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

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ABSTRACT

Ground source heat pump (GSHP) technology has great potential to help the nation meet its energy and decarbonization goals, but several barriers hinder the wide application of GSHP. Important barriers include the lack of a coherent toolset for analyzing the technical feasibility and economic viability of the GSHP application. The current design and analysis methods are ineffective and require significant expertise to apply. Although building energy modeling is increasingly important in designing buildings, the tools for GSHP modeling and simulation are lacking. A web-based free-to-use tool is being developed for quick techno-economic analysis of GSHP applications in nearly any building in the United States. This tool is enabled by improvements in the calculation methodology to allow rapid sizing of borehole configurations that provide significant cost savings. The screening tool currently uses US Department of Energy (DOE) prototype building models and an extended g-function library to size ground heat exchangers and simulate the performance of GSHP systems. The team is integrating with DOE's Oak Ridge National Laboratory's AutoBEM program to automatically create a building model based on user inputs. This paper introduces the structure, components, features, and results of the web-based screening tool for GSHP applications. Future directions for further developing the tool are also discussed.

INTRODUCTION

Ground-source heat pumps (GSHPs) can efficiently keep residential and commercial buildings thermally comfortable year-round. However, the application of GSHPs is hindered by their high initial cost, mostly because of the cost of drilling boreholes in the ground to install ground heat exchangers (GHEs) (Liu et al. 2019). This factor plays an important role in decision making. A public-facing tool that can accurately analyze the costs and benefits of investing in GSHPs will help identify GSHP projects with favorable economics.

However, such a tool does not yet exist. Most existing tools are dedicated to sizing the GHE, which is the most unique and critical component of a GSHP system (GLHEPro 2016, Gaia Geothermal LLC 2016, BLOCON 2017).

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These GHE sizing tools rely on inputs of the thermal loads of the GHE, which must be estimated or calculated with other methods or programs. Also, these dedicated GHE sizing tools do not predict the performance of a GSHP system. The feasibility of installing a GSHP system for a specific project is usually assessed based on heating and cooling degree days to estimate the building thermal loads and required equipment capacity, and size of the GHE (NRC 2005). This rough estimation often results in a GSHP system that does not meet economic expectations or a GSHP system that does not perform as efficiently as it could.

The size and cost of a GHE are sensitive to the amount of energy rejected to the ground when cooling compared with the amount of energy extracted when heating. Given the large thermal mass of the ground, the heat transfer process of a GHE is almost completely transient, and thus both the peak and the total thermal loads of a GHE need to be accounted for when sizing a GHE. The thermal loads are affected by the design and operation of the building and its mechanical system. As buildings become more complex owing to the increasing diversity in functions and efforts to reduce the environmental footprint of buildings, building energy simulation (BES) is more commonly used to predict the thermal loads of a building. Integrating BES with the GHE design tool not only provides a seamless transition between the building's thermal loads and the GHE sizing but also, more importantly, allows the user to assess the effects on the GHE size and the GSHP system performance resulting from variations in the design and operation of the building and its mechanical system (Liu and Hellström 2006). With a side-by-side comparison between a GSHP system and a conventional HVAC system that serves the same building, the energy savings and carbon emission reductions resulting from using the GSHP system can be evaluated. Furthermore, an integrated tool enables a simulation-based holistic design approach for lowering the overall cost and energy consumption of the building by improving the design and controls of the building and the GSHP system.

The bottleneck of the simulation-based design approach is creating a detailed and accurate BES model to predict thermal loads. This work is time-consuming and requires many inputs. Having access to a software package that can estimate hourly thermal loads with minimal user input will be beneficial. Additionally, GHE sizing tools should be improved to allow highly customizable designs of the GHE so that the GHE performance can be optimized based on the given thermal loads and the constraints of the available land area for installing the GHE.

The goal of this project was to develop a web-based and user-friendly techno-economic analysis tool for quickly assessing the viability of applying a GSHP for a given residential or commercial building. This tool, the GSHP Screening Tool, is based on EnergyPlus and OpenStudio (NREL 2020), the US Department of Energy's (DOE's) flagship program in BES, and the latest development in GHE modeling, which can quickly simulate the performance of highly customized GHE designs with satisfactory accuracy (Spitler et al. 2020, 2021a). The project initially considered systems in which the GHE is expected to meet most of the thermal load; a hybrid configuration that uses a combination of GHE and conventional heat rejection/addition equipment may be included in the future.

This paper reviews the implementation of the web-based GSHP Screening Tool, including an automated process for creating GSHP system simulation and sizing GHEs within a given rectangular land area; the interfaces of the web-based screening tool; and examples of the screening results of GSHP applications in 16 prototype commercial buildings in 15 climate zones in the United States.

METHODOLOGY

The three components of the GSHP Screening Tool are (1) an auto-sizing tool for vertical bore GHE (VBGHE), which allows highly customized borehole field patterns; (2) a seamless approach to integrating the state-of-the-art BES programs, EnergyPlus and OpenStudio, with the advanced VBGHE sizing tool; and (3) a user-friendly interface to accept user inputs, display key simulation results, and perform economic analysis based on the cost data of HVAC equipment and energy prices.

