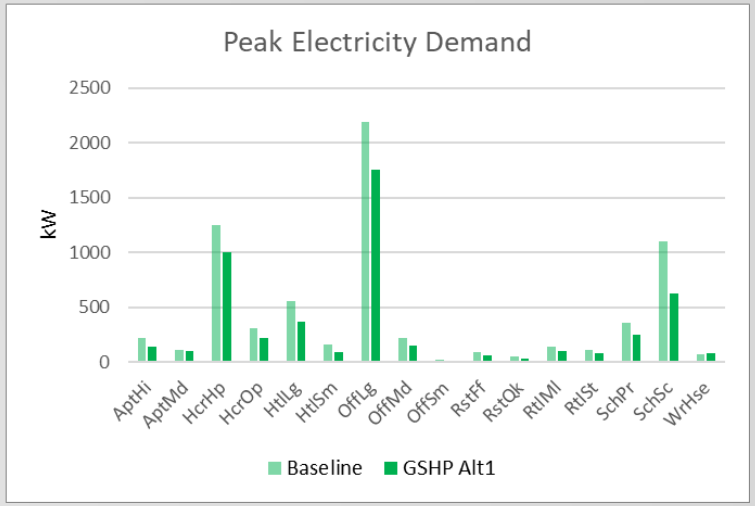
Example results of the GSHP screening tool for various commercial buildings in climate zone 6A (cold and humid climate)

Screening results are consistent with building types and climate zones. They are also in line with available case study results.









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Summary

- Developed a first-of-its-kind screening tool to quickly evaluate the techno-economic feasibility of GSHP applications
  - Provide quick screening results using precalculated results for DOE's 16 prototype buildings at 15 climate zones in the US
  - Perform real-time simulations to conduct GSHP screening for any of the 125 million existing buildings in the US
  - Auto-size GHE using the latest development of the GHE design tool
  - Conduct economic analysis in real time
- The simulation results are consistent with building types and climate zones. They are also in line with available case study results.

Future Work

- Further validate screening results against data from real GSHP systems. If necessary, update building energy models and representations of conventional HVAC and GSHP systems to improve accuracy
- Validate the new GHE design tool for simulating and sizing alternative vertical bore GHEs against high-quality field measurements
- Add new features in the web-based GSHP screening tool to :
  - Allow users to specify available land areas and no-go zones and auto-size GHE to meet these constraints
  - Allow users to specify geometry and other key parameters of new buildings
  - Conduct techno-economic analysis based on user-provided more detailed building energy models
- Improve EnergyPlus and OpenStudio to simulate hybrid and district GSHP systems with central or distributed configurations

Acknowledgements and Disclaimers

This study was funded by the US Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy, Geothermal Technologies Office.

The Groundwork for Sustainability: Geothermal

Thank You!

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