Ground-Source Heat Pumps: Overview of Market Status, Barriers to Adoption, and Options for Overcoming Barriers

Final Report

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List of Acronyms

AFUE	Annual fuel utilization efficiency
ARI	Air-Conditioning and Refrigeration Institute
ASHP	Air-source heat pump
BT	U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Building Technologies Program
CDD	Cooling degree day
CHP	Combined Heat and Power
COP	Coefficient of Performance
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
EERE	U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy
EIA	U.S. Department of Energy, Energy Information Administration
GHP	Geothermal Heat Pump
GSHP	Ground-source Heat Pump
GT	U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Geothermal Technologies Program
HDD	Heating degree day
HPWH	Heat Pump Water Heater
HSPF	Heating Seasonal Performance Factor
IEA	International Energy Agency
kWh	Kilowatt-hour
MMBtu	Million British thermal units
MW_t	Megawatt (thermal)
NREL	National Renewable Energy Laboratory
ORNL	Oak Ridge National Laboratory
Quad	Quadrillion (10^{15}) British thermal units
R&D	Research and development
SEER	Seasonal energy efficiency ratio
TBtu	Trillion (10^{12}) British thermal units
UEC	Unit energy consumption
UES	Unit energy savings
WSHP	Water-source heat pump
ZEB	Zero-energy building
ZEH	Zero-energy home

Executive Summary

We conducted this investigation to:

- Summarize the status of ground-source heat pump (GSHP) technology and market penetration globally
- Estimate the energy saving potential of GSHPs in the U.S.
- Identify and describe the key market barriers that are inhibiting wider market adoption of GSHPs
- Recommend initiatives that can be implemented or facilitated by the DOE to accelerate market adoption.

Of the 15,400 MW_t (4.38 x 10^6 tons) global installed base of GSHPs, about 56 percent of this capacity is installed in the U.S., corresponding to about 65 percent of the GSHP unit installations. Europe follows, with about 39 percent of the installed capacity, and Asia has about 5%. In Europe, Sweden is the dominant player in the GSHP market, with almost 2500 MW_t (711,000 tons) installed—more than double any other European country.

The U.S. GSHP market is split roughly evenly between residential and commercial applications, with only a very small market for industrial applications.

GSHPs can provide significant primary unit energy savings compared to typical ASHPS or typical furnaces with air conditioners. Savings are often in the range of 30 to 60 percent of space-conditioning energy consumption, depending on GSHP efficiency, technology replaced, climate, and application.

Our energy-savings and economics analysis compares two high-efficiency technologies (GSHPs and advanced ASHPs) to two typical-efficiency baseline systems (typical ASHPs, and furnaces with air conditioners). We used general relationships between fundamental (unsubsidized) economics and market penetration to project ultimate market penetrations of GSHPs and the associated national primary energy savings. Table E-1 summarizes the technical potential energy savings (savings if all technically applicable applications are converted to GSHPs) and projected primary energy savings based on the ultimate market penetration, predicted based on economics.

Table E-1: National Primary Energy Savings Potential of GSHPs

Sector	Technical Potential (Quad)	Market Potential (Quad)
Residential	3.1	0.1
Commercial	0.6	0.05
Total	3.7	0.15

In addition to high energy efficiency, GSHPs offer two key benefits:
- Can have factory-packaged refrigeration loop
- Can reduce peak electric demand.

GSHPs face three key barriers:
- High equipment costs compared to ASHPs
- Cost and difficulty of evaluating the suitability of individual installation sites
- Installation-specific design and engineering of the ground loop is generally required
- Space requirements for ground coupling can be problematic in densely built areas.

While advanced ASHPs offer lower unit energy savings compared to GSHPs, they tend to be more economically attractive and may be able to save similar amounts of energy on a national basis. We, therefore, recommend that DOE support advanced heat pumps in general, rather than supporting only one type. Incentives such as federal tax credits or utility rebates can be based on energy efficiency achieved, rather than type of heat pump. R&D projects can be pursued based on the individual merit of each prospective project, rather than type of heat pump. This will require close coordination between the DOE Geothermal Technologies Group (which is responsible for GSHPs) and DOE Building Technologies Group (which is responsible for ASHPs). This coordination will help ensure that both types of heat pumps are developed, evaluated, and promoted based on apples-to-apples cost and performance comparisons, and that duplication of effort is avoided to the extent possible.

1 Introduction

The U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE), Geothermal Technologies Program has commissioned this study of ground-source heat pumps (GSHPs), also known as geothermal heat pumps, to help assess whether new initiatives are appropriate to further the development and market adoption of this advanced, energy-efficient technology. The report that follows provides an overview of the technology, describes that status of the international GSHP market, assesses the energy savings potential of GSHPs in the U.S., explains key barriers to widespread adoption of the technology, and suggests some initiatives that might help accelerate market adoption.

1.1 Background

The Geothermal Technologies Program has in the past addressed GSHPs, but in recent years has focused primarily on conversion of high-temperature supplies of geothermal energy into electricity. However, the increasing importance of building energy efficiency generally, as well as EERE's programmatic focus on net-zero energy homes (NZEH) and net-zero energy commercial buildings (NZEBs), suggest that the topic of GSHPs should be reassessed to determine whether any new DOE initiatives are warranted to increase the relatively small market penetration of GSHPs.

Residential, commercial, and institutional buildings account for about 40% of US primary energy consumption and carbon emissions, 72 percent of electricity consumption, 55 percent of natural gas consumption, and significant oil consumption in the Northeastern U.S. (DOE 2008). Over the long term, buildings are expected to continue to be a significant component of increasing energy demand and a major source of carbon emissions, driven in large part by the continuing trends of urbanization, population and GDP growth, as well as the longevity of building stocks. However, because building equipment and many structural features are frequently upgraded, the short term potential for improving the energy integrity of the existing building stock is substantial.

Over the past several decades GSHP systems have gradually improved and have achieved a small but growing share in heating, cooling and (in some cases) water heating equipment markets, with modest policy emphasis and research to accelerate technology improvement or enhance affordability. Yet large energy savings have been demonstrated at the individual project level, suggesting that even today's proven GSHP technology may be underutilized. In areas like the

Northeast where many building owners are dependent on fuel oil, high oil prices may create unprecedented demand for high efficiency heating and cooling solutions such as GSHPs. New initiatives may be needed to effectively address the barriers that continue to inhibit greater adoption of GSHPs in applications where they are cost-competitive.

1.2 Objectives

The objectives of this effort were to:

- Summarize the status of GSHP technology and market penetration globally
- Estimate the energy saving potential of GSHPs in the U.S.
- Identify and describe the key market barriers that are inhibiting wider market adoption of GSHPs
- Recommend initiatives that can be implemented or facilitated by the DOE to accelerate market adoption.

The project took a national perspective. However, the investigation paid particular attention to Northeastern markets where heating oil and propane are common fuel sources and have become very expensive in recent years, which could provide an opportunity for GSHPs to improve their market penetration.

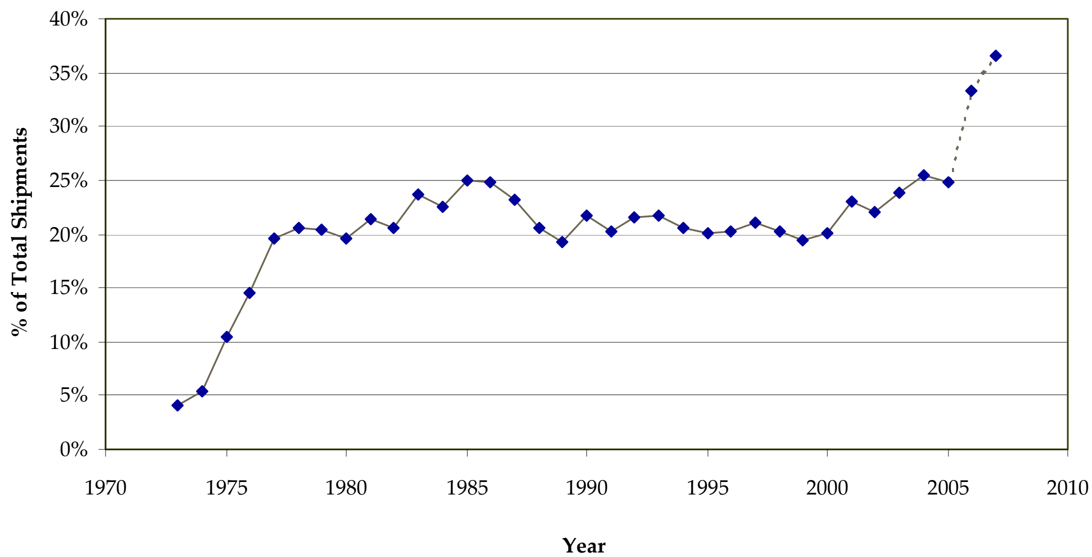
This investigation is meant to provide an overview of current market conditions and make recommendations to DOE policymakers for improving market penetration. It is based on readily available data and information on market penetration and energy consumption but does not include extensive, detailed new modeling.

Appendix A contains the complete statement of work for this analysis.

1.3 Overall Approach

Figure 1-2 summarizes the overall approach to this investigation. To understand the benefits associated specifically with coupling a heat pump to the ground, we compare the potential impacts of GSHPs to those for advanced air source heat pumps (ASHPs). Historically, ASHPs have been used for heating and cooling primarily in moderate climates such as the Southern and Western U.S., but have not been very common in cold Northern climates. The relatively high electricity rates in the Northeast, combined with the need for expensive and inefficient resistance heating during cold weather, typically made heat pumps unattractive in the Northeast. However, this regionality has begun to change in recent years, as high natural gas prices and advanced technology which avoids the need for resistance heating during cold weather, have combined to make ASHPs much more attractive in colder climates. In fact, some manufacturers have introduced "cold climate" air source heat pumps that are suitable for virtually any climate.[1] Such technology is expected to continue to advance, and we can expect to see far more air source heat pumps used in cold climates in the future. Heat pumps have historically comprised 20-25% of U.S. unitary space-conditioning equipment sales (Figure 1-1). However, in the past five years heat pump market share has risen to approximately 35% (AHRI, Appliance Magazine).

Figure 1-1: ASHP Heat Pump Market Share of Total Unitary A/C and Heat Pump Sales



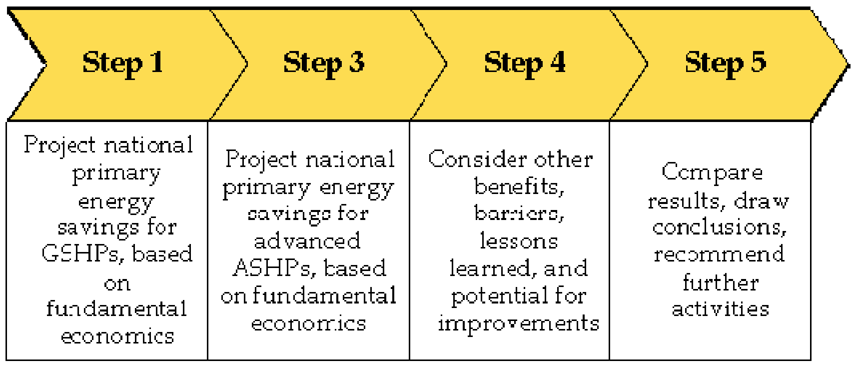
Source: AHRI 2005 (data for 1973-2005), Appliance Magazine 2008 (total shipment data for 2006-2007).
Note: ASHP data for 2006-2007 is projected by NCI based on the average annual growth rate for 2001-2005 of 10%.

Our process starts with a comparison of the fundamental economics of each technology in the residential and commercial markets and the likely national impacts. While GSHPs are generally more energy efficient compared to the best-available ASHPs, national impacts also depend on likely market penetrations of each alternative. We also consider other benefits and barriers that are not reflected in the economic analysis, including lessons learned from global

[1] See for example http://www.mrslim.com/UploadedFiles/Resource/H2i_brochure.pdf. Products are designed achieve 100% capacity down to 5 °F outdoor and 75% capacity down to -13 °F, with a COP >1 even at those low temperatures.

experience with GSHPs. We then compare results, draw conclusions, and make recommendations.

Figure 1-2: Overall Approach to GSHP Evaluation



In gathering information for this investigation, we:

- Conducted interviews with the following organizations and companies:
  - Advanced Hydronics, Inc. (http://advancedhydronics.com/)
  - CDH Energy Corp. (http://www.cdhenergy.com/)
  - Geothermal Heat Pump Consortium (http://www.geoexchange.org/)
  - Geo-Heat Center, Oregon Institute of Technology (http://www.geoexchange.org/)
  - Major Geothermal (http://www.majorgeothermal.com/)

- Reviewed the proceedings from the following conferences:
  - 7th IEA Heat Pump Conference, Beijing 2008
  - 8th IEA Heat Pump Conference, Las Vegas 2005
  - 9th IEA Heat Pump Conference, Zurich 2008
  - World Geothermal Congress 2005
- Conducted internet searches and reviewed websites of several organizations involved in GSHP development or promotion, including:
  - International Energy Agency
  - Oak Ridge National Laboratory
  - National Renewable Energy Laboratory
  - Geothermal Heat Pump Consortium
  - California Energy Commission Consumer Energy Center
  - American Council for an Energy Efficient Economy
  - European Heat Pump Association
  - International Ground Source Heat Pump Association
  - Natural Resources Canada

1.4 Report Organization

This report is organized as shown in Table 1-1. This structure is consistent with the work statement.