The auto-sizing tool of the VBGHE was developed and integrated with an OpenStudio Workflow to establish a fully automated process for replacing an existing HVAC system sub-model in a BES model with a GSHP system, sizing each component of the GSHP system, including the VBGHE, and simulating the performance of the GSHP system. A web interface was also developed to take user inputs and display screening results from an automated design and economic analysis process. The structure and data flow of the automated process is shown in Figure 1.

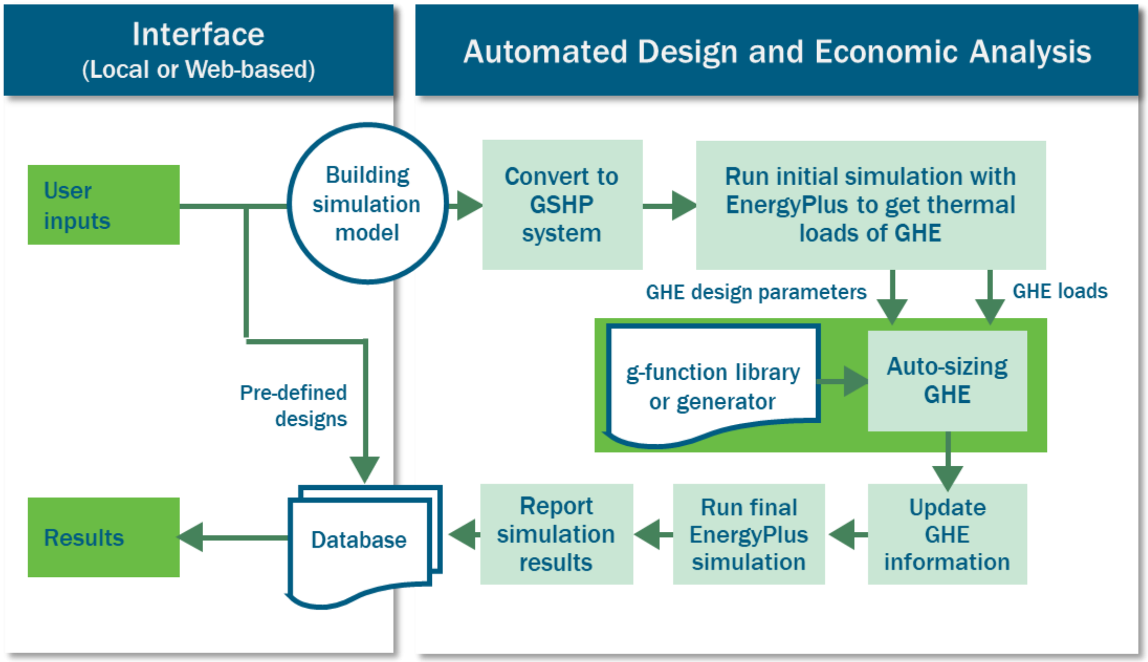

Figure 1 Flowchart of the GSHP Screening Tool.

The automated design and economic analyses start from a BES model, which can be an existing BES model (created with the OpenStudio program) or a simplified BES model created with AutoBEM, developed by DOE's Oak Ridge National Laboratory (ORNL) (New et al. 2018), for almost any existing building that can be specified through a satellite view of the United States. The design and economic analyses include the following subsequential steps:

1. Replace the existing HVAC system in the BES model with a GSHP system using an OpenStudio measure.
2. Simulate the initial design of the GSHP system to obtain the thermal loads of the VBGHE. In this initial simulation, the borehole number is estimated based on the floor space of the building. Default values are used for borehole depth (200 ft [61 m]), response factors of VBGHE (i.e., the g-functions), and borehole design parameters. The program can calculate the undisturbed ground temperature based on a user-specified location of the building. Users can specify ground thermal properties or take default values.
3. Size the VBGHE with a new design tool to determine the borehole field arrangement and the depth of each borehole, as well as the associated g-functions.
4. Update the input of the BES model with the described sizing results of the VBGHE.
5. Perform a simulation of the updated GSHP system to predict its performance and perform a simulation with the original HVAC system to establish a baseline for comparison.
6. Report key performance metrics of the simulated GSHP system and pass them to the interface and a database.

The GSHP system was designed and simulated based on the following criteria. Default values of VBGHE design parameters are listed in Table 1.

- Existing HVAC systems in a building are replaced with a new distributed GSHP system, which provides independent climate control in each thermal zone of a building without using any supplemental heating or cooling system.
- The rated heating and cooling coefficients of performance of the GSHP unit are 4.0 and 6.5, respectively. EnergyPlus auto-sizes and simulates water-to-air heat pumps of distributed GSHP systems. The entering water temperature of the heat pump is from the supply water temperature of the GHE, so the effect of GHE supply temperature on the heat pump efficiency is modeled in annual simulations.
- A VBGHE with boreholes laid out in a square of a near-square field with 6.1 m bore spacing is sized to maintain the leaving fluid temperature of the VBGHE between 1°C and 35°C year-round.
- Outdoor air is provided with a dedicated ventilation system in parallel with the distributed GSHP system.
- Energy savings are not only from the higher operational efficiency of the GSHP system but also the avoided simultaneous heating and cooling, which is common in the conventional variable air volume systems, as well as the improved fan control and fan efficiency.

