An Overview of Geothermal Heat Pump Applications and a Preliminary Assessment of Its Technical Potential in the United States

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Geothermal heat pumps, vision study, residential, commercial, buildings, space heating, space cooling, water heating, technical potential, renewable thermal

ABSTRACT

Geothermal heat pumps (GHPs) utilize the shallow subsurface of the ground as a heat source for heat pumping operation and a heat sink for the cooling or refrigeration process. GHPs have been proven capable of producing large reductions in primary energy use and associated carbon emissions for satisfying the thermal demands of buildings, such as space conditioning and water heating. However, the current adoption rate of GHPs in the United States is low and GHPs receive little attention by either the general public or policy-makers. The U.S. Department of Energy, Geothermal Technologies Office (GTO) is developing a Geothermal Vision Study (Vision Study) in order to articulate GTO’s investment strategies, discuss geothermal growth scenarios for 2020, 2030, 2040 and 2050, and to address all market segments of the geothermal industry. The Vision Study Thermal Task Force is developing tools and data that include GHPs for non-electric-power-generation geothermal applications. Work described in this paper is being conducted to provide a credible analysis of potential GHP growth scenarios. This paper gives an overview of the current status of GHP applications, including system configurations, cost and performance, market penetration, and the barriers preventing wider adoption. This paper also introduces the methodology, supporting data, and preliminary results of an assessment for the technical potential of applying GHP systems in businesses and homes of the United States. The assessed technical potential includes energy savings, carbon emissions reductions, reduced summer electrical peak demands, and consumer energy cost savings. Preliminary results from this assessment indicate that GHPs have potential, in each year, to save 6.4 Quads of primary energy, avoid 412.7 Million tons of CO₂ emissions, and cut $77.3 Billion energy costs. In addition, GHPs can also significantly reduce peak demand on the electric grid.

1. Introduction

Geothermal heat pumps (GHPs), also referred to as ground source heat pumps (GSHPs), have been proven capable of producing large reductions in energy use, CO₂ emissions and peak electricity demand in buildings while satisfying the demands for space heating, space cooling, and domestic water heating. However, there are some barriers that prevent wider adoption of GHPs in the US.

The U.S. Department of Energy, Geothermal Technologies Office (GTO) is developing a Geothermal Vision Study (Vision Study) in order to articulate GTO’s investment strategies, discuss geothermal growth scenarios for 2020, 2030, 2040 and 2050, and to address all market segments of the geothermal industry. GHP is one of the thermal applications of the low-temperature geothermal resources included in the Vision Study. Work described in this paper is being conducted to provide a credible analysis of potential GHP growth scenarios. The objectives of this study include: (1) a review of the current status of GHP applications; (2) an assessment of technical potential of GHP applications; (3) an analysis of
the economic potential of GHP applications under different scenarios and the resulting impacts; and (4) recommended solutions to realize the potential of GHPs.

The overview of the current status of GHP applications presented in this paper includes system configurations, cost and performance, market penetration, and the barriers preventing wider adoption. This paper also introduces the methodology, supporting data, and preliminary results of an assessment for the technical potential of applying GHP systems in United States businesses and homes.

2. Current Status of GHP Applications

GHP, GSHP, and GeoExchange are all-inclusive terms for the family of GHP systems. GHP systems can be categorized based on whether (1) the ground, groundwater, or surface water is used as the heat source and sink, and (2) the exterior heat exchange system’s fluid circulates in a closed loop or is once-through (open loop) as follows:

- Ground coupled heat pump with closed-loop ground heat exchangers (GHXs)
- Groundwater heat Pump with open loop water wells
- Surface water heat pump with closed or open loops connected to lakes, streams reservoirs, or other surface water bodies

GHP systems further vary by the design of GHXs being used (e.g., a single pipe, multiple pipes, coiled pipes, co-axial pipes or other types of heat exchangers), and, for ground-coupled closed-loop systems, whether the GHXs are installed horizontally or vertically.