Table 1-1: Report Organization

Section	Content/Purpose
1	Introduction—Describes work scope, objectives, and overall approach
2	Status of Global GSHP Markets—Summarize the global market situation for GSHPs and identify lessons learned that are applicable to the U.S., if any
3	National Energy-Savings Potential—Documents analysis of unit energy savings, technical potential, likely ultimate market based on economics, and likely national primary energy savings. Residential and commercial building examples used.
4	Other Benefits of GSHPs—Briefly describes benefits of GSHPs that are not captured in our economic analysis
5	Key Barriers to GSHPs in the U.S.—Briefly discusses various barriers to GSHPs
6	Applicability to Zero-Energy Homes and Buildings—Briefly discusses GSHP implications for ZEH and ZEB
7	Summary/Conclusions
8	Recommendations
References	--
Appendix A	Scope of Work
Appendix B	Residential Primary Unit Energy Consumptions
Appendix C	Residential Primary Unit Energy Savings
Appendix D	Commercial Primary Unit Energy Consumptions
Appendix E	Commercial Primary Unit Energy Savings
Appendix F	Residential Electricity Price Projections—EIA projections of residential electricity prices for three cases/scenarios
Appendix G	Residential Annual Energy Costs
Appendix H	Commercial Annual Energy Costs

2 Status of Global GSHP Markets

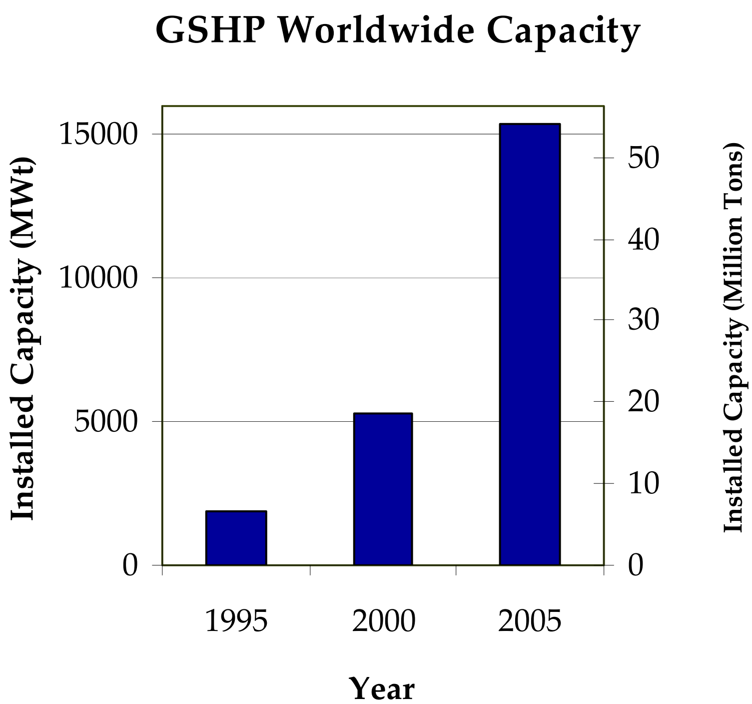
Global Overview

Ground-source heat pumps (GSHP) are a small but growing fraction of the global installed base of space-conditioning equipment. The global installed capacity has reached about 15,400 MWt, and annual energy use is estimated to be 87,500 TJ (Lund 2005). The global GSHP capacity has seen tremendous growth in recent years. Annual growth rates have exceeded 10% over the last 10 years (Le Feuvre 2008), mostly in North America and Europe. Figure 2-1 shows the increase from 1,900 MWt in 1995 to 5,300 MWt in 2000 and 15,400 MWt in 2005. As of 2005, 33 countries had installed at least 100 MWt of GSHP capacity.

As shown in

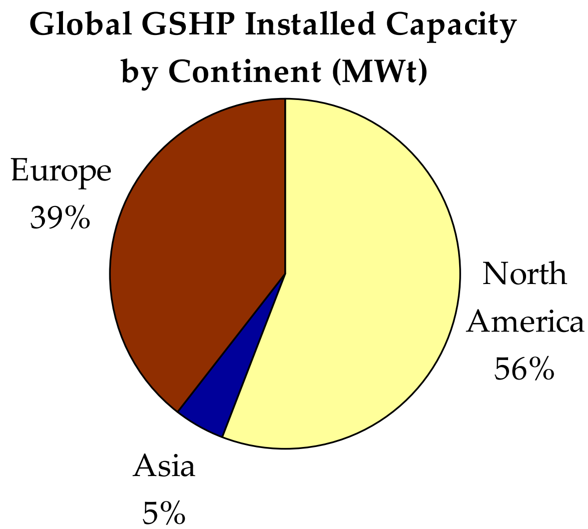
Figure 2-2, North America represents the largest portion of installed GSHP capacity at 56%, followed by Europe at 39% and Asia at a modest 5%.

Figure 2-1: GSHP World-wide Installed Capacity in MWt



Source: Lund, et al. "Direct application of geothermal energy: 2005 Worldwide review" (2005).

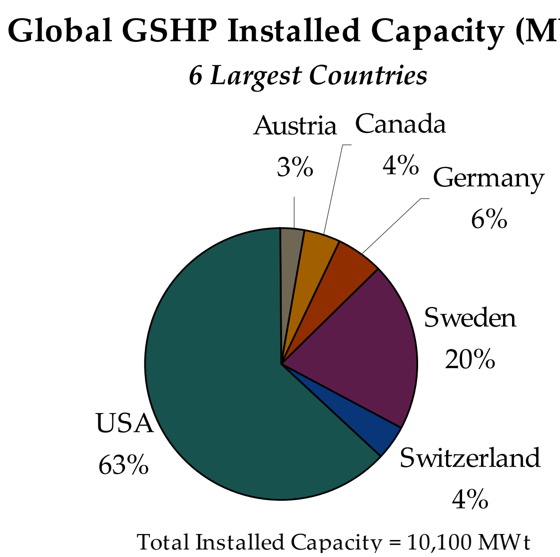
Figure 2-2: Global GSHP Installed Capacity (MWt) by Continent



Source: Lund, et al. "Direct application of geothermal energy: 2005 Worldwide review" (2005).

Figure 2-3 shows the GSHP installed base by country in terms of MWt of capacity. The United States comprises approximately two thirds of the installed base and Sweden, the leading European country, represents one fifth. In total, 900,000 individual units were estimated to be installed as of 2005.

Figure 2-3: Global GSHP Installed Capacity by Country (MWt)



Source: Curtis, et al. World Geothermal Congress, 2005.

Equipment Description

Ground source heat pumps are generally classified by the type of ground loop (see Figure 2-4). Market share of each type varies by country depending on site characteristics, promotion, and applications.

Open loop systems, or "groundwater-source" heat pumps, shown in Figure 2-4(a), are the oldest and cheapest type of GSHP system, assuming the groundwater is suitable for use. Open loop systems have been in common use since the 1970's and currently represent approximately 10-20% of the U.S. market (Lund 2005). In such systems, groundwater is used as the heat carrier and is brought directly to the heat pump. The water is discharged either back into the well or into a body of surface water. These systems require an ample, shallow, and pure supply of groundwater. Because of their effect on the community groundwater, municipal regulations sometimes inhibit the installation of open loop systems.

Closed loop, or ground-coupled, systems use a loop containing water or a glycol solution through the ground loop and use a refrigerant loop to transfer the heat to the heat pump (Figure 2-4b). The ground loop can be laid vertically or horizontally in the ground, or occasionally laid in a pond or lake.

The vertical configuration involves a borehole drilled to a depth of 150 to 220 ft per ton of capacity (Rafferty 2008). The vertical loop has a smaller ground surface area requirement, typically 200-400 ft^2 (5-10 m^2/kW), which makes it more feasible for small properties, but it adds on significant drilling costs to the total installation cost of the system (ASHRAE 1995).

The horizontal loop is usually a less expensive option, because it only involves digging a 4-5 ft trench as opposed to a deep well. However, it requires much more space, and the ground temperature is subject to seasonal fluctuation at shallow depths. The horizontal trench length ranges from 125 to 300 ft per ton of capacity (Rafferty 2008). The length of pipe necessary is a function of system size, climate, soil/rock thermal characteristics and loop type. The ground surface area necessary for a typical horizontal loop ranges from 2000 ft^2 to 3500 ft^2 per ton (50-90 m^2/kW) (ASHRAE 1995).

A variation of the horizontal loop is the spiral, or "slinky", loop configuration in which the piping is laid out in an overlapping circular fashion. This configuration requires less ground area but more pipe length and pumping energy than a basic horizontal setup.

In a pond loop, the ground loop is submerged in a lake or a pond. If a suitable body of water is available, this design is an economical option, because it involves minimal digging.

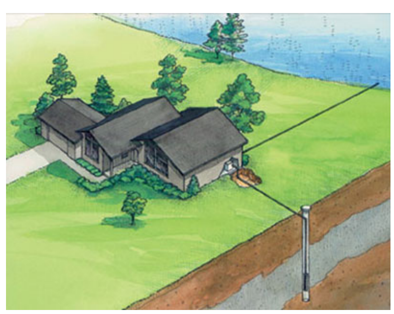
Direct exchange systems run refrigerant through the ground loop to exchange heat directly. Such systems do not have to use a pump, but require a much greater copper tube length and refrigerant charge. They are not commonly used.

Ground-source heat pumps can be applied in a variety of residential, commercial, and institutional settings. In addition, a number of community-based systems have been installed in various countries around the world. The size of individual units ranges from about 1.5 tons for small residential applications to over 40 tons for commercial and institutional applications. As shown in Figure 2-5, larger commercial applications can involve numerous rows of piping connected either in series or in parallel.

In the U.S., the capacity of most units is sized for the cooling load and is consequently oversized for the heating load, except in northern climates where the primary load is the heating load. In Europe, the capacity is usually sized for heating load, often to provide base load, with peak load provided by fossil fuel.

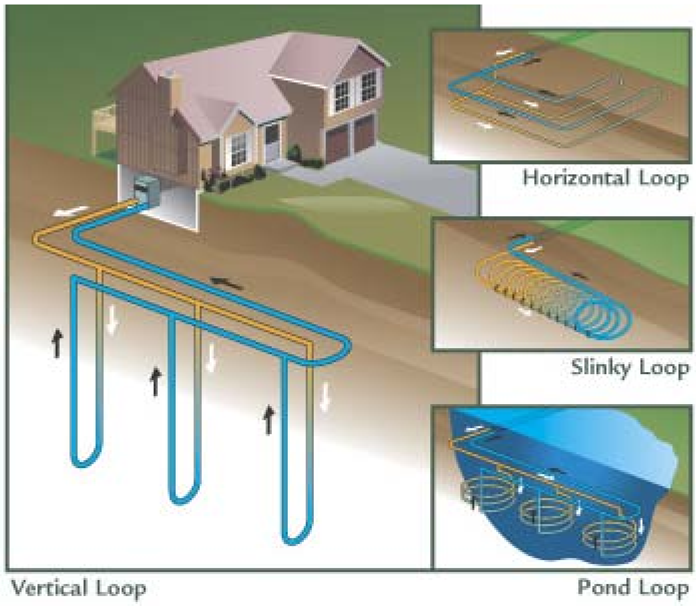
Figure 2-4: Residential Ground Loops

a) Open Loop



Source: Water Furnace 2008

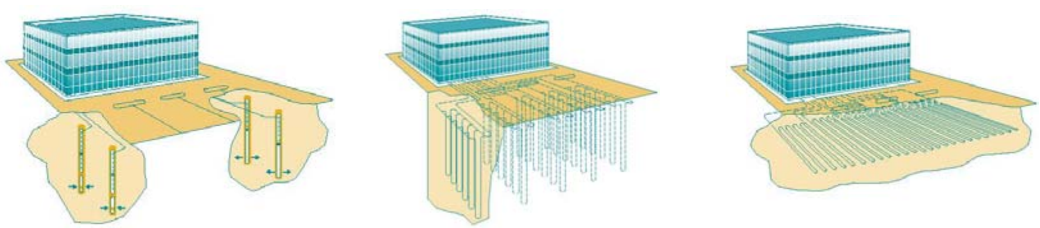
b) Closed Loop



Source: KCPL 2008.

Figure 2-5: Commercial/Institutional Ground Loops

a) b c)



Open Loop (Groundwater) Vertical Closed Loop Horizontal Closed Loop

Source: NRCan 2008

Europe

Europe has seen significant growth in the GSHP industry in the past 10 years. GSHPs represent 25% of all heat pumps sold in Europe (Forsén 2008). Over 690,000 units, representing 7,300 MWt of capacity, have been installed in Europe through 2006 (EUObserv'ER 2007, EHPO 2008).