Table 1. Default values of VBGHE design parameters

Parameter	Default value	Parameter	Default value
Borehole radius (m)	0.0762	Grout heat capacity (kJ/m^3-K)	3,901
U-tube pipe thickness (m)	0.002	Ground conductivity (W/m-k)	1.29*
U-tube pipe outer diameter (m)	0.027	Ground heat capacity (kJ/m^3-K)	2,347
U-tube leg spacing (m)	0.025	Undisturbed ground temperature (°C)	Site-specific. Calculated with the method by Xing and Spitler (2015)
Pipe conductivity (W/m-K)	0.39	Bore spacing (m)	6.1
Pipe heat capacity (kJ/m^3-K)	1,542	Maximum GHE supply temp. (°C)	35
Grout conductivity (W/m-k)	1.29	Minimum GHE supply temp. (°C)	1

* The screening tool allows users to change the ground thermal conductivity value through the interface.

Simulations of DOE prototype models for 16 types of commercial buildings (DOE 2022) in 15 US climate zones (ASHRAE 2021) were performed with an existing conventional HVAC system and a new GSHP system, separately. The simulation results are stored and managed through a database. These precalculated results can quickly indicate the techno-economic viability of a GSHP application.

NEW DESIGN TOOL FOR VBGHE

The state-of-the-art design method for VBGHEs, which are the most used type of GHE (especially for commercial buildings), is based on thermal response functions known as g-functions (Eskilson and Claesson 1988). A new g-function generator was developed that overcomes the limitations of previous efforts. This generator can calculate g-functions on the fly during the iterative configuration selection and sizing process for VBGHEs (Cook and Spitler 2021a). In addition, an extended g-function library for more than 34,000 borehole field configurations was generated and published to provide more options for designing VBGHEs (Spitler et al. 2021b). The new g-function generator and the extended g-function library were leveraged to develop a new design tool, named GHEDesigner, that can automatically select and size VBGHEs with flexible configurations. Intermodal validation indicates GHEDesigner provides results that differ by less than 4% for the same burial depth and load representation as constrained to GLHEPro (2016), a widely accepted design tool for VBGHEs. Furthermore, GHEDesigner enables many alternative designs that are not possible with existing design tools, such as various spacing among boreholes, boreholes with inclined angles, and boreholes with nonuniform depths in a bore field. It can find the near-optimal borehole field arrangement within the user-specified available regular or irregular land area (Spitler et al. 2022a). Case studies have shown that the required drilling can be reduced by using a near-optimal borehole field arrangement (in some cases, by greater than 40%) while meeting the thermal loads (Spitler et al. 2020, 2022a, 2022b). The reduced drilling requirement can help lower the cost and enable the wider adoption of GSHP systems.

EXAMPLE OF PRECALCULATED RESULTS

Simulations with various combinations of the following design parameters were conducted and the key simulation results were stored in a database. The following pre-calculated results can provide quick information for GSHP screening.

- Sixteen DOE commercial prototype buildings, which are designed based on the 2007 version of ASHRAE Standard 90.1 (ASHRAE 2011) to represent existing buildings that are near the time to retrofit their existing HVAC systems
- Fifteen climate zones in the United States
- Two HVAC systems: (1) an existing HVAC system in the prototype building and (2) a distributed GSHP system
- Four variations in windows
    - Minimum code-compliant windows (used in the original prototype models)
    - High-performance windows
    - A 20% larger window-to-wall (WWR) ratio than that used in the prototype models
    - High-performance windows and a 20% larger WWR
- Two levels of ground thermal conductivities: low and high

Table 2 lists key screening results of the GSHP retrofit for 16 types of commercial buildings in 15 climate zones in the United States (indicated in the header using 1A–8A), which includes the percentage of annual energy cost savings, GHE length per system capacity, simple payback period, and annual return on investment (ROI). As noted, the current analysis does not include hybrid systems. The following observations can be made:

- The percentage of energy cost savings from a GSHP system is generally higher in very hot or cold climates (note darker green columns for climate zones 1A, 2A, 2B, and 8A in the first part of the table). However, the required length of GHE per ton of GSHP system capacity is also very high in these climates (note the red columns in the second part of the table). This resulted in higher payback periods and lower or negative annual ROI for most building types in those climates (note red cells in the third and fourth tables).
- Small hotels, outpatient hospitals, and high-rise apartments are among a few building types that have a higher-energy cost savings percentage from a GSHP system installation in most climate zones (note rows with darker green cells in the first table). Even though these building types have the moderately high required length of GHE per ton of GSHP system capacity (note corresponding rows having lighter green cells in the second part of the table) requiring higher capital cost, installing a GSHP system is generally cost-effective for these buildings in most moderately hot or cold climate zones with a lower payback period and a higher annual ROI (note green cells in the third and fourth parts of the table).