The vast majority of GHP systems in the United States use closed-loop GHXs. It has been estimated that 46% of the existing GHP systems use vertical closed-loop GHXs and 38% of GHP systems use horizontal closed-loop GHXs. The remaining 16% of GHP systems use groundwater or surface water in an open-loop or closed-loop configuration (Lund 2001).

Truck-mounted rotary or sonic drilling equipment, which is usually designed for water well or oil drilling, is most commonly used to drill the boreholes for vertical closed-loop GHXs (Sachs 2002). Directional drilling technology, which is primarily used in the oil and natural gas industry, has been adapted recently to drill angled or horizontal boreholes to reduce land requirements and disturbance of the ground surface (Remund 2009). The most commonly used equipment for installing horizontal loops includes: bulldozer, backhoe, vibratory plow, chain trencher or a directional borer.

The most common GHP system configuration used in US homes consists of a packaged or split water-to-air heat pump (WAHP) with a centrally ducted forced-air distribution system that conditions one floor of a multi-story home, or the entire house. For commercial buildings—such as offices, schools, hotels, or large residential buildings with multiple dwelling units—distributed GHP systems are predominantly used in the United States (Liu 2012). With a distributed GHP system, each zone of the building is conditioned with an individual WAHP, and the multiple WAHPs are connected to a common water loop. Traditionally, a two-pipe water loop is used with a variable speed central pumping station (Liu et al. 2015a).

The cooling capacities of the GHP units range from 0.5 to 20 ton (1.74–70 kW). The Energy Star minimum efficiency requirement for GHP units, which is a prerequisite for obtaining federal tax credits (DOE 2013), is listed in Table 1. Currently, more than 3,600 GHP models have been certified by Energy Star. Many currently available two-stage GHP units have higher energy efficiency than the Energy Star requirement at part load conditions (i.e., when the heat pump compressor running at low stage).

Central GHP systems, which use large heat pumps or modular water-to-water heat pumps to generate hot and/or chilled water for delivery to the conditioned space, have also been used in the United States, especially for retrofitting existing central chiller and boiler systems (e.g., the central district GHP system at Ball State University in Indiana). To satisfy the simultaneous demands for heating and cooling in different zones of a building, central GHP systems in the United States usually have four-pipe distribution systems: two pipes for supply and return of chilled water and another two pipes for supply and return of hot water.

<table>
<thead>
<tr>
<th>Table 1. Energy Star minimum efficiency requirements for residential GHP units for various Applications.</th>
</tr>
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<tbody>
<tr>
<td><strong>Energy Star specifications (effective January 1, 2012)</strong></td>
</tr>
<tr>
<td><strong>Product type</strong></td>
</tr>
<tr>
<td>Water-to-air</td>
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<tr>
<td>Water-to-water</td>
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</table>

Notes:
- The “closed-loop” and “open-loop” applications refer to “ground loop” and “groundwater” applications as defined in ISO/AHRI/ASHRAE Standard 13256, respectively.
- EER = energy efficiency ratio, used to indicate the cooling efficiency of heat pump equipment. The numbers shown in the table are expressed in Btu/W.
- COP = coefficient of performance, used to indicate the heating efficiency of heat pump equipment. The numbers shown in the table are expressed in W/W.
The efficiency and applicability of GHP units have been improved significantly in recent years as a result of a number of technological advancements, including inverter–compressor technology with communicating controls, along with improvements and refinements to refrigerant coils and to all aspects of variable-speed motors (Horwitz-Bennet 2014). The latest GHP models launched by a few manufactures have energy efficiency ratios (EERs) for cooling higher than 40\(^1\) and coefficients of performance (COPs) of up to 5.3 for heating. At least one of these new GHP models can provide not only space heating and cooling but also 100% of the domestic hot water (Rice et al. 2013). These GHP units can vary their heating or cooling outputs in a wide range—from 20 to 130%—provide good humidity control and can even eliminate the need for auxiliary heat in cold climates. More and more GHP manufacturers offer online control and monitoring capabilities to provide homeowners with key data on their energy usage and tools to control it. These features also help contractors diagnose and fix problems more efficiently (Horwitz-Bennet 2014).