Figure 2-6: Global GSHP Installed Capacity by Country

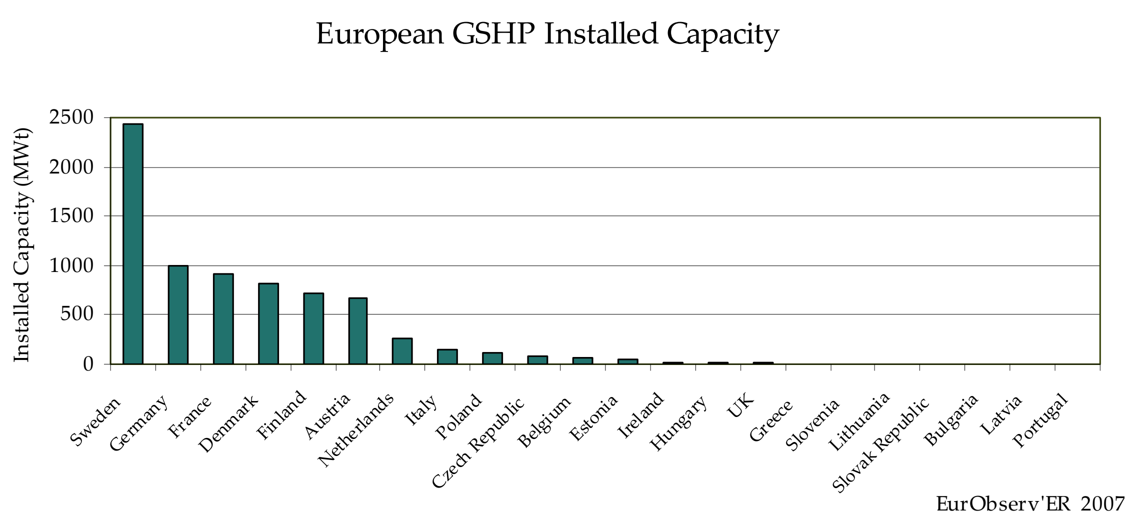


Figure 2-7: European GSHP Installed Base (units)

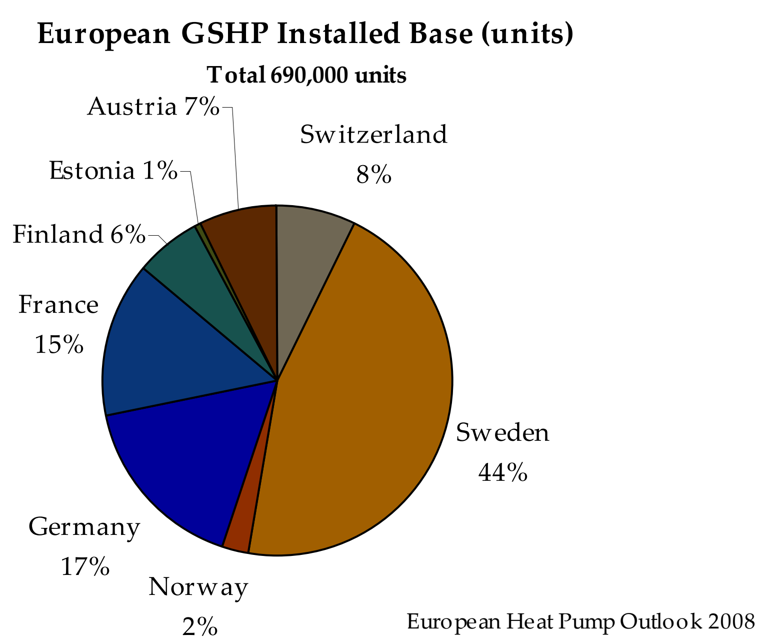


Figure 2-8 shows the rise in annual sales GSHPs in eight European countries between 2004 and 2006. The compound annual growth rate for this period is approximately 30%.

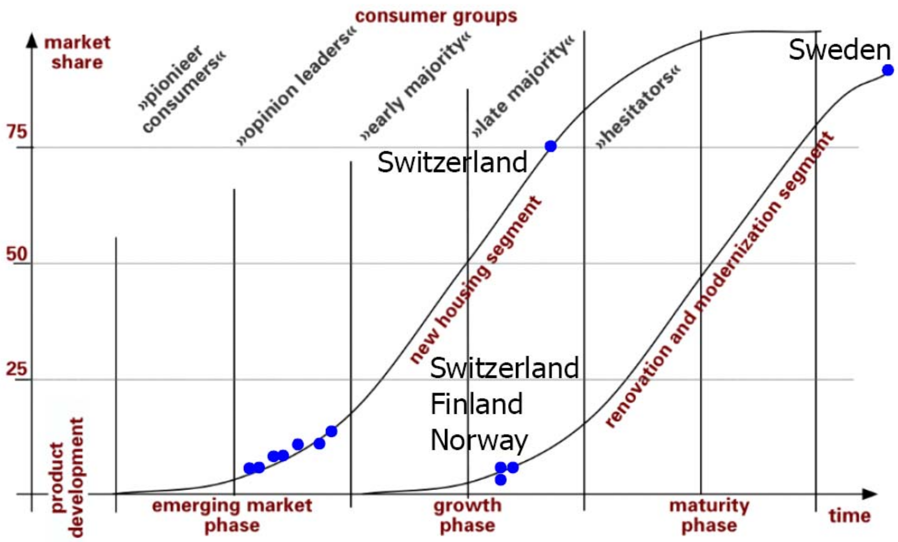
Figure 2-8: Total Sales of GSHPs in 8 European Countries[2]

Source: GroundReach 2007 (Market Status)

Figure 2-9 shows the estimated market penetration for the same eight European countries for both the new construction and retrofit markets. The countries are plotted as along both curves, although only Sweden, Switzerland, Finland, and Norway have significant retrofit markets. The figure shows how successful Sweden has been in penetrating the retrofit market with over 75% market penetration. In addition, it is clear that GSHPs have a very strong stake in the Swiss new construction market.

[2] Austria, Estonia, Finland, France, Germany, Norway, Sweden, and Switzerland

Figure 2-9: Market Penetration for GSHPs in 8 European Countries, 2006



Source: GroundReach 2007 (Market Status)

Individual European Countries

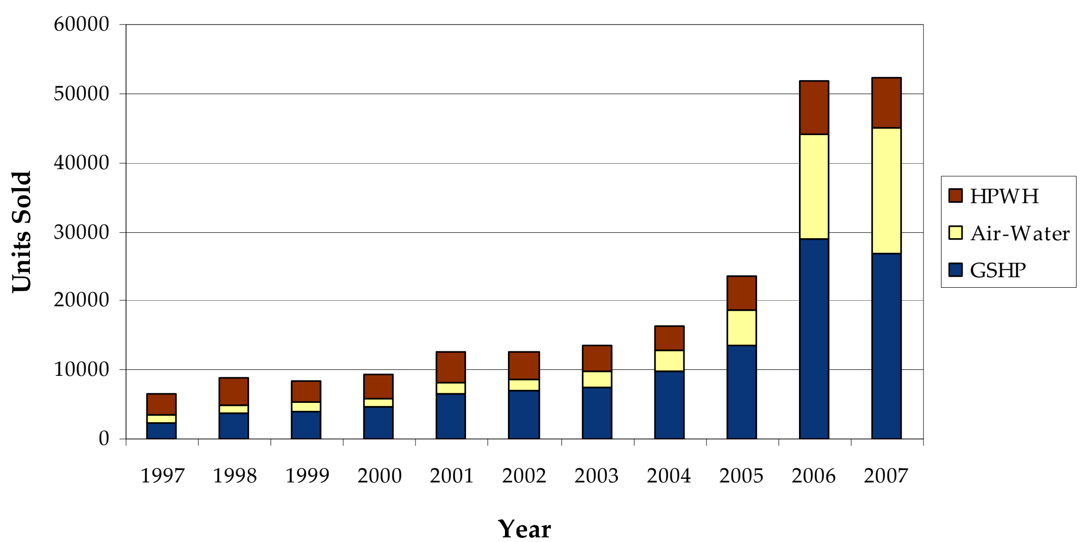
Austria has the fifth highest capacity density per land area worldwide with 23,000 heat pumps installed (Le Feuvre 2008). Approximately 95% of heat pumps used in the Austrian housing market are ground-source (Le Feuvre 2008). As in so many countries during the late 1970's and early 1980's, the heat pump market was plagued by poor performance and reliability once less-experienced companies started entering the explosive market during the oil crisis. The LGW (Leistungsgemeinschaft Wärmepumpe) trade association was formed in 1990 to promote heat pumps and develop education and training programs and has helped the market achieve renewed growth.

The French heat pump market first developed between 1975 and 1985 during the oil crisis. After this initial boom, the market essentially disappeared due to a lack of skilled installers and poor equipment quality. The market was jumpstarted in 1997 by an initiative of Electricite de France (EDF), the national French electricity company, in association with ADEME (French environment and energy management agency) and BRGM (French mining and geological research board). In 2005, public authorities including the French Electricity Board and the French Environment and Energy Management Agency have implemented a substantial subsidy scheme for heat pumps in general which will continue through 2009.

This subsidy has helped grow the retrofit GSHP market from 2% of the total GSHP market before the subsidy to 13% in 2007. In addition, France has set the objective for 2010 to equip 20% of all new single family homes with GSHPs (~40,000 units per year).

Germany has the second largest installed base in Europe. Figure 2-10 shows the growth of annual heat pump sales in Germany since 1997. Electric utilities have been an ally to the industry through promotion of heat pump benefits. Several utilities offer special heat pump tariffs that benefit the consumer (EHPO 2008). In 2008, the German government instituted a new market incentive program to support renewable energy systems, which the German government defines to include GSHPs. The dramatic boom in sales between 2005 and 2006 was caused by a particularly long winter in 2005-2006, further increases in energy prices, and the considerable media attention to climate change.

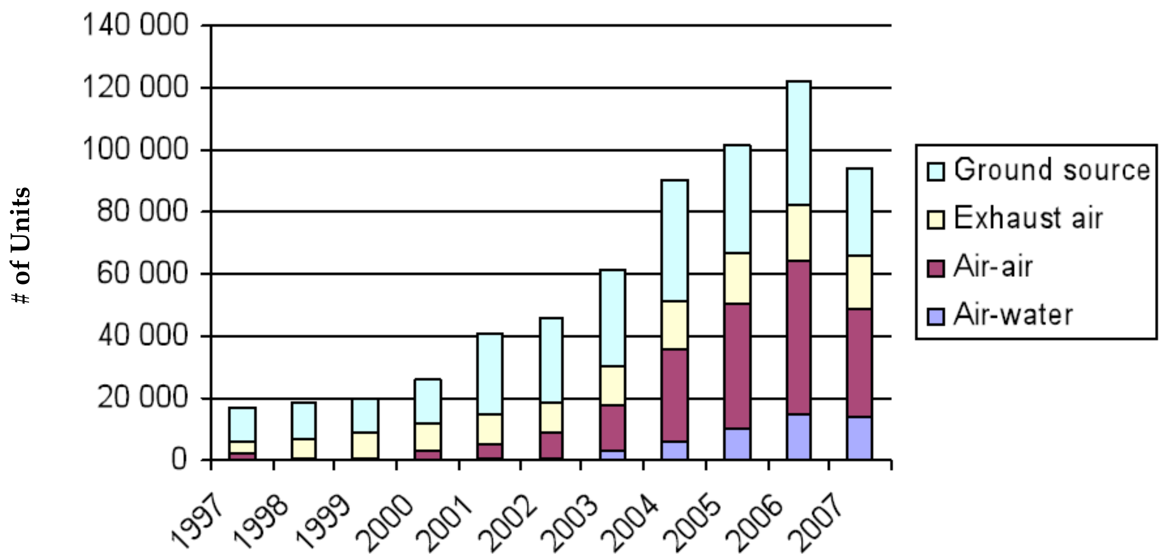
Figure 2-10: German Heat Pump Market Development 1997-2007



Source: European Heat Pump Outlook 2008
Note: Heat pump water heaters (HPWH) are used for water-heating only, as opposed to space-heating. Air-water heat pumps heat a hydronic circuit.

Sweden stands out as the most developed market among all European countries, with the highest capacity per capita worldwide (Le Feuvre 2008). The dramatic growth in the domestic market can be attributed to the escalating price of oil and electricity as well as an increase in energy related taxes. In Sweden, heat pumps are the most common space-heating in both new construction and retrofitting of single family homes, at approximately 34% (EHPO 2008). Unlike other European countries, Sweden has had considerable success at capturing a large portion of the retrofit market. GSHP sales reached a peak in 2006, before dropping by 30% in 2007. Sales are estimated to drop another 20% in 2008 (Figure 2-11), mostly due to the global economic slowdown.

Figure 2-11: Swedish Heat Pump Market Development 1997-2007[3]

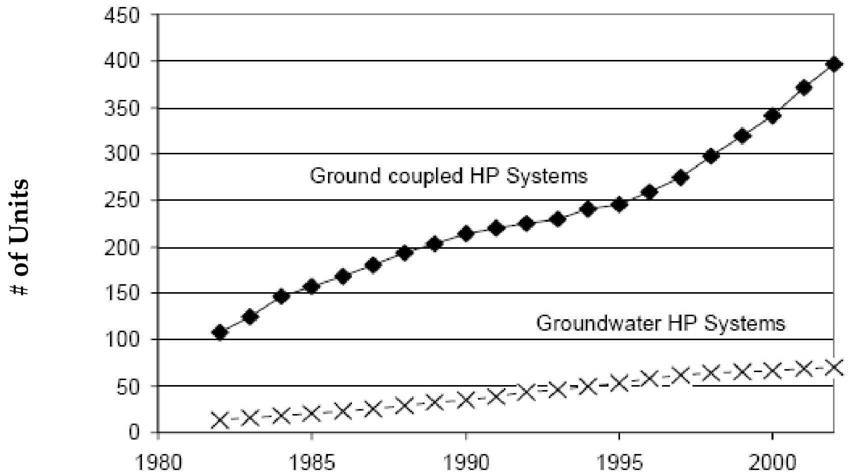


Source: European Heat Pump Outlook 2008

Switzerland, with over 25,000 GSHP systems in operation, is estimated to have the highest installed density in world, with an average of more than one unit per 2 km^2 (Curtis 2005). Figure 2-12 shows the how the installed capacity has grown since 1980. Swiss public utilities have used a system called "energy contracting" to effectively provide an incentive for the adoption of GSHPs, which involves planning, installing, operating, and maintaining GSHP systems at their own cost and selling the heat (or cold) to the property owner at a contracted price in cents per kilowatt-hour (Curtis 2005). In general GSHPs are installed primarily in a decentralized manner to meet individual needs, which avoids the cost of heat distribution associated with district heating.