Table 2. Examples of key screening results of GSHP applications[1]

Energy Cost Savings (%)	1A (Very Hot Humid)	2A (Hot Humid)	2B (Hot Dry)	3A (Warm Humid)	3B (Warm Dry)	3C (Warm Marine)	4A (Mixed Humid)	4B (Mixed Dry)	4C (Mixed Marine)	5A (Cool Humid)	5B (Cool Dry)	6A (Cold Humid)	6B (Cold Dry)	7A (Very Cold)	8A (Subarctic /Arctic)
High-rise Apartment	38.7	36.5	37.1	32.1	30.1	21.1	32.5	29.8	27.8	33.3	31.2	34.2	31.4	33.6	36.0
Mid-rise Apartment	24.4	22.7	24.3	20.2	19.4	14.6	20.4	19.9	19.1	19.4	20.9	23.5	19.7	17.5	18.1
Hospital	21.1	30.6	28.0	30.3	27.5	20.1	31.3	28.6	25.0	30.0	29.8	30.9	30.1	30.8	35.2
Outpatient Healthcare	38.2	39.9	38.8	38.4	36.7	35.2	40.0	37.7	38.0	39.9	39.8	40.1	39.4	42.1	46.7
Large Hotel	35.8	34.3	31.7	29.5	25.8	19.8	28.0	22.1	22.6	27.8	23.1	27.1	22.7	26.3	28.0
Small Hotel	43.9	44.1	45.3	41.6	40.2	36.1	41.2	42.4	39.1	42.1	43.9	42.2	42.3	43.2	45.5
Large Office	20.8	20.5	14.8	19.0	12.8	4.1	19.0	10.6	7.0	13.5	10.9	13.6	10.9	12.2	13.6
Medium Office	19.0	20.6	19.0	18.1	14.6	10.5	20.0	12.7	17.2	21.1	16.1	24.0	18.1	24.2	29.1
Small Office	15.6	15.5	16.5	13.6	13.0	8.9	13.8	13.7	11.1	13.8	14.2	14.5	14.6	14.3	15.0
Full Service Restaurant	23.3	24.2	25.9	22.4	22.9	9.8	23.8	21.2	19.5	23.6	22.8	26.2	24.2	27.1	29.3
Quick Service Restaurant	17.4	19.5	22.3	18.3	19.4	11.6	20.0	17.3	16.9	19.7	18.0	22.0	20.3	23.2	27.7
Strip Mall	25.0	26.7	30.1	23.7	24.8	15.5	23.8	22.2	20.3	23.0	23.4	23.9	23.4	24.2	26.8
Stand-alone Retail	30.0	29.6	30.2	28.7	28.4	23.0	29.5	26.8	24.3	30.4	29.5	31.8	30.9	32.2	35.8
Primary School	23.9	22.3	22.0	18.4	16.9	12.1	19.4	14.6	14.5	19.2	15.7	20.1	16.4	20.5	23.9
Secondary School	35.4	33.5	30.3	28.4	23.8	12.7	28.8	19.2	17.8	27.0	21.2	27.6	22.5	27.5	29.8
Warehouse	22.0	12.3	23.8	11.1	17.1	3.3	10.0	9.0	4.6	10.0	8.6	11.2	7.6	12.4	8.2

GHE Length per System Capacity (ft/ton)	1A (Very Hot Humid)	2A (Hot Humid)	2B (Hot Dry)	3A (Warm Humid)	3B (Warm Dry)	3C (Warm Marine)	4A (Mixed Humid)	4B (Mixed Dry)	4C (Mixed Marine)	5A (Cool Humid)	5B (Cool Dry)	6A (Cold Humid)	6B (Cold Dry)	7A (Very Cold)	8A (Subarctic /Arctic)
High-rise Apartment	432	352	485	261	381	148	207	219	138	215	156	289	188	430	1,055
Mid-rise Apartment	378	310	443	214	337	136	175	185	118	186	129	255	180	390	982
Hospital	483	398	541	308	383	231	251	253	203	228	199	189	171	153	163
Outpatient Healthcare	463	368	508	283	362	221	230	244	192	210	190	177	164	143	340
Large Hotel	398	305	450	227	316	148	182	186	136	168	138	143	117	136	400
Small Hotel	295	234	349	172	254	147	143	156	125	128	115	117	103	105	286
Large Office	416	339	463	259	343	194	208	218	169	190	167	161	145	125	142
Medium Office	342	286	430	213	297	154	178	186	143	165	138	136	119	188	610
Small Office	317	260	379	206	275	114	165	167	129	156	123	209	152	298	24,288
Full Service Restaurant	373	290	409	203	281	90	149	153	98	145	109	125	92	130	584
Quick Service Restaurant	402	302	437	197	299	86	146	164	87	145	105	129	107	195	674
Strip Mall	310	259	369	172	258	107	142	152	96	140	101	170	163	246	687
Stand-alone Retail	262	239	362	163	227	86	124	137	98	103	95	131	84	192	600
Primary School	439	342	453	250	315	193	207	216	150	202	162	179	126	277	802
Secondary School	408	310	410	240	286	167	192	191	127	182	144	161	124	242	691
Warehouse	244	168	332	144	202	86	207	146	204	281	218	383	318	570	1,567