Numerous previous studies confirmed that properly designed, installed, and operated GHP systems use significantly less energy than conventional heating, ventilation, and air-conditioning (HVAC) systems (Hughes and Shonder 1998, Shonder et.al. 2000, Southard et al. 2014 a, Southard et al. 2014 b). Recent case studies of GHP demonstration projects, which were funded in part by the 2009 American Recovery and Reinvestment Act (ARRA) grant, found that these GHP systems save 30-65% primary energy compared with conventional HVAC systems. Correspondingly, they reduced CO\(_2\) emission in the range from 20 to 65%, and the operating cost was reduced by 18 to 63% (Liu et al. 2015b). In these case studies, the energy savings is determined based on the measured performance of the installed GHP system and the calculated performance of a comparable baseline HVAC system for satisfying the same thermal loads.

However, the installed cost of GHP systems is higher than conventional HVAC systems. The cost varies widely depending on geological conditions, building loads, system designs, and heat pump equipment. A few surveys have been conducted in the United States to collect cost information for GHP systems. According to those surveys, the average cost of a commercial GHP system increased by 129%, from $9.07/ft\(^2\) in 1995 to $20.75/ft\(^2\) in 2012, or about 1.5% annually over the 17 year period (Kavanaugh 2012). This study determined that the cost increase (177%) for the interior portion of the GHP system (including the heat pump and other major equipment, controls, piping, and duct work) exceeded the cost increase for the closed-loop GHX portion (52%) over the 17 year period. In other words, costs for the indoor components, for which the technology is relatively mature, rose at a slightly higher rate (3.4% annually) than inflation; whereas the cost of the newer underground components rose more slowly, presumably as a result of innovations in cost reduction and increased competition in the market. The typical price of a GHP system installed in a new home is in the range of $3,000–5,000 per ton (Ellis 2008); the average price for large-scale housing retrofits is $4,600 per ton in 2006 dollars (DOD 2007).

Table 2 presents the typical cost of ground coupled heat pump (GCHP) systems that use vertical closed-loop GHXs. These cost data are from a survey conducted by Kavanaugh (2012), except the cost of water source heat pump, which was estimated based on data from a recent Energy Information Administration’s report (EIA 2010).

The simple payback period for a GHP retrofit project in the United States is usually 8–14 years; and for new construction, the simple payback period is shorter, but a payback period of more than 5 years is still common (Hughes 2008).

According to the Office of the Assistant Secretary of Defense Memorandum, October 14, 2015, GHPs have the highest estimated useful life of all Energy Efficiency, Renewable Energy and Water Conservation Technologies potentially used for DOD Energy Conservation Investment Program Projects\(^2\).

GHPs have been used in all 50 states and the District of Columbia in the United States. Figure 1 graphically shows the distribution of GHP applications in the United States, which is based on the 2009 data on the destinations of GHP unit shipments in the United States (EIA 2010) and is color-coded based on the total rated capacity (in cooling ton\(^3\)) shipped in that year. Various climate zones in the US are indicated by solid lines in this figure. About 52% of domestic GHP shipments went to ten states: Florida, Illinois, Indiana, Michigan, Minnesota, Missouri, New York, Ohio, Pennsylvania, and Texas. It appears GHP applications are more concentrated in areas with a cold climate and high population density.

The split between the cumulative residential and commercial GHP applications by 2012 is 3.5:1 (Navigant Research 2013). It is estimated that 75% of residential applications are in new construction and 25% in retrofits of existing homes (Ellis 2008).

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1 It is equivalent to a cooling COP of 11.7.


3 A cooling ton is equal to 3.5 kW cooling capacity.
Total GHP shipments in 2009 were 118,818 units. The recent economic recession and low cost of fossil fuels coincide with a reduced growth in GHP deployment. The U.S. Census Bureau reports that GHP year-over-year installed capacity in the United States declined 11% between 2010 and 2011, and 5% between 2011 and 2012 (Navigant Research 2013).