[3] Exhaust air, air-air, air-water heat pumps, all depicted in Figure 7, fall within the air-source heat pump category. Exhaust air heat pumps are often used for the production of domestic hot water. Air-water heat pumps are typically connected to a hydronic distribution system.

Figure 2-12: Installed Capacity (MWt) of GSHPs in Switzerland (1980 – 2001)



Source: Curtis 2005

Asia

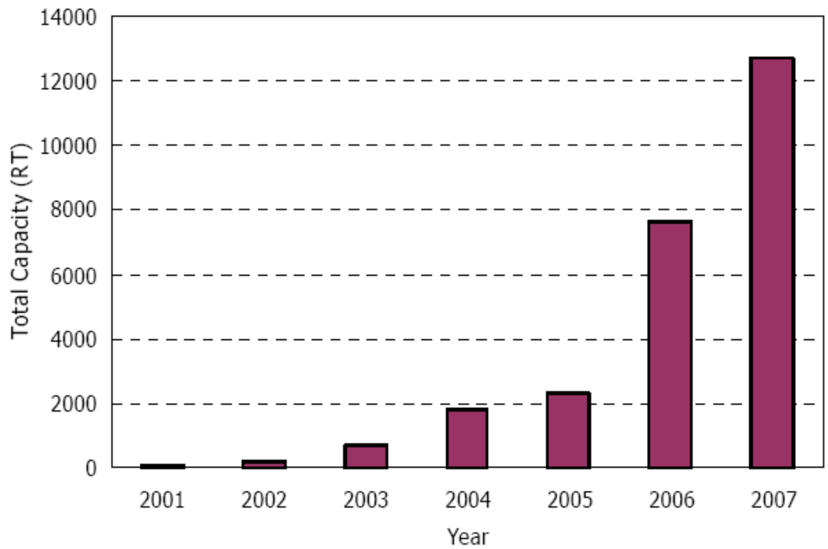
The Asian heat pump market is currently much less established than that of Europe and North America, but there has been some recent growth in China and Japan, as well as active research and development.

China has approximately 630 MWt of installed GSHP capacity. Applications include residences, office buildings, schools, hotels, commercial buildings, hospitals, and banks. In Beijing, China, over 38,000 ft^2 of the Olympic Village was air-conditioned by GSHPs (Zheng, 2008).

The central government maintains a GSHP policy with ambitious expectations in all provinces. For public buildings, such as schools, hospitals, and administrative buildings, the government will cover the initial investment for a GSHP. For other buildings, the government will subsidize the cost by $4/ ft^2 of building floorspace for a surface or groundwater heat pump and $6/ ft^2 for a ground-coupled heat pump. In 2005, the city of Ningbo in the Zhejiang province included a 20% subsidy of installed cost for GSHPs as part of their "Measures to Administrate the Particular Fund to Develop Energy-Saving and Clean Production".

The Korean GSHP market has shown tremendous growth since 2001 (Figure 2-13). This growth has been fueled by legislation passed in 2005 by the Korean government that required new public buildings to incorporate alternative and renewable energy sources.

Figure 2-13: Total capacity of GSHP supply in Korea



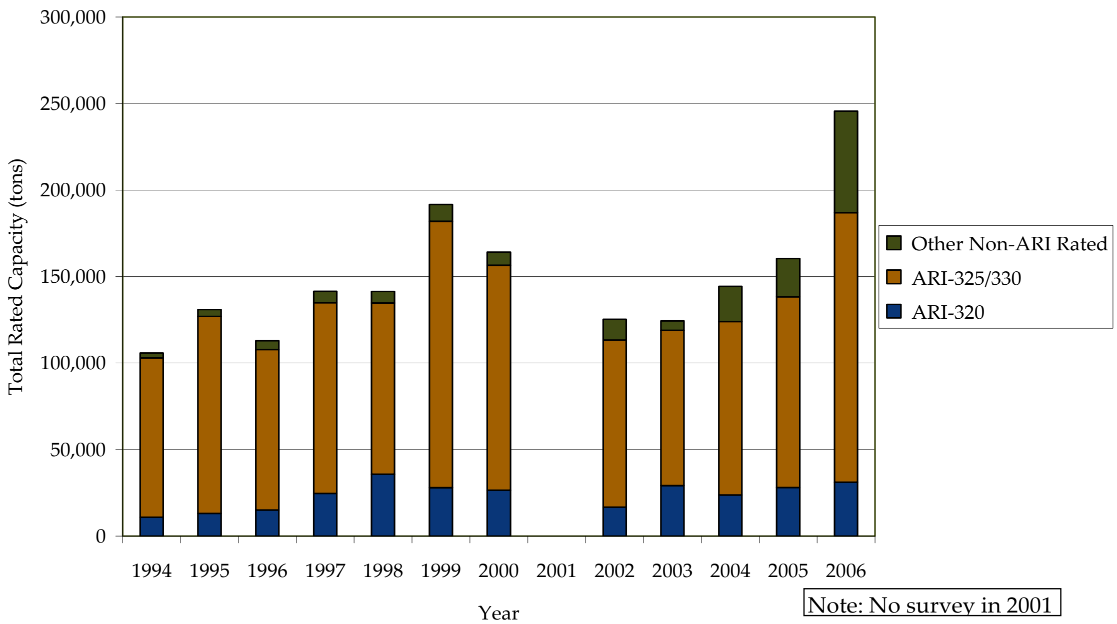
Source: Park, 2008 (IEA HPC 2008, S9,P6)

U.S.

The United States has the largest worldwide GSHP installed base at approximately 1,000,000 units. Annual sales are currently estimated to be approximately 60,000 units per year, representing 245,000 tons of capacity (EIA 2006). The energy consumption of the U.S. GSHP market is estimated to be 25.5 trillion Btu in primary energy, which is five times what it was in 1990.

Figure 2-14 shows the annual shipments in terms of tons of capacity since 1994. In 2006, shipments reached just under 245,000 tons.

Figure 2-14: Capacity of GSHP Shipments by Model Type[4]



Source: EIA Survey of Geothermal Heat Pump Shipments 2006, Table 3.2 (2008).

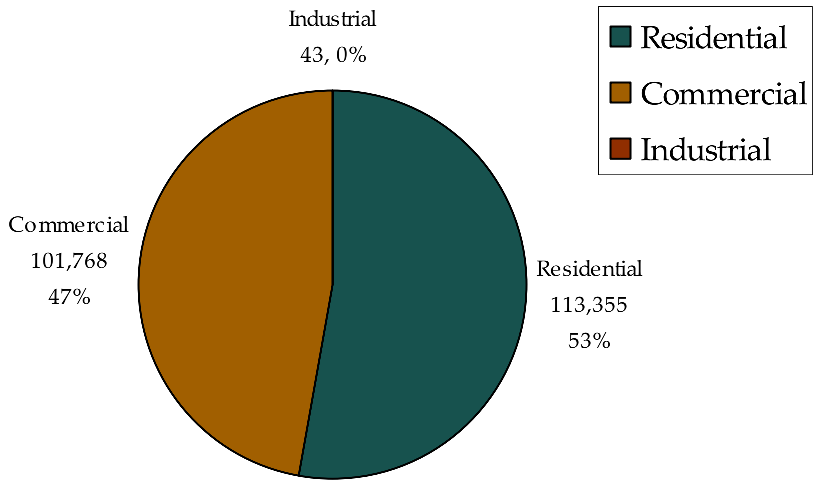
Figure 2-15 through Figure 2-18 give a sense for how the GSHP market is segmented. Just over half of shipments in 2006 were for residential applications, while the remaining shipments were commercial. The retrofit market for schools has seen substantial growth in recent years. Over 600 schools have GSHP systems installed, especially schools located in Texas.

As shown in Figure 2-16, GSHPs have a presence in all census regions although the market has historically been dominated by the Midwestern and southern states. Figure 2-17 shows the segmentation by census region, weighted by the population of each census region. The Midwest and South are home to the major GSHP manufacturers and have more personnel trained in GSHP installation and maintenance than other regions.

GSHP rated efficiencies are shown in Figure 2-18. With a heating COP of about 4.0, and a cooling SEER of up to 19.4 under rating conditions, GSHPs offer a high-efficiency alternative to conventional heating and cooling methods as well as air-source heat pumps. See footnote above for descriptions of the subcategories.

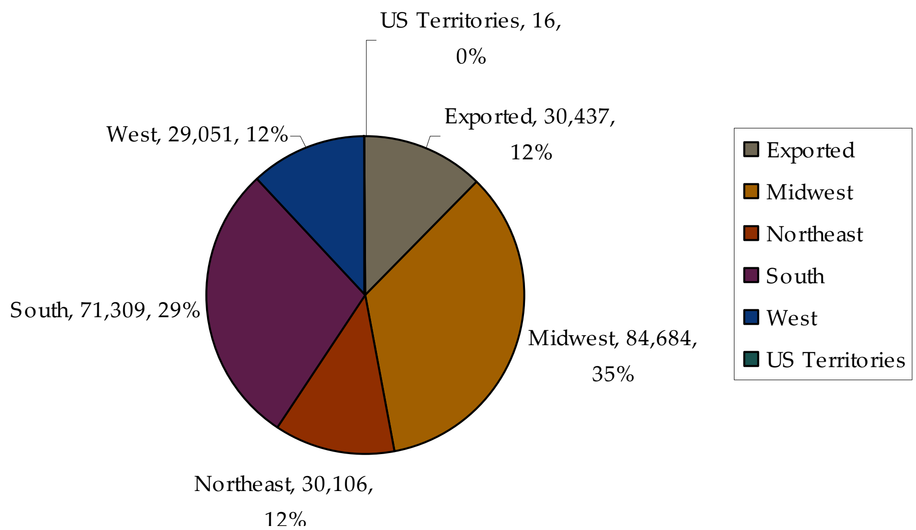
[4] ARI-320 refers to ARI-rated water-source heat pumps, ARI-325 to ARI-rated groundwater-source heat pumps (open loop), and ARI-330 to ARI-rated ground-source heat pumps (closed loop).

Figure 2-15: GSHP Shipments by Sector in tons (2006)



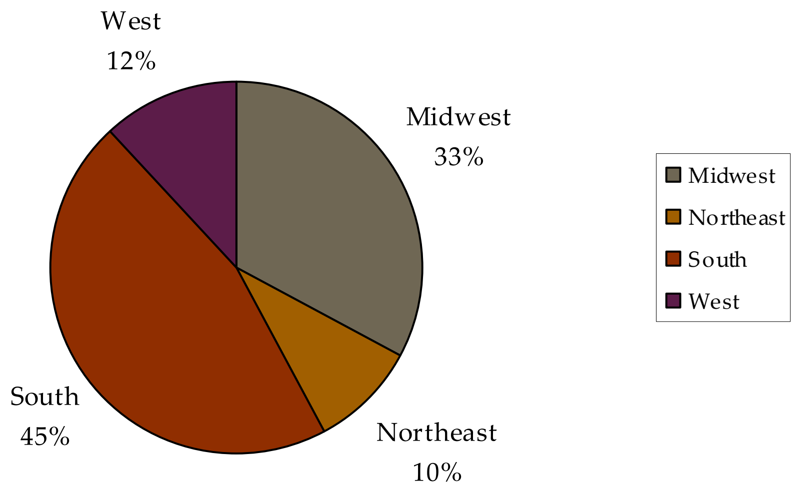
Source: EIA Survey of Geothermal Heat Pump Shipments 2006, Table 3.2 (2008)

Figure 2-16: GSHP Shipments by Census Region in tons (2006)