Simple Payback (year)	1A (Very Hot Humid)	2A (Hot Humid)	2B (Hot Dry)	3A (Warm Humid)	3B (Warm Dry)	3C (Warm Marine)	4A (Mixed Humid)	4B (Mixed Dry)	4C (Mixed Marine)	5A (Cool Humid)	5B (Cool Dry)	6A (Cold Humid)	6B (Cold Dry)	7A (Very Cold)	8A (Subarctic /Arctic)
High-rise Apartment	12	11	16	9	13	8	7	8	6	7	6	8	7	13	26
Mid-rise Apartment	18	16	22	12	17	8	10	10	7	11	7	10	10	24	53
Hospital	16	8	13	6	9	8	5	6	6	5	5	4	4	3	3
Outpatient Healthcare	9	7	10	5	7	4	4	5	4	4	4	3	3	2	5
Large Hotel	10	8	14	8	13	8	7	10	8	7	7	6	6	6	16
Small Hotel	9	7	10	6	8	5	5	5	4	4	3	4	3	3	7
Large Office	18	15	32	13	27	50	11	23	28	15	18	13	15	11	12
Medium Office	28	22	39	19	34	25	15	27	15	13	17	9	12	12	31
Small Office	33	28	43	25	34	19	19	21	20	18	15	22	17	31	2,324
Full Service Restaurant	19	15	18	12	14	11	8	8	6	7	6	5	4	5	18
Quick Service Restaurant	30	21	23	15	16	8	9	10	6	8	6	6	5	8	18
Strip Mall	26	21	24	17	19	13	13	13	10	13	9	15	13	24	59
Stand-alone Retail	18	18	25	14	18	9	11	12	11	9	8	11	7	16	46
Primary School	19	17	25	15	21	19	13	20	14	13	14	11	10	15	35
Secondary School	14	12	20	12	18	23	10	18	14	11	13	9	10	14	33
Warehouse	24	25	25	24	18	28	33	26	49	50	44	55	79	78	310

Annual ROI (%)	1A (Very Hot Humid)	2A (Hot Humid)	2B (Hot Dry)	3A (Warm Humid)	3B (Warm Dry)	3C (Warm Marine)	4A (Mixed Humid)	4B (Mixed Dry)	4C (Mixed Marine)	5A (Cool Humid)	5B (Cool Dry)	6A (Cold Humid)	6B (Cold Dry)	7A (Very Cold)	8A (Subarctic /Arctic)
High-rise Apartment	0.88	1.59	(0.37)	2.33	0.60	3.27	3.49	2.84	4.33	3.60	4.51	2.97	3.88	0.66	(2.82)
Mid-rise Apartment	(1.12)	(0.36)	(2.00)	1.02	(0.74)	2.84	2.06	1.99	3.93	1.47	3.82	1.92	2.01	(2.03)	(5.78)
Hospital	(0.42)	2.92	0.64	4.17	2.47	3.03	5.37	4.41	4.73	5.50	5.80	6.72	6.81	7.86	8.54
Outpatient Healthcare	2.53	4.00	1.98	5.08	3.72	6.06	6.38	5.70	6.92	6.75	7.23	7.85	8.01	9.33	5.74
Large Hotel	2.12	2.90	0.09	3.28	0.81	3.00	3.82	2.09	3.52	4.17	3.55	4.88	4.44	4.90	(0.24)
Small Hotel	2.57	3.75	1.98	4.90	3.22	5.46	5.82	5.84	6.47	6.50	7.51	7.33	8.02	7.86	3.67
Large Office	(0.96)	(0.27)	(3.93)	0.65	(2.97)	(5.99)	1.60	(2.21)	(3.19)	(0.07)	(1.03)	0.86	(0.21)	1.48	1.39
Medium Office	(3.22)	(2.18)	(4.90)	(1.43)	(4.14)	(2.79)	(0.07)	(3.16)	(0.29)	0.61	(0.68)	2.40	0.92	0.87	(3.67)
Small Office	(4.00)	(3.32)	(5.30)	(2.69)	(4.25)	(1.43)	(1.44)	(1.93)	(1.62)	(1.01)	(0.32)	(1.90)	(0.80)	(3.62)	(22.11)
Full Service Restaurant	(1.47)	(0.08)	(1.07)	1.14	0.33	1.27	3.29	2.89	4.47	3.69	4.91	5.47	6.68	5.63	(0.67)
Quick Service Restaurant	(3.60)	(1.69)	(2.24)	(0.05)	(0.57)	3.26	2.42	2.13	4.77	2.98	4.56	4.86	5.82	3.28	(0.58)
Strip Mall	(2.86)	(1.74)	(2.41)	(0.67)	(1.27)	0.70	0.58	0.45	2.12	0.65	2.49	0.24	0.59	(2.22)	(6.34)
Stand-alone Retail	(1.01)	(1.11)	(2.74)	0.17	(1.16)	2.24	1.60	0.78	1.48	2.39	2.84	1.51	3.45	(0.31)	(5.39)
Primary School	(1.41)	(0.73)	(2.63)	(0.23)	(1.90)	(1.19)	0.70	(1.41)	0.19	0.79	0.14	1.80	1.88	0.06	(3.93)
Secondary School	0.04	0.79	(1.61)	0.86	(1.05)	(2.18)	1.87	(0.97)	0.44	1.70	0.78	2.58	2.02	0.60	(3.59)
Warehouse	(2.51)	(2.72)	(2.65)	(2.31)	(1.15)	(2.55)	(3.39)	(2.52)	(5.03)	(5.20)	(4.82)	(5.46)	(7.18)	(7.02)	(12.73)

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[1] Based on heating and cooling degree-days, ASHRAE (2021) defines climate zones 1 through 8 as very hot, hot, warm, mixed, cool, cold, very cold, and subarctic/arctic; and subclimate zones A, B, and C as moist, dry, and marine, respectively.