A recent Navigant Research report (2013) indicates that the United States represented 29% of global GHP installations by capacity with 13,564 MWt (3.9 million tons, or 1.1 million GHP units given the typical GHP unit size is about 12 kWt) installed by 2012. These GHP systems provide space conditioning to roughly 199 million m² (2.14 billion ft²) of residential and commercial buildings in the United States. The current market share of GSHP in the U.S. HVAC market is approximately 1% (EIA 2016c). A report issued by Priority Metrics Group (2009) estimated that the GHP market in the United States was about $3.7 billion in 2009, including design, equipment, and installation. It is estimated that the total revenue from sales of domestic GHP units was approximately $319.5 million in 2009 (EIA 2010).

In 2008 several dozen U.S. GHP industry experts were surveyed for the key barriers preventing rapid growth of the GHP industry (Hughes 2008). Experts grouped the identified barriers into three tiers (tier 1 being the most important) as shown in Table 3. The survey indicates that high initial cost and the lack of public awareness and strong governmental support prevent rapid adoption of GHP technology in the US. The recent low price of oil and natural gas reduces the monetary value of the energy savings, which makes consumers less willing to invest in GHP systems. Finally tax credits for GHP installations will expire at the end of 2016 unless industry efforts to encourage Congress to extend them are successful.

3. Assessment of Technical Potential of GHP Applications

Technical potential of GHP applications represents the maximum achievable energy savings given the performance of GHP systems and energy consumptions of existing conventional systems for satisfying the thermal loads of the buildings, and land-use constraints. Since GHPs can be used almost anywhere in the US (Hughes, 2008), it is assumed that all the buildings can use GHP systems to provide space heating, space cooling, and water heating (SH–SC–WH). The main

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4 The split between cumulative residential and commercial GSHP applications by 2012 is 3.5:1 [34]. The total floor space conditioned by GSHP systems is estimated based on the typical floor space per ton ratio in the United States—400 ft² per ton for commercial buildings and 600 ft² per ton for residential buildings.

5 Revenue includes charges for cooperative advertising and warranties but does not include excise taxes and the cost of freight or transportation.
purpose of assessing the technical potential is to establish an upper-boundary estimate of development potential. The technical potential analysis also provides a foundation for the further assessment of the economic potential of GHP applications, in which many potential scenarios to improve market penetration and environmental impacts of GHPs will be evaluated.

### 3.1 Methodology

The GHP technical potential is assessed based on: (1) the energy consumption data obtained from the latest residential and commercial buildings energy consumption survey, which is conducted by the U.S. DOE’s Energy Information Administration; and (2) the energy savings data of GHP systems compared with existing conventional SH–SC–WH systems.

Energy savings that can be realized by GHP systems is affected by many factors, including thermal loads (determined by the location, construction, and activity of the building), performance of the existing HVAC systems, and the local geological condition, as well as the design, installation, and operation of the GHP system. All of these factors have been taken into account in the assessment. The step-by-step procedure for assessing the technical potential is described below:

**Step 1:** Select reference buildings to represent building stocks in residential and commercial sectors. A reference building—a 1,644 ft² one-story, slab-on-grade, wood-frame house—is used to represent typical U.S. homes with space heating (EIA 2009). DOE’s Commercial Building Benchmark Models (DOE 2014) are used to represent various types of commercial buildings in the US.

**Step 2:** Calculate annual site energy consumptions of a state-of-the-art GHP system and the conventional SH–SC–WH systems for each of the reference buildings at various locations that represent major climate zones within each of the four U.S. census regions.

The residential GHP system used in this study consists of a packaged WAHP unit with a two-stage scroll compressor and variable-speed electronically commutated fan-motor, a properly sized and highly energy-efficient loop fluid circulator, and a properly designed and installed vertical-borehole ground heat exchanger. The nominal cooling efficiency of the two-stage GHP unit is an energy efficiency ratio (EER) of 18.2 at full capacity and an EER of 27 at 76 percent of full capacity. The nominal heating efficiency of the two-stage GHP unit has a COP of 4 at full capacity and a COP of 4.5 at 76 percent of full capacity.