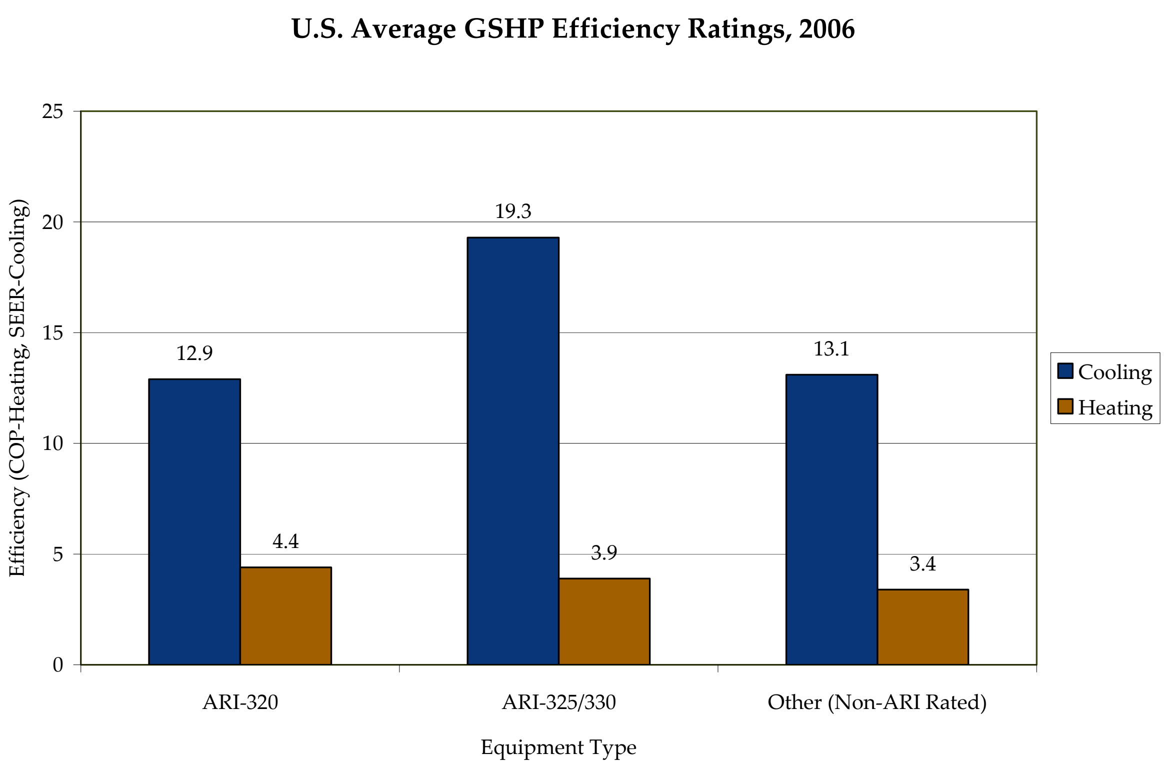
Source: EIA Survey of Geothermal Heat Pump Shipments 2006, Table 3.2 (2008)

Figure 2-17: GSHP Shipments by Census Region in tons (2006) - Weighted by Population



Source: EIA Survey of Geothermal Heat Pump Shipments 2006, Table 3.2 (2008)

Figure 2-18: US Average GSHP Efficiency Ratings (2006)



Source: EIA Survey of Geothermal Heat Pump Shipments 2006, Table 3.2 (2008)

3 National Primary-Energy-Savings Potential for GSHPs

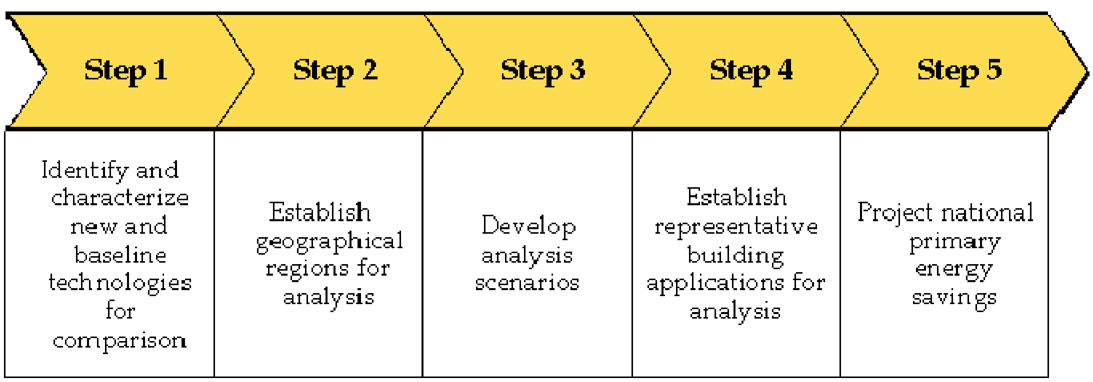
Our approach to projecting the national primary-energy savings[5] of GSHPs is outlined below.

3.1 Approach to Projecting National Energy Savings

Our review of the available literature provided a number of analyses of the economics and energy-savings potential of GSHPs. However, we found no direct comparisons to alternative high-efficiency HVAC technologies, such as advanced ASHPs, nor sufficient documentation to use available analyses for projecting national energy savings. Therefore, we used simplified spreadsheet analyses to project the economics and energy-saving potential of GSHPs. Figure 3-1 outlines our overall approach to projecting the national energy savings for GSHPs and other advanced technologies. We first identified the cost and performance characteristics of the two energy-saving technologies considered (GSHPs and advanced ASHPs), as well as the existing space-conditioning technologies that would be displaced:

- Conventional ASHPs
- Conventional furnaces and air conditioners.

Figure 3-1: Approach to Projecting National Energy Savings



We then established geographical regions for analysis. We do this because energy savings and economics can vary significantly, depending on regional construction practices, climate conditions, and utility rates. We analyze two representative building applications (single-family residential and small commercial/institutional). We then project national energy impacts for each:

- Technology displacement option

[5] Primary energy includes the energy associated with generation (for electricity only), transmission, and distribution to the end user. For electricity, we use the national average efficiency for 2006 (31.5%). For other fuels, we neglect the transmission and distribution losses.

- Scenario
- Representative building application.

The economics and energy savings of GSHPs (or any advanced space-conditioning technology) will vary with geographic region due to variations in:

- Utility rates
- Climate conditions
- Typical construction characteristics
- Financial incentives provided by the state or local utility.

There are other geographic variables that impact the cost and performance of ground coupling (such as soil type, available land, and environmental regulations), but these characteristics can vary significantly within any reasonably sized geographic region, so it is difficult to evaluate their impacts quantitatively.

Figure 3-2 outlines our approach to projecting energy impacts for a given region, scenario, and application. We evaluate potential energy savings two ways:

- *Technical potential:* Primary energy savings that would result if 100 percent of installations of the baseline technology are replaced with the advanced technology. Technical potential places a theoretical upper bound on energy-savings potential.
- *Market potential:* Ultimate primary energy savings that one would expect based on the "fundamental" energy-savings economics. Market potential is always lower than technical potential because the higher first costs and other complexities of the advanced technology will prevent complete displacement of the baseline technology. We assume that the advanced technology has been in the marketplace sufficiently long to have reached its ultimate saturation (typically 10 to 20 years for high-efficiency building equipment—see Section 3.12 below).

Figure 3-2: Approach to Projecting Energy Savings for a given Region, Application and Scenario

Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
Gather regional installation information for baseline technology	Calculate unit energy savings	Project regional technical potential for primary energy savings	Calculate energy costs and fundamental economics	Project market penetration	Project regional primary energy savings

The "fundamental" energy-savings economics are determined assuming that market-entry barriers have been surmounted, but that no financial incentives, such as rebates, tax credits or low-interest loans, are available. Market-entry barriers can include:

- Increased first costs, poor performance, or poor reliability specifically associated with:
  - Low manufacturing volumes
  - Immature product designs
  - Inexperienced/poorly trained installers and service technicians
- Lack of awareness
- Lack of familiarity, leading to perceived risks that can, in turn, inflate costs or discourage potential end users
- Lack of supporting sales, installation, and service infrastructure.

While incentives are often available to install energy-saving technologies, looking at the unsubsidized economics gives a better sense of which advanced technology would leverage incentives most effectively.

We then project market penetrations based on generalized relationships for market penetration as a function of economic attractiveness. We adjust the results to consider the impacts of financial incentives and non-economic factors, as appropriate. Lastly, we multiply projected market penetrations by expected energy savings to project national energy savings.

3.2 Installed-Cost and Performance Estimates

Outlined below are installed-cost and performance estimates for residential and commercial applications. Cost estimates are for retrofit applications, as this is the most common application. However, significant reductions in installation costs are possible in new construction, especially in housing developments or other planned communities.

3.2.1 Residential Applications

Table 3-1 lists rated efficiencies and installed-cost estimates for a range of residential space-conditioning technologies as of 2007. Values in bold are used in this analysis.

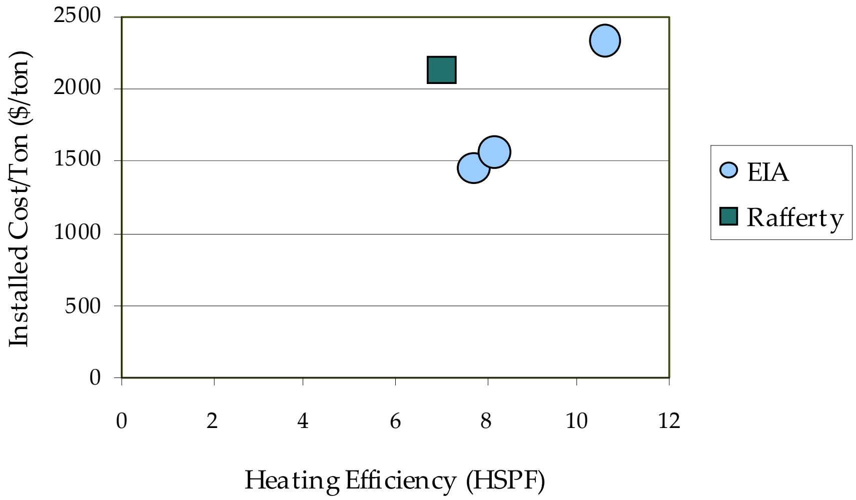
Table 3-1: Competing Residential Space-Conditioning Technologies [EIA 2007]

Technology	Rated Cooling Efficiencies	Rated Heating Efficiencies	Typical Installed Cost[a]
Gas-Fired Furnace	--	**Typical: 80% AFUE; 780 kWh/yr** ENERGY STAR®: 90% AFUE; 500 kWh/yr 2007 Best Available: 96% AFUE; 275 kWh/yr	**$24.00/kBtuh** $32.70/kBtuh $44.00/kBtuh
Oil-Fired Furnace	--	**Typical: 81% AFUE; 850 kWh/yr** ENERGY STAR®: 83% AFUE; 800 kWh/yr 2007 Best Available: 95% AFUE; 650 kWh/yr	**$23.80/kBtuh** $26.20/kBtuh $50.50/kBtuh
Central A/C (Air Source)	**Typical: 13 SEER** ENERGY STAR®: 14 SEER Best Available: 21 SEER	--	**$814/ton** $886/ton $1714/ton
Central Heat Pump (Air Source)	Typical: 13 SEER ENERGY STAR®: 14 SEER Best Available: 17 SEER[b]	**Typical: 7.7 HSPF** ENERGY STAR®: 8.2 HSPF **2007 Best Available: 10.6 HSPF[b]**	**$1450/ton** $1570/ton **$2300/ton**
Ground-Source Heat Pump	Typical: 16 EER ENERGY STAR®: 14.1 EER Best Available: 30 EER	**Typical: 3.4 COP** ENERGY STAR®: 3.3 COP **2007 Best Available: 5.0 COP**	**$3000/ton** $2830/ton **$5250/ton**

a) Based primarily on retrofit installations, as this is the general case. Figures are mid-range values from EIA 2007. Heat-pump costs are per nominal ton of cooling capacity.
b) The "best available" was selected based on highest heating efficiency. Higher cooling efficiencies are available.

Figure 3-3 compares EIA installed-cost estimates for the residential ASHPs to those from one other source [Rafferty 2008]. EIA costs are lower than other estimates. Upon reviewing the alternative source, the EIA estimates appeared most credible. Estimates by Kavanaugh are old [Kavanaugh 1995]. Estimates by Rafferty were adjusted from a 1995 estimate of $4400 for a 3-ton ASHP [Kavanaugh 1995}. It is not clear how Rafferty adjusted the 1995 estimate.

Figure 3-3: Installed-Cost Estimates for Residential ASHPs vs. Heating Efficiency



Kavanaugh and Rafferty also provided estimates for the combined installed cost of a gas furnace and conventional 3-ton air-conditioning system:

- Kavanaugh 1995: $4300 (in $1995)
- Rafferty 2008: $6200.

Comparing these estimates to EIA's (Table 3-1 above), we would estimate and installed cost of about $4200, based on a:

- 75-kBtuh gas furnace (capacity assumed) at $24.00/kBtuh: $1800
- 3-ton air conditioner at $814/ton: $2400
- Total : $4200.

For reasons similar to those outlined above for ASHP costs, we elected not to use the Kavanaugh and Rafferty estimates.

Figure 3-4 compares installed-cost estimates for residential GSHPs (as a function of rated heating efficiency) from various sources. Most estimates are for GSHPs having 3-ton nominal cooling capacities. For reasons similar to those outlined above for ASHP costs, we elected not to use the Kavanaugh and Rafferty estimates. While DOD has a substantial installed-cost database, their average costs seemed suspiciously high given the large contracts let—many were to install hundreds of residential heat pumps [DOD 2007]. We do not know if DOD had special provisions that contributed to the costs.