REAL-TIME SIMULATION WITH AUTOMATED MODEL CREATION AND SIMULATION

To evaluate GSHP applications in other buildings that were not precalculated, a fully automated process was implemented to create a BEM and perform the screening analysis, as depicted in Figure 2. AutoBEM was used to automatically create a BEM. The BEM was created based on a few characteristics of a building, including the footprint, height, principal function, and age (New et al. 2018). AutoBEM has a database covering 98% of the 125,714,640 existing buildings detected in the United States, and it adopts other building properties, such as occupancy, equipment, and insulation, from the DOE prototype buildings to complete the BEM. With this fully automated process, users can specify an existing building from a satellite view of a map and all the needed calculations will be performed automatically to determine the cost and benefits of retrofitting the existing conventional HVAC system with a new GSHP system.

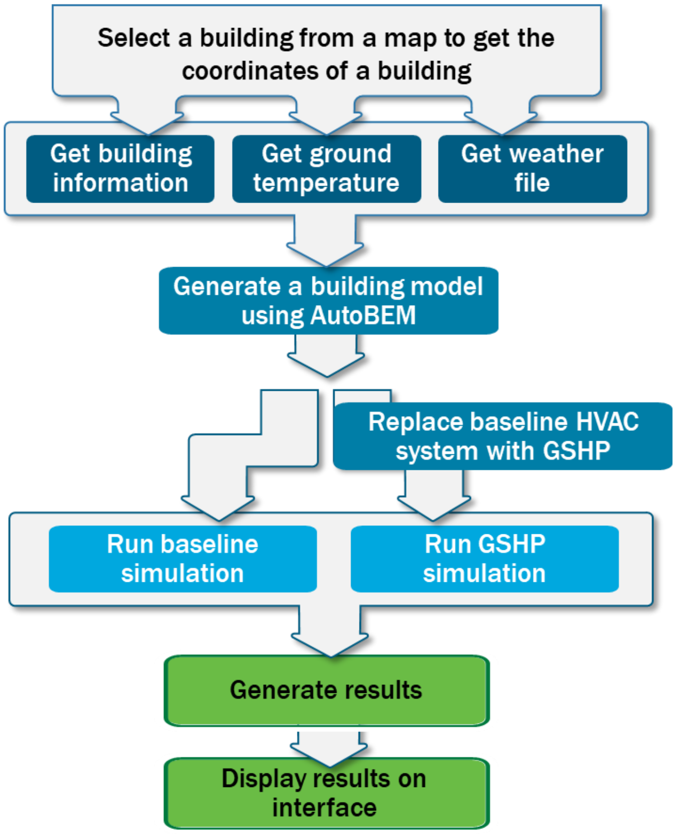
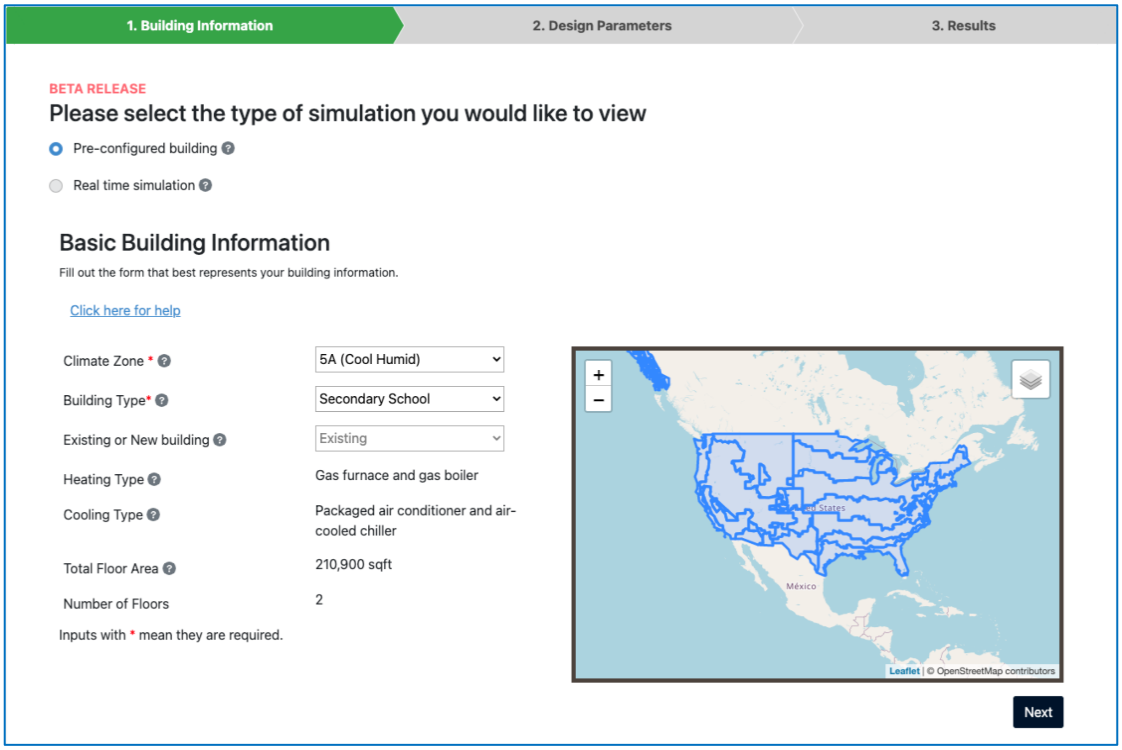


Figure 2 Flowchart of an automated real-time simulation for a user-selected existing building.