The ground heat exchanger is sized to maintain the fluid temperature from the ground loop (the entering fluid temperature [EFT] to the GHP unit) within the range of 30–95°F (-1–35°C) for given building loads, ground thermal properties, and undisturbed ground temperature. This GHP system can contribute to WH through the use of a desuperheater, which provides hot water as a byproduct whenever the GHP unit runs for cooling or heating, but it cannot satisfy all the domestic hot water demand by itself. Typically, the desuperheater option on a GHP unit only provides supplemental WH to an electric resistance water heater, and the option would not be installed if the existing water heater is fossil fuel fired. The newly developed ground source integrated heat pump (GS-IHP) can provide 100% domestic hot water and thus can replace both the electric and fossil fuel fired water heaters. The GS-IHP can generate greater energy savings than the two-stage GHP unit with desuperheater, but with increased cost premium. The potential contribution of the GS-IHP will be assessed later in the economic potential analysis.

The commercial GHP system used in this study is a distributed GHP system, which is commonly used in the US as introduced in the previous section. It is assumed that multiple two-stage GHP units are used in the commercial GHP systems. There are ground source water-to-water heat pump water heaters (HPWHs) that can provide domestic hot water for commercial buildings. However, it is not accounted for in the assessment of the technical potential given the relatively small domestic hot water demand in commercial buildings. The impact of ground source HPWHs will also be assessed later in the economic potential analysis.

For commercial buildings, the energy consumptions are calculated with eQUEST, a widely used building energy modeling program that uses the most recent version of the DOE-2 program as its simulation engine (Hirsch et al. 2016); for residential buildings, the energy consumptions are calculated with GeoDesigner®, an energy saving calculator developed by ClimateMaster (ClimateMaster 2016). GeoDesigner® uses the ASHRAE’s (American Society for Heating, Refrigerating and Air-Conditioning Engineers) bin analysis method to calculate the energy consumption of GHP and other residential SH–SC–WH systems. It is assumed in the computer simulations that both the GHP system and the conventional SH–SC–WH systems are properly designed for the buildings loads, and properly installed and operated according to the design.

**Step 3:** Calculate the regional average of annual site energy consumption of the GHP and conventional SH–SC–WH systems serving a reference building with Eq. (1). The population in each climate zone within a census region is used as a weighting factor to account for the impact of climates on the energy consumption of the GHP and conventional SH–SC–WH systems.

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6 The EER is the cooling capacity (in British thermal units [Btu]/hour) of the unit divided by its electrical input (in watts) at standard conditions.

7 The COP and EER are measured at AHRI/ISO/ASHRAE/ANSI 13256-1 rating conditions: for cooling at full capacity, EFT is 77°F; for heating at full capacity, EFT is 32°F.
\[
\text{Avg }_\text{Sys }_\text{SE}(j,k) = \frac{\sum_{i=1}^{n} \text{Sys }_\text{SE}(i,j,k) \cdot CZ(i,k)}{\sum_{i=1}^{n} CZ(i,k)}
\]

(1)

where,

\( \text{Avg }_\text{Sys }_\text{SE}(j,k) \) is the regional average of annual site energy consumption of system \( j \) in census region \( k \);

\( \text{Sys }_\text{SE}(i,j,k) \) is the annual site energy consumption of system \( j \) in climate zone \( i \) of census region \( k \);

\( CZ(i,k) \) is the population in climate zone \( i \) of census region \( k \);

\( n \) is the number of major climate zones in census region \( k \).

The 2004 International Energy Conservation Code climate zones for the United States are used in this study. Table 4 lists the percentages of the population in each climate zone in each of the four U.S. census regions. Where the percentage of the population in a climate zone is very low (i.e., less than 5 percent of the total population in the census region), that climate zone is omitted from this study. Totally 14 locations (cities) were selected to represent all the major climate zones in the four census regions.