Figure 3-4: Installed-Cost Estimates for Residential GSHPs vs. Heating Efficiency

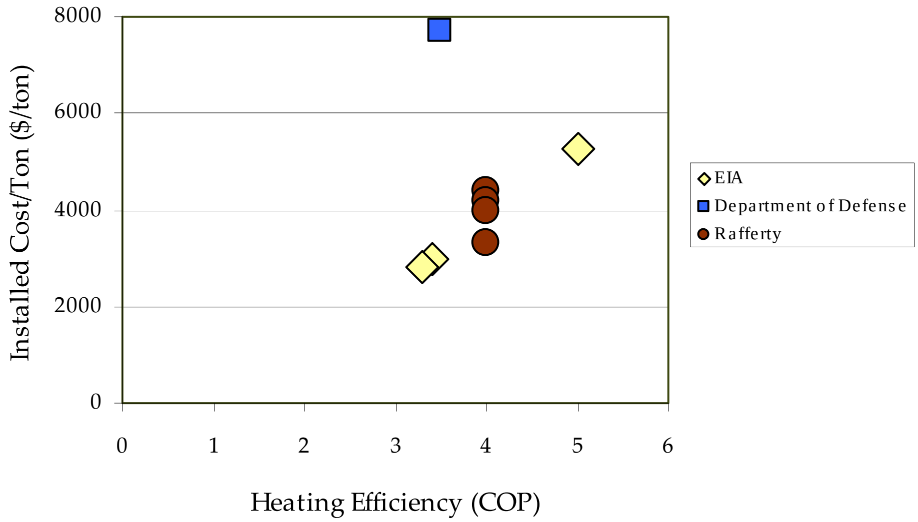
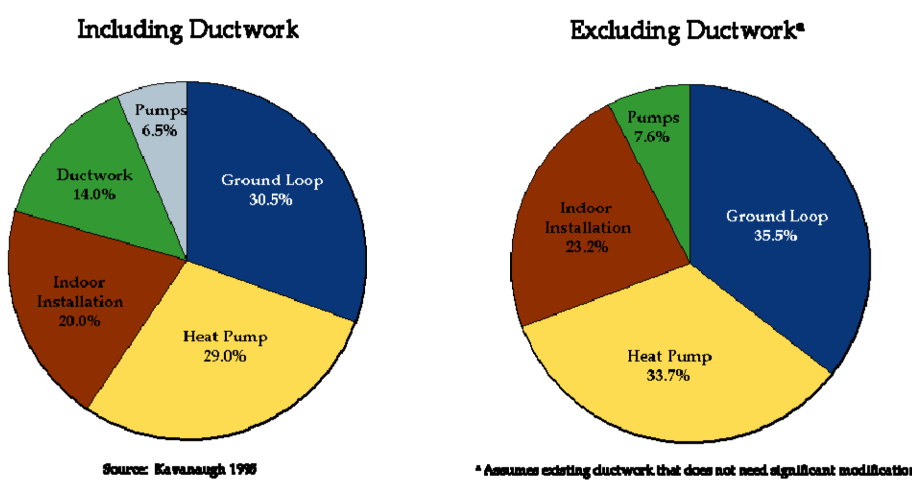


Figure 3-5 shows the approximate breakdown of GSHP cost by major component. The ground loop is the single most expensive component, accounting for about 30 to 35 percent of the installed cost (depending on whether the ductwork is included). Henderson reports that ground loops for four demonstration homes in New York State cost between $1000/ton and $1800/ton[6] [Henderson 1998]. If we assume this is 35.5 percent of the installed cost, then the associated installed costs would range from $2800/ton to $5100/ton, which is not inconsistent with the installed cost we used ($3000/ton for a typical-efficiency GSHP).

Figure 3-5: Approximate GSHP Cost Breakdown by Component



[6] Two homes used direct-exchange ground loops (refrigerant flows through ground loop). Report was written in 1998, so costs are dated. Also, costs for demonstration projects may not reflect typical costs.

In reality, ground-loop costs vary, depending on type used. Estimated installed costs for various types of ground loops are shown in Table 3-2.

Table 3-2: Installed-Cost Estimates for Ground Loops

Type	Ground-Loop Installed Cost			
	Kavanaugh 1995 (1995 dollars)		Rafferty 2008 (2008 dollars)	
	$/ton	Relative Cost	$/ton	Relative Cost
Vertical Loop	$ 2,999	1.11	$4400/ton	1.32
Slinky	$ 2,875	1.06	$4200/ton	1.26
Horizontal Loop	$ 2,712	1.00	$4000/ton	1.20
Open Loop	-----	-----	$3300/ton	1.00

3.2.2 Commercial Applications

Table 3-3 lists rated efficiencies and installed-cost estimates for a range of small-commercial space-conditioning technologies as of 2007. Values in bold are used in this analysis.

Table 3-3: Competing Commercial Space-Conditioning Technologies [EIA 2007]

Technology	Rated Cooling Efficiencies	Rated Heating Efficiencies	Typical Installed Cost[a]
Gas-Fired Furnace	--	Typical: 80% thermal High Efficiency: 82% thermal	$8.1/kBtuh $8.8/kBtuh
Oil-Fired Furnace	--	Typical: 81% thermal	$8.1/kBtuh
Roof-Top Air Conditioner	Typical: 10.1 EER High Efficiency: 12.0 EER	--	$65.6/kBtuh $85.0/kBtuh
Roof-Top Heat Pump	Typical: 10.3 EER High Efficiency: 11.7 EER	Typical: 3.2 COP High Efficiency: 3.4 COP	$73.0/kBtuh $97.0/kBtuh

a) Based primarily on retrofit installations, as this is the general case. Figures are mid-range values from EIA 2007. Heat-pump costs are per nominal ton of cooling capacity.

Figure 3-6 shows installed-cost estimates for commercial ASHPs as a function of rated heating efficiency.

Figure 3-6: Installed-Cost Estimates for Commercial ASHPs

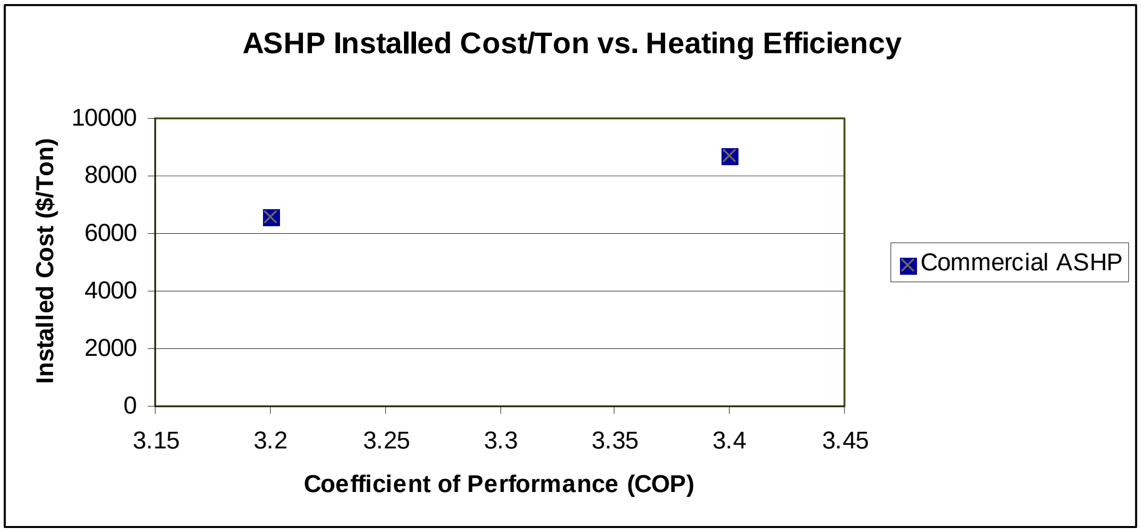
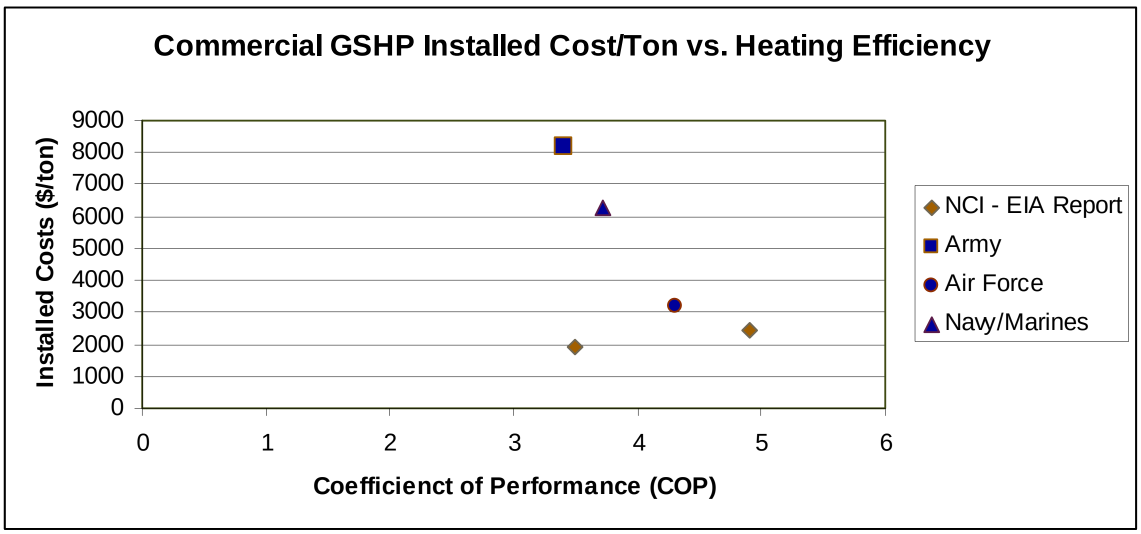


Figure 3-7 compares installed-cost estimates for commercial GSHPs as a function of rated heating efficiency. EIA estimates are similar (per unit capacity) to EIA estimates for residential applications. DOD estimates, however, are substantially higher, which is surprising, given the large scope of most of the DOD projects. Again, we elected to use EIA values.

Figure 3-7: Installed-Cost Estimates for Commercial GSHPs



3.3 Maintenance Costs

Two investigators of commercial/institutional GSHPs report reduced maintenance costs compared to conventional equipment [Martin 2000; Cane 2000]. These investigators, however, did not account for differences in equipment age, and neither suggests that their results can be applied broadly.

For residential applications, ASHPs require periodic cleaning of the outdoor coil to maintain good performance, while GSHPs may require some maintenance to maintain the glycol solution in the ground loop. In either case, we assume that both require one annual maintenance call, and the fixed costs associated with that call are the bulk of the cost.

In the end, we assumed that maintenance costs were roughly the same for all technology options and did not account for them.

3.4 U.S. Regions for Analysis

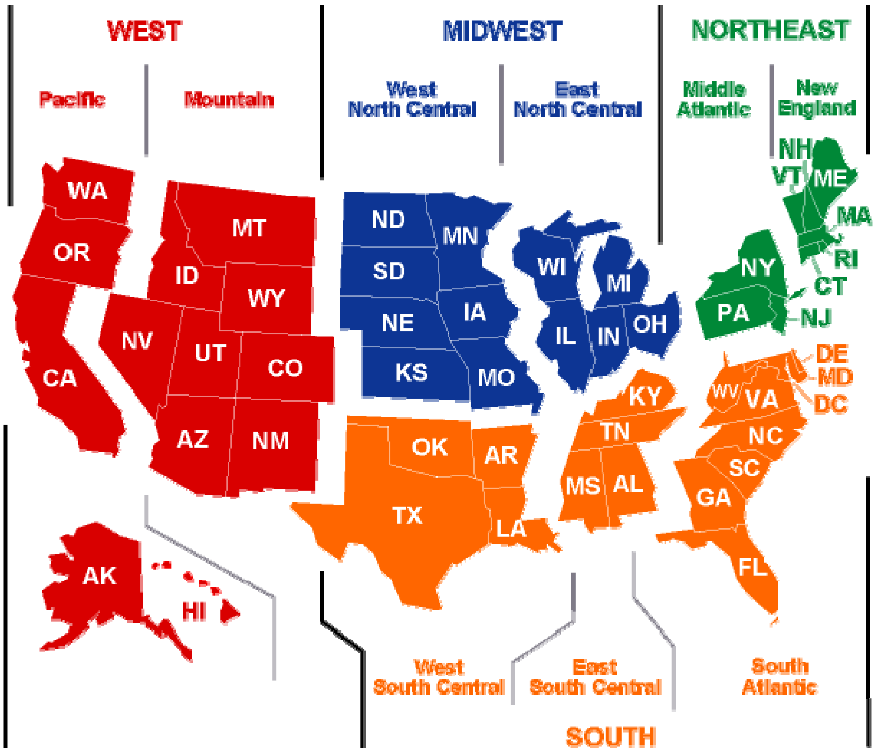
Common ways to divide the U.S. geographically include:

- Climate regions/zones
- U.S. census regions
- States
- Other geopolitical divisions, such as counties or zip codes
- Utility service areas.

We used U.S. major census regions (see Figure 3-8) for our regional analysis because:

- Heat-pump installation and shipment data are available by census region
- Although they don't make ideal climate regions, one can assign approximate climate conditions to census regions
- More detailed modeling is beyond the scope of this analysis.

Figure 3-8: U.S. Census Regions



Source: EIA website

3.5 Scenarios for U.S. Market Projections

We selected three scenarios under which to project the national energy-saving potentials of GSHPs:

- "Carbon Tax plus R&D" Scenario: DOE invests in successful cost-reduction R&D and a carbon tax increases utility rates, including electricity, natural gas, fuel oil, and propane
- 'Successful R&D" Scenario: DOE invests in successful cost-reduction R&D, but no carbon tax is imposed
- "Business as Usual" Scenario: No successful R&D and no carbon tax imposed.