WEB INTERFACE

The web interface was built using the JHipster framework stack, which comprises Java EE (a programming language) with MySQL (a relational database) and an Angular/HTML front end. The web application has three web pages. The first page (Figure 3) collects user input for the climate zone, building type, and vintage of the target building through dropdown menus. Also, a map feature allows users to select the location of any existing building shown on the satellite view of the map. The map feature will determine the climate zone of the location. Other fields on this page display more information about the target building, including the existing heating and cooling system (or the default HVAC system if it is new construction), total floor area, and number of floors.



BETA RELEASE

Please select the type of simulation you would like to view

● Pre-configured building

○ Real time simulation

Basic Building Information

Fill out the form that best represents your building information.

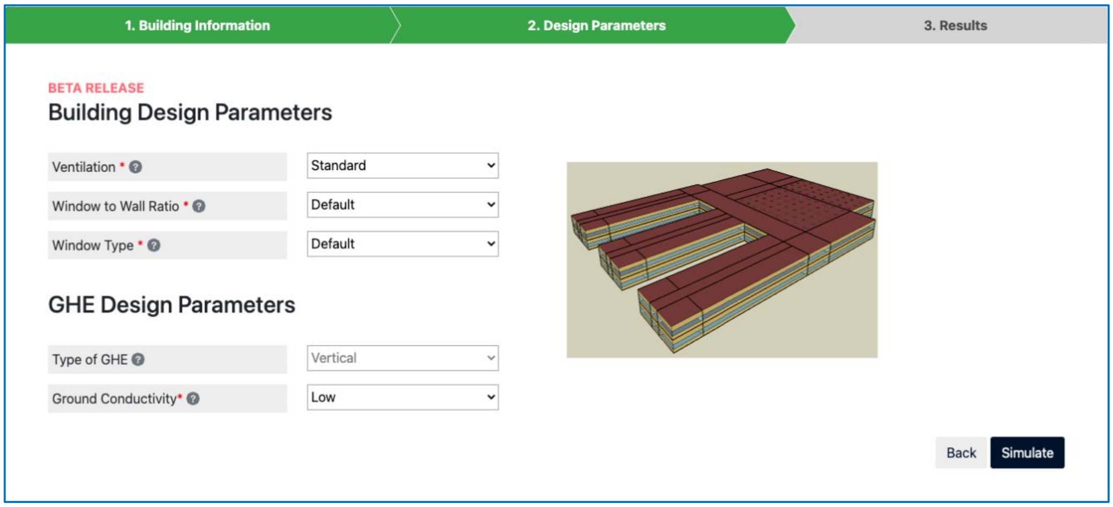
Click here for help

Climate Zone *	5A (Cool Humid)
Building Type*	Secondary School
Existing or New building	Existing
Heating Type	Gas furnace and gas boiler
Cooling Type	Packaged air conditioner and air-cooled chiller
Total Floor Area	210,900 sqft
Number of Floors	2

Inputs with * mean they are required.

Figure 3 The first page of the web-based GSHP Screening Tool for selecting a target building.

The second page (Figure 4) allows users to select some design parameters of the building and the GHE. These parameters include the ventilation rate, WWR, window type, and ground thermal conductivity. Fields are initially set to default values, but users can change the fields to select different values. Users can select the "Simulate" button at the right-bottom of this webpage to display precalculated results or run real-time automated design and analysis.