**Step 4:** Calculate the regional average of annual site energy savings achievable by the GHP system with Eq. (2).

\[
\text{ESPct }_\text{SE}(j,k) = \frac{\text{Avg }_\text{Sys }_\text{SE}(j,k) - \text{Avg }_\text{Sys }_\text{SE}(l,k)}{\text{Avg }_\text{Sys }_\text{SE}(j,k)} \times 100\%
\]

(2)

where,

\( \text{ESPct }_\text{SE}(j,k) \) is the regional average of annual site energy saving percentage of the GHP system compared with conventional SH–SC–WH system \( j \) in census region \( k \);

\( \text{Avg }_\text{Sys }_\text{SE}(l,k) \) is the regional average of annual site energy consumption of the GHP system in census region \( k \).

**Step 5:** Calculate the national annual site energy savings resulting from retrofitting all the existing conventional SH–SC–WH systems with the state-of-the-art GHP system with Eq. (3).

\[
\text{National }_\text{SES} = \sum_{K=1}^{4} \sum_{j=2}^{m} \text{Reg }_\text{Tol }_\text{SE}(j,k) \times \text{ESPct }_\text{SE}(j,k)
\]

(3)

where,

\( \text{National }_\text{SES} \) is the national annual site energy savings from the GHP retrofits;

\( \text{Reg }_\text{Tol }_\text{SE}(j,k) \) is the total annual site energy consumed by all existing system \( j \) in census region \( k \), which is obtained from the latest residential and commercial buildings energy consumption survey;

\( m \) is the number of existing systems used in census region \( k \).

The savings in primary (source) energy, the reduction of CO\(_2\) emissions and energy cost are calculated following the same procedure. In these calculations, the annual site energy consumption of each existing conventional SH–SC–WH system is replaced with the associated primary energy consumptions, CO\(_2\) emissions, or energy costs, which are converted from the site energy consumption data using corresponding conversion factors published by the National Renewable Energy Laboratory (NREL 2007) and the energy cost data from EIA (2010).

### 3.2 Supporting Data

1) **Current Energy Use for SH-SC-WH in Existing Buildings**

According to the 2009 Residential Energy Consumption Survey (RECS, EIA 2016a), there were 113.6 million housing units in the United States, of which 186.8 billion square feet floor space is heated with various SH systems and 139.8 billion square feet is cooled with various SC systems. The predominant type of residential buildings in the United States is single-family house, which accounts for 85 percent of the floor space in residential sector. The U.S. residential...
sector consumed 20.8 Quads primary energy annually (which is 20 percent of the total annual primary energy consumption in the US), of which SH, SC, and WH consume 5.5, 2.7, and 2.6 Quads annually, respectively.

The 2012 Commercial Buildings Energy Consumption Survey (CBECS, EIA 2016b) shows that there were 5.6 million commercial buildings in the United States, comprising 87.4 billion square feet of floor space. Commercial buildings represent 19 percent (17.9 Quads annually) of the U.S. annual primary energy consumption. The 2009 building energy data book (DOE 2009) stated that SH, SC, and WH are responsible for 2.3, 2.2 and 1.1 Quads primary energy annually, respectively. The 2012 CBECS data indicates that, in U.S. commercial buildings, SH, SC, WH, and ventilation consume 2, 14.9, 0.5, and 15.8 percent of all the annual 4.2 Quads site energy consumption in the form of electricity; and SH and WH consume 59.6 and 18.9 percent of all the annual 2.2 Quads site energy consumption in the form of natural gas.

Figure 2 shows the site energy use of electricity and natural gas for SH, SC, WH, and ventilation. As can be seen from this figure, offices, schools, lodgings, and retails and/or malls collectively are responsible for 55 percent of the site energy consumption in commercial sectors. These building types are also a good fit for GHP applications given the usually large available land (e.g., parking lots) and high energy consumptions for space conditioning. These types of buildings will be the focus of this vision study.

2) Market Share and Performance of Existing SH-SC-WH Systems

The 2009 RECS (EIA 2016a) report indicates that natural gas is the prominent fuel for SH and WH in U.S. homes at all the census regions, but there is substantial consumption of heating oil for SH and WH in the Northeast. SC is dominated by electric-driven air-conditioners and air-source heat pumps. The site energy consumption for SC is low except in the South, and the total national site energy consumption for SC is only about 1/5 of that for SH (however, the ratio is ½ when comparing the associated source energy consumptions). Table 5 summarizes the existing SH–SC–WH systems used in residential buildings and their energy efficiencies in 2000 and 2012 (EIA 2000 and EIA 2016c). These data shows that while the energy efficiencies of existing conventional residential SH and WH equipment at 2012 are about the same as they were in 2000, the average energy efficiencies of existing residential SC equipment in 2012 are about 30% higher than a decade ago.