None of the three scenarios includes the impacts of financial incentives such as tax credits or utility rebates, consistent with our objective of investigating the fundamental economics of GSHPs compared to alternatives.

As illustrated in Appendix B, EIA projections for electric rates under three scenarios (high price, low price, and reference) show very little variation in projected rates through 2030 (adjusted to 2006 dollars) [AEO 2008]. EIA projections also vary little within each census region. However, the EIA does not account for the possibility of a carbon tax in their projections, even in their high-price case. Projections of the cost impacts of a carbon tax vary, as shown in Table 3-4. We assume that 2006 electric rates do not vary for the foreseeable future unless a carbon tax is imposed. We assume a carbon tax, if imposed, would increase electricity prices by 30 percent. We use 30 percent for all regions, even though carbon taxes would probably vary significantly by region.

Table 3-4: Projected Impacts on Electricity Price if a Carbon Tax is instituted

Source	Projected Electricity Price Increase by 2020 (%)	
	Real	Adjusted to 2006 Dollars
Lieberman-Warner Climate Security Act of 2008 (Bill) [EIA 2008]	--	5% to 27%
Sanders-Boxer Proposal [Paltsev 2007]	73%	36%[a]
Bingaman-Specter Proposal [Paltsev 2007]	44%	13%[a]
Assumed Scenario for Analysis (see discussion)	--	30%

a) Adjusted based on an expected 27% electricity price increase (real dollars) between 2005 and 2020 [Paltsev 2007].

Likewise, EIA projections show little variation in natural-gas rates over time (when adjusted for inflation). We assume that all inflation-corrected fuel prices remain at 2006 levels, if no carbon tax is implemented. If a carbon tax is implemented, we assume a 30 percent increase in all fuel prices. The impacts of an actual carbon tax would probably vary by fuel, and might vary regionally as well.

When considering potential GSHP cost reductions associated with R&D, we considered only improvements in the ground loop, assuming that improvements in other system components would apply equally well to the baseline technology (ASHPs) and, therefore, not change the overall economics of using GSHPs. As shown in Figure 3-5 above, the ground loop accounts for about 30 to 35 percent of the a typical GSHP installed cost.

Each of the three scenarios is described further below.

Under the “Carbon Tax plus R&D” Scenario, we assumed the following conditions prevail:

- No financial incentives are available for high-efficiency GSHPs or ASHPs

- GSHP R&D results in a 30-percent decrease in the average installed cost of a ground loop (in current dollars), with no performance penalty
- Any improvements in ASHP installed costs are similarly applicable to GSHPs, and vice versa, i.e., no change in installed-cost differentials except for the reduction in ground-loop costs discussed above
- A carbon tax is instituted, raising utility prices by 30 percent (in current dollars).

Under the "Successful R&D" Scenario, we assumed the following conditions prevail:

- No financial incentives are available for high-efficiency GSHPs or ASHPs
- GSHP R&D results in a 30-percent decrease in the average installed cost of a ground loop (in current dollars), with no performance penalty
- Any improvements in ASHP installed costs are similarly applicable to GSHPs, and vice versa, i.e., no change in installed-cost differentials except for the reduction in ground-loop costs discussed above
- No carbon tax is instituted, and utility prices remain steady (in current dollars) per EIA projections.

Under the "Business as Usual" Scenario, we assumed the following conditions prevail:

- No financial incentives are available for high-efficiency GSHPs or ASHPs
- Any improvements in ASHP installed costs are similarly applicable to GSHPs, and vice versa, i.e., no change in installed-cost differentials
- No carbon tax is instituted, and utility prices remain steady (in current dollars) per EIA projections.

3.6 Representative Building Applications

We selected representative building profiles for two applications (one residential and one commercial) for each of the nine census regions. While construction characteristics vary to reflect local codes and architecture, the profiles used are intended to represent comparable applications among the various regions.

3.6.1 Residential Application

We selected a single-family home of about 3000 sq. ft. This is much larger than average, but probably more representative of the typical purchaser of a GSHP than an average-size home would be. Table 3-5 summarizes the characteristics of this home in the five cities for which load data were available [TIAX 2006][7].

[7] The load data are based on load profiles developed by MAISY (Jackson Associates).

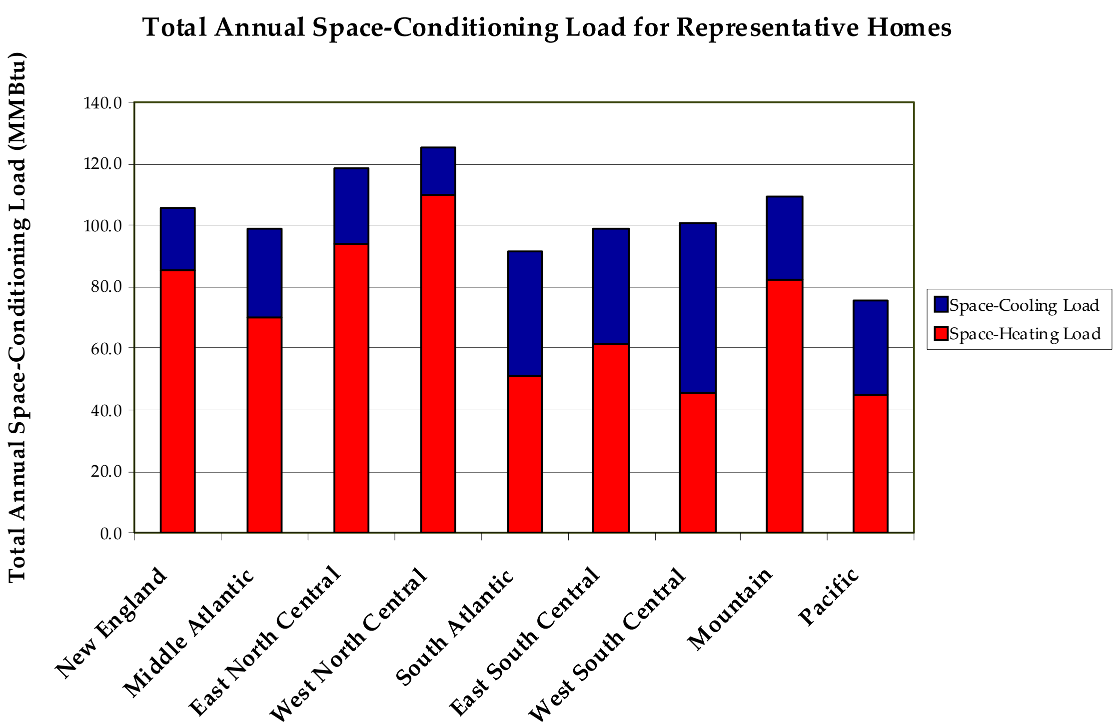
Figure 3-9 shows the annual space-conditioning loads used for the each census region. We either selected a city from our database, or extrapolated load data by rationing heating degree days (or cooling degree days) for a city we judged to represent better the climate in that census region.

Table 3-5: Characteristics of Representative Single-Family Home [TIAX 2006]

Item	Description
Construction	• Suburban, Single Family • 1 – 2 Stories • Post-2000 Construction • 2800 to 3320 sq. ft. Conditioned Space • Crawl Space
Occupancy	• 2 – 4 Occupants, depending on location
Locations	• Minneapolis; Washington, DC; New York City; Sacramento; Chicago[a]

a) For cities not included in original load data, we ratioed heating degree days to estimate heating loads, and cooling degree days to estimate cooling loads.

Figure 3-9: Annual Heating & Cooling Loads for Representative Single-Family Home (3000 ft²)



3.6.2 Commercial Application

We selected a small office building of about 6500 sq. ft. for our analysis. This is a smaller commercial building than average, but will be representative of a large subset of commercial buildings. The size of building will vary slightly due to differences in northern construction methods versus southern construction methods.

Table 3-6 summarizes the characteristics of this representative small office building in the five cities for which load data were available [Huang 1999][8]. Figure 3-10 shows the annual space-heating and space-cooling loads for this building.

We selected cities in our database that represented the climate of the separate census regions. The five cities for which we have heating and cooling loads are Minneapolis, Chicago, Washington D.C., Los Angeles, and Houston. These matched to an appropriate census region based on climate.

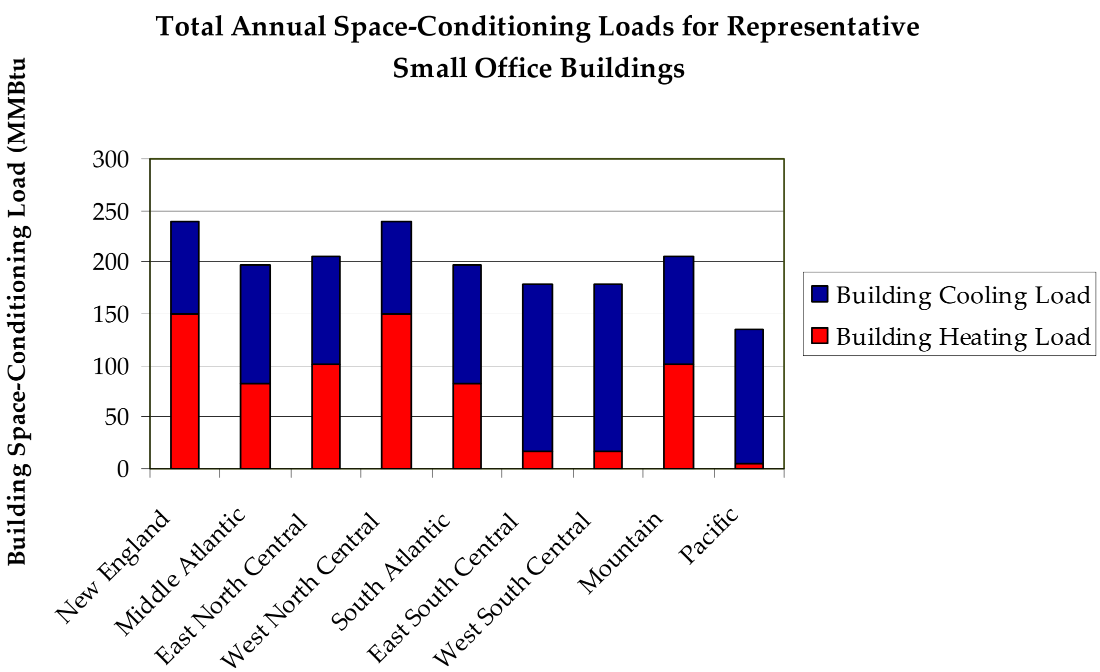
Table 3-6: Characteristics of Representative Commercial Building [Huang 1999]

Item	Description
Construction	• Small Office • 1 – 2 Stories • Post-2000 Construction • ~6500 sq. ft. Conditioned Space
Occupancy	• 470 Occupants
Locations	• Minneapolis; Washington, DC; Chicago; Houston; Los Angeles[a]

a) For cities not included in original load data, we ratioed heating degree days to estimate heating loads, and cooling degree days to estimate cooling loads.

[8] The load data are based on load profiles developed by Lawrence Berkeley National Lab (Huang 1999).

Figure 3-10: Annual Heating and Cooling Loads for Representative Small Offices (~6000 sq. ft.)



3.7 Baseline Technology Energy Consumption

Energy consumptions for the baseline technologies are estimated below. "Baseline technology" is the technology against which we wish to compare performance. Since new equipment generally has higher efficiencies compared to the installed base (because of appliance and equipment energy-conservation standards, or simply because of advances in product design), some energy savings will accrue simply through normal replacement cycles, without additional DOE action. So that we don't double count this portion of the energy savings associated with high-efficiency technology options, we calculate energy savings relative to typical new equipment, not the existing stock.

3.7.1 Baseline Technology Energy Consumption—Residential

We compare GSHPs and advanced ASHPs to two baseline residential technologies described in Section 3.2 above:

- Typical (conventional) ASHP
- Typical furnace and central air conditioner.

We consider three fuel types for the furnace—natural gas, fuel oil, and propane, although not intermediate results are shown for fuel oil and propane. We include parasitic electric consumption associated with furnaces.

3.7.2 *Baseline Technology Energy Consumption—Commercial*

We compare GSHPs and advanced ASHPs to one baseline commercial technology described in Section 3.2 above—a typical (conventional) ASHP.

3.8 *Unit Energy Savings*

We projected unit energy savings for both the commercial and residential representative applications. We consider both space-cooling and space-heating benefits of GSHPs, but we did not consider the option for domestic (service) water heating using the heat pump. We did not include domestic water heating because it is also an option for ASHPs and air-source air conditioners, although the later provides the benefit only during the cooling season. In any case, the energy savings associated with GSHP water heating are small compared to the space-heating savings in all but southern climates [Rafferty 2008].

3.8.1 *Residential Unit Energy Savings*

Figure 3-11 and Figure 3-12 compare the primary unit energy consumptions (UECs) for the various technology options in the New England and Middle Atlantic regions. Similar charts for the other census regions are included in Appendix B.