BETA RELEASE

Building Design Parameters

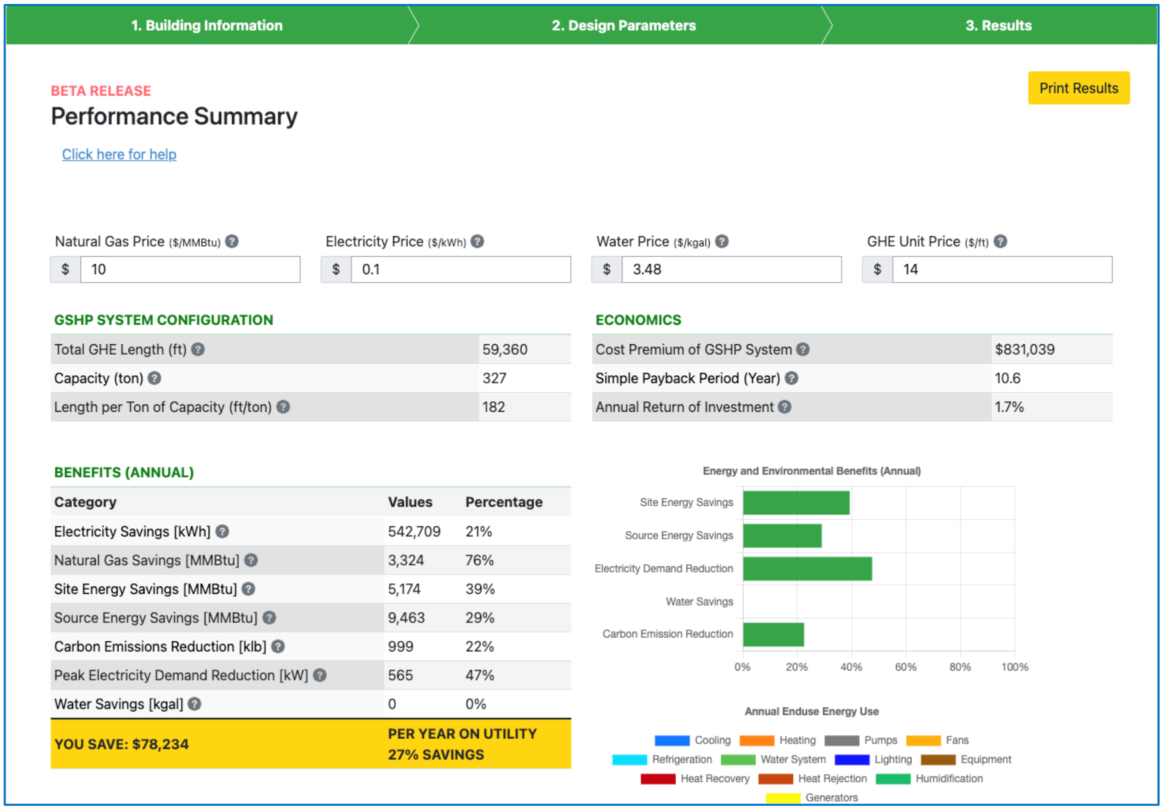
Ventilation *	Standard
Window to Wall Ratio *	Default
Window Type *	Default

GHE Design Parameters

Type of GHE	Vertical
Ground Conductivity*	Low

Figure 4 The second page of the web-based GSHP Screening Tool for selecting design parameters.

The results are displayed on the third page (Figure 5), including the total borehole length and the total capacity of the GSHP system, benefits, and the economics of the GSHP system compared with the conventional HVAC system commonly used for the simulated building. The displayed results include annual savings in electricity, natural gas, site energy, and source energy, as well as the reduction in annual carbon emissions, annual peak electricity demand, and annual water usage. In addition, the cost premium of the GSHP system,[2] simple payback period, and annual ROI are displayed. These economic results can be updated in real-time based on user inputs of the prices of natural gas, electricity, water, and GHE.



Performance Summary

Natural Gas Price ($/MMBtu): $ 10

Electricity Price ($/kWh): $ 0.1

Water Price ($/kgal): $ 3.48

GHE Unit Price ($/ft): $ 14

GSHP SYSTEM CONFIGURATION

Total GHE Length (ft)	59,360
Capacity (ton)	327
Length per Ton of Capacity (ft/ton)	182

ECONOMICS

Cost Premium of GSHP System	$831,039
Simple Payback Period (Year)	10.6
Annual Return of Investment	1.7%

BENEFITS (ANNUAL)

Category	Values	Percentage
Electricity Savings [kWh]	542,709	21%
Natural Gas Savings [MMBtu]	3,324	76%
Site Energy Savings [MMBtu]	5,174	39%
Source Energy Savings [MMBtu]	9,463	29%
Carbon Emissions Reduction [klb]	999	22%
Peak Electricity Demand Reduction [kW]	565	47%
Water Savings [kgal]	0	0%
YOU SAVE: $78,234	**PER YEAR ON UTILITY 27% SAVINGS**	

Figure 5 The third page of the web-based GSHP Screening Tool for displaying results.

CONCLUSIONS AND FURTHER DEVELOPMENT

A web-based tool to quickly evaluate the techno-economic feasibility of GSHP applications was developed to enable wider consideration and adoption of GHP technologies. A beta version of the tool (https:/gshp.ornl.gov/) is now available online. The GSHP Screening Tool includes precalculated screening results with DOE prototype building models in 15 climate zones in the United States. It also enables real-time simulation of almost any existing building in the United States by integrating with ORNL's AutoBEM to automatically create a building model based on simple inputs of footprint, height, function, and age of the building. The results of this tool include the design, benefits, and economics of the GSHP system compared with the conventional HVAC system commonly used for the simulated building. The economic results can be updated in real-time based on user inputs of the prices of natural gas, electricity, water, and GHE.

Further development is planned to improve flexibility, convenience, and accuracy of the screening, including

- Adding a function to obtain utility rates from utility companies serving the region where the building is located;

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[2] In the alpha release, the cost premium of the GSHP system is approximated as the cost of the GHE.

- Allowing users to perform hypothetical analyses to evaluate alternative designs of the building and the GSHP system, including hybrid systems in which part of the load is met through other systems (e.g., a GSHP combined with a cooling tower or boiler), user inputs for the desired supply temperature range of the GHE, and proper models of the phase change of water in the ground surrounding the borehole when the GHE is allowed to run at a below-freezing temperatures;
- Compiling and integrating a database of available ground thermal conductivities in the United States; and
- Compiling and integrating a database of the costs of conventional HVAC and GSHP systems in the United States

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