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Table 5. Typical SH–SC–WH systems used in U.S. Single-family units.

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Space heating</td>
<td>ASHP</td>
<td>3.2 COP</td>
<td>3.2 COP</td>
</tr>
<tr>
<td></td>
<td>Electric heater</td>
<td>1.00 EF</td>
<td>1.00 EF</td>
</tr>
<tr>
<td></td>
<td>Natural gas–fired furnace/boiler</td>
<td>0.8 AFUE</td>
<td>0.84 AFUE</td>
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<tr>
<td></td>
<td>Propane- or LPG-fired furnace/boiler</td>
<td>0.80 AFUE</td>
<td>0.80 AFUE</td>
</tr>
<tr>
<td></td>
<td>Heating oil–fired furnace/boiler</td>
<td>0.8 AFUE</td>
<td>0.86 AFUE</td>
</tr>
<tr>
<td>Space cooling</td>
<td>CAC/ASHP</td>
<td>10 SEER</td>
<td>13.2 SEER</td>
</tr>
<tr>
<td></td>
<td>RAC</td>
<td>7.7 SEER</td>
<td>9.9 SEER</td>
</tr>
<tr>
<td></td>
<td>Combination of CAC and RAC</td>
<td>7.7–10 SEER</td>
<td>9.9–13.2 SEER</td>
</tr>
<tr>
<td>Water heating</td>
<td>Electric heater</td>
<td>0.88 EF</td>
<td>0.90 EF</td>
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<tr>
<td></td>
<td>Natural gas heater</td>
<td>0.58 EF</td>
<td>0.61 EF</td>
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<tr>
<td></td>
<td>Propane or LPG heater</td>
<td>0.58 EF</td>
<td>0.65 EF</td>
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<tr>
<td></td>
<td>Heating oil heater</td>
<td>0.58 EF</td>
<td>0.58 EF</td>
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</table>

Notes: AFUE, annual fuel utilization efficiency, is the ratio of the annual amount of heat actually delivered to the amount of fuel supplied to the furnace. COP, coefficient of performance, is the ratio of heating energy provided to the space to the electric energy consumed. The COP of the ASHP listed in the above table is measured at standard, mild weather (47°F) rating conditions. EF, energy factor, indicates a water heater’s overall energy efficiency based on the amount of hot water produced per unit of fuel consumed over a typical day. SEER, seasonal energy efficiency ratio, is the average annual cooling efficiency of an air-conditioning or heat pump system determined with a standard methodology and assuming typical weather. CAC stands for central air conditioner and RAC stands for room air conditioner.

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8 CBECS 2012 has not yet released the updated source energy consumption when this report is written.
The 2012 CBECS preliminary report indicates that the “packaged air conditioning units” (e.g., the typical rooftop units) are used in more than 50 percent of all types of commercial buildings, except for lodging. However, the CBECS report does not provide data on the efficiency of the existing SH-SC-WH equipment for commercial buildings. Energy codes for commercial buildings, such as ASHRAE Standards 90.1 (ASHRAE 2014), and the vintages of those codes adopted by local jurisdictions provide information on minimum allowed efficiency for new space conditioning equipment for commercial buildings by vintage and location. This information is used to establish a baseline system, with which the performance of commercial GHP system is compared to determine the energy savings.

3.3 Preliminary Results

The technical potential of GHPs is calculated with the methodology and the supporting data described above. It is assumed that GHPs displace all the existing SH and SH systems in all residential and commercial buildings. However, as discussed in the Methodology section, it is assumed that residential GHPs only provide supplemental water heating to existing electric resistance water heaters, and the commercial GHPs do not provide any WH service.

Table 6 summarizes the calculated technical potential of residential GHPs, including primary energy savings, carbon emissions reductions, electricity peak demand reductions, and consumer energy cost saving, in each census region and the entire nation. The percentages of primary energy savings of residential GHPs are significant, varying from 35.3 percent in the West to 46.5 percent in the South. Similar reduction percentages exist for CO₂ emissions, peak electricity demand, and energy cost. The South census region has the greatest technical potential since its population, cooling demand, and usage of electric resistance water heating is the highest among all the census regions.

Retrofitting existing buildings with GHP has different impacts on the residential electricity intensity, which is the ratio of annual electricity consumption per household, at the four census regions. It will increase the electricity intensity by 70% and 25% in Northeast and Midwest, respectively, where GHPs consume electricity in winter instead of burning natural gas or oil to satisfy the large space heating demand. However, the GHP retrofit will reduce the electricity intensity by 42% in South since it saves a large amount electricity due to more efficient space cooling, and furthermore, it replaces existing electric heaters for space heating, which is used in 19% of the southern households. In West, the GHP retrofit will increase the electricity intensity by 7% due to the relatively smaller heating demand there. Overall, the residential electricity intensity of the whole country will decrease by 13%.

Table 7 summarizes the calculated technical potential of commercial GHPs, including primary energy savings, carbon emissions reductions, and consumer energy cost saving, in each census region and the entire nation. The percentages of primary energy savings of commercial GHPs range from 18 percent in the West to 43 percent in the Midwest. It is consistent with the results of the recent case studies (Liu et al. 2015b). Computer simulations indicate GHPs can reduce peak electric demand at percentages similar to that for the primary energy savings. However, due to the lack of existing peak electric demand data of commercial buildings, the absolute value of the peak electric demand reduction is not computed.

The relatively smaller energy savings of commercial GHPs is thought to be due to: (1) the pumping energy consumed for circulating heat transfer media (i.e., water or anti-freeze solution) through large underground GHXs and the multiple
WAHPs throughout the building; (2) smaller heating demands due to the heat gains from occupants, equipment, and lighting in commercial buildings, and (3) the air-side economizer used in the baseline variable air volume (VAV) system.

The combined annual technical potential of both the residential and commercial GHPs are listed below:

- a savings of 6.4 Quads annually primary (source) energy annually (4.6 residential, 1.8 commercial);
- a reduction of 412.7 Million tons of CO₂ annually (296.6 residential, 116.1 commercial);
- a savings of $77.3 Billion in energy costs annually (57.8 residential, 19.5 commercial); and
- a reduction of 144 GW in peak electricity demand (only accounts for residential).

Conclusions and Plans for Further Study

Using GHP systems is an effective way to utilize low temperature geothermal resources to serve the thermal demands in buildings. GHP systems have been used in all 50 states in the US with proven higher energy efficiency than conventional HVAC systems. However, GHP applications are limited by their high initial costs and the lack of knowledge of and/or trust by policy makers and potential consumers.

This paper presents a preliminary assessment of the technical potential of GHP applications in both residential and commercial buildings in the US. This technical potential represents the maximum achievable benefits from applying GHPs and it provides a vision of the potential of GHPs to be a key component of the national energy and climate change mitigation strategies. The GHP technical potential is assessed based on the energy consumption data of existing residential and commercial buildings and the expected energy savings from properly designed, installed, and operated GHP systems. Preliminary results from this assessment indicate that GHPs have the potential to annually save 6.7 Quadrillion Btus of primary energy, avoid 433.3 Million tons of CO₂ emissions, and cut $80.4 Billion in energy costs compared with using the existing conventional SH-SC-WH systems. In addition, GHPs can significantly reduce peak demand to the electric grid.

There are several scenarios that may result in wider market adoption of GHPs, including technology development to reduce cost and improve performance, financial incentives and 3rd party financing, higher energy prices, and the possible charge for carbon emissions. To further analyze the economic potential of GHP applications for inclusion in the Geothermal Vision Study, these scenarios will be evaluated using a distributed geothermal (dGeo) model, which is under development at the National Renewable Energy Laboratory.

Works Cited


Liu, et al.