Figure 3-11: Primary Unit Energy Consumption Comparison—New England Residential

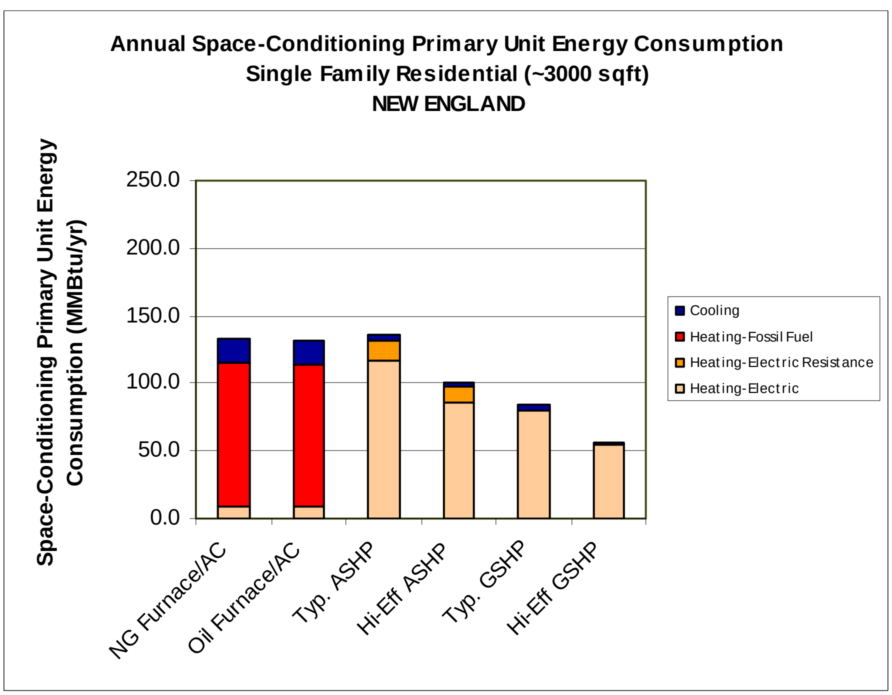


Figure 3-12: Primary Unit Energy Consumption Comparison—Middle Atlantic Residential

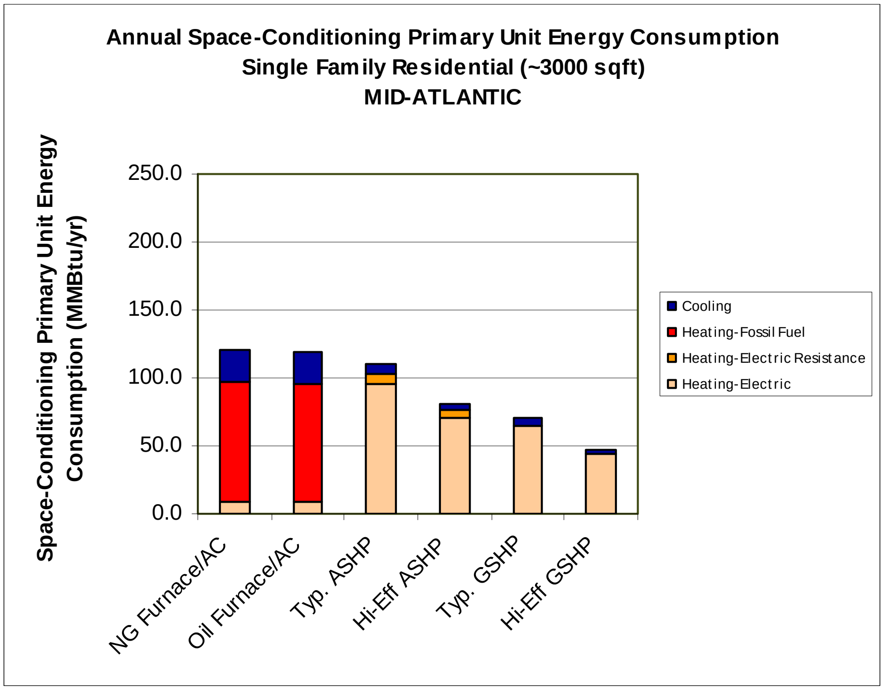


Figure 3-13 and Figure 3-14 show the resulting unit energy savings (UES) for New England and the Middle Atlantic, respectively, for the typical ASHP baseline. Appendix B includes the charts for other regions. Figure 3-15 and Figure 3-16 show the resulting unit energy savings (UES) for New England and the Middle Atlantic, respectively, for the gas furnace/AC baseline. Appendix C contains the charts for other census regions.

Figure 3-13: Primary Unit Energy Savings Comparison—ASHP Baseline—New England Residential

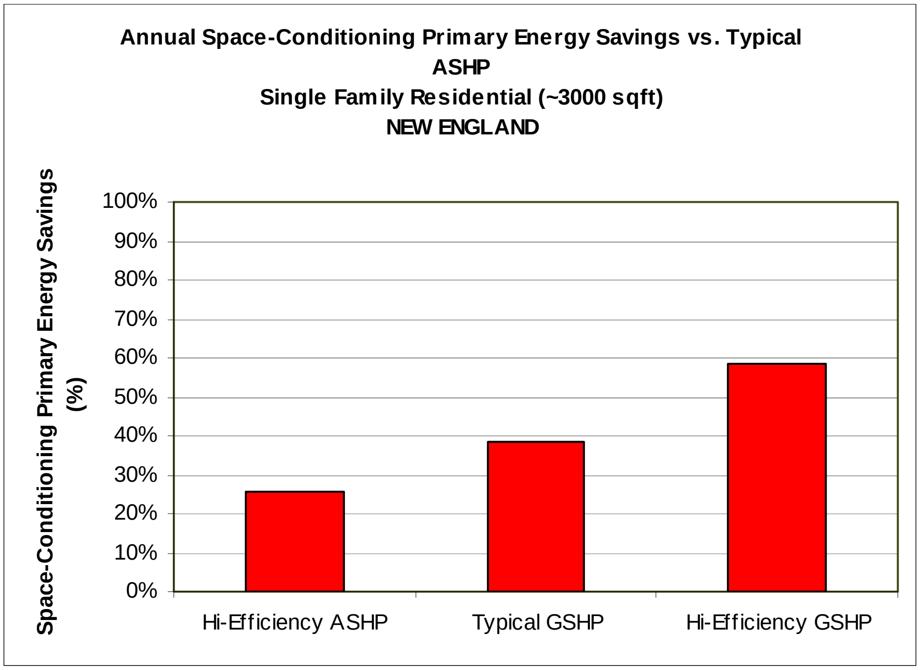


Figure 3-14: Primary Unit Energy Savings Comparison—ASHP Baseline—Middle Atlantic Residential

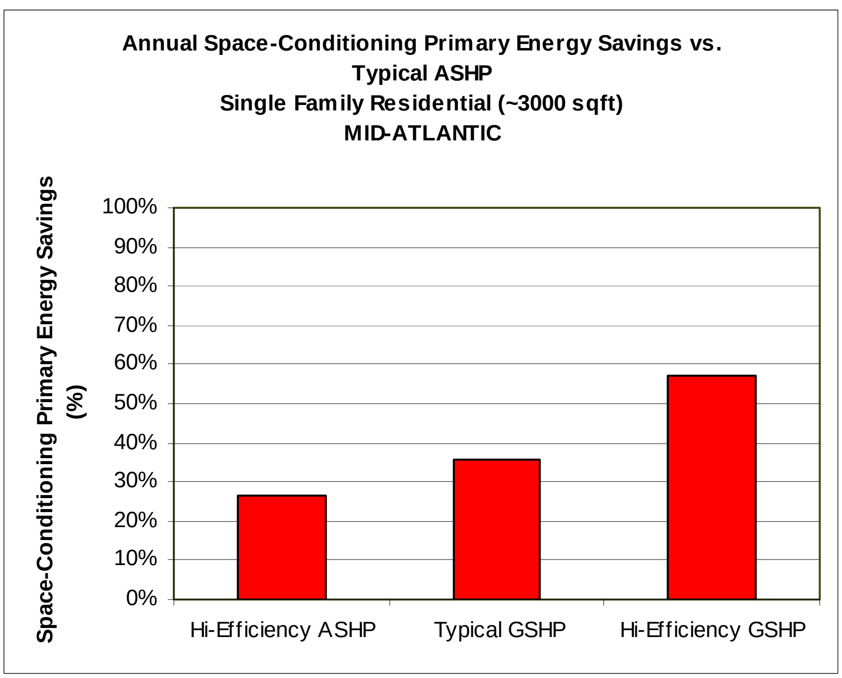


Figure 3-15: Primary Unit Energy Savings Comparison—Furnace/AC Baseline—New England Residential

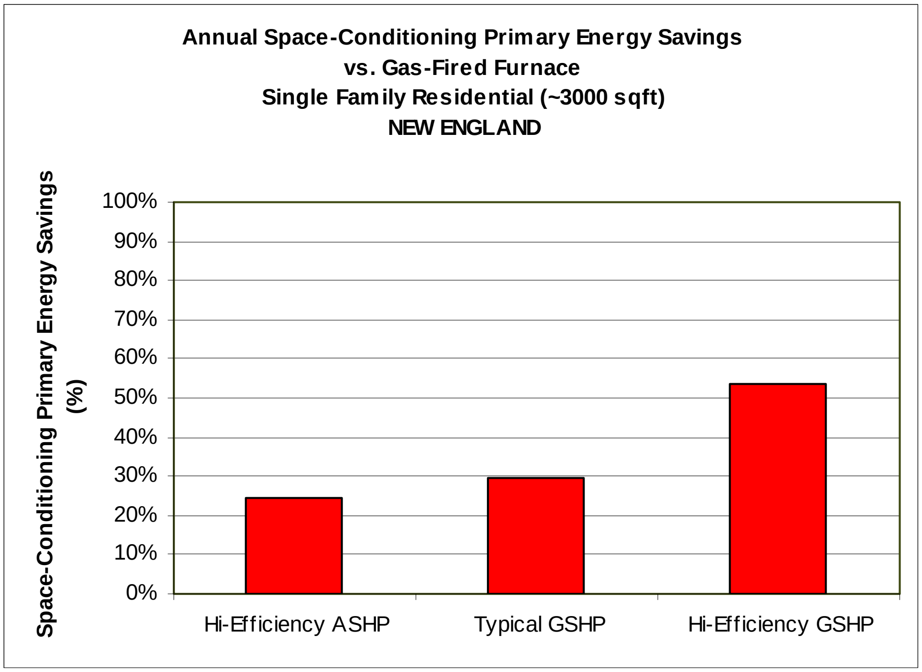
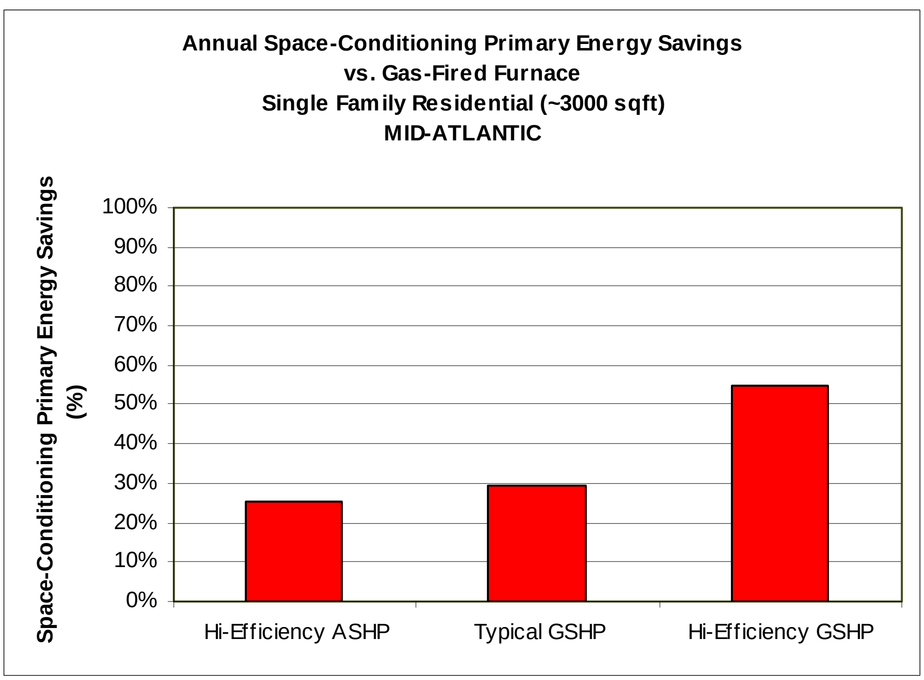


Figure 3-16: Primary Unit Energy Savings Comparison—Furnace/AC Baseline—Middle Atlantic Residential



Compared to typical-efficiency ASHPs, ranges of primary unit energy savings are (as a percent of space-conditioning energy consumption):

- Advanced ASHPs: 20 to 30 percent
- Typical-Efficiency GSHPs: 25 to 50 percent
- High-Efficiency GSHPs: 50 to 70 percent

Compared to typical-efficiency furnaces (natural gas, propane or fuel oil) and air conditioners, ranges of primary unit energy savings are (as a percent of space-conditioning energy consumption):

- Advanced ASHPs: 20 to 30 percent
- Typical-Efficiency GSHPs: 25 to 30 percent
- High-Efficiency GSHPs: 50 to 60 percent.

These ranges are slightly narrower than reported above for the typical-efficiency-ASHP baseline because there is less regional variation in heating-season performance compared to ASHPs.

3.8.2 Commercial Unit Energy Savings

Figure 3-17 and Figure 3-18 compare the primary unit energy consumptions (UECs) for the various technology options in the New England and Middle Atlantic regions. Similar charts for the other census regions are included in Appendix D.

Figure 3-17: Primary Unit Energy Consumption Comparison—New England Commercial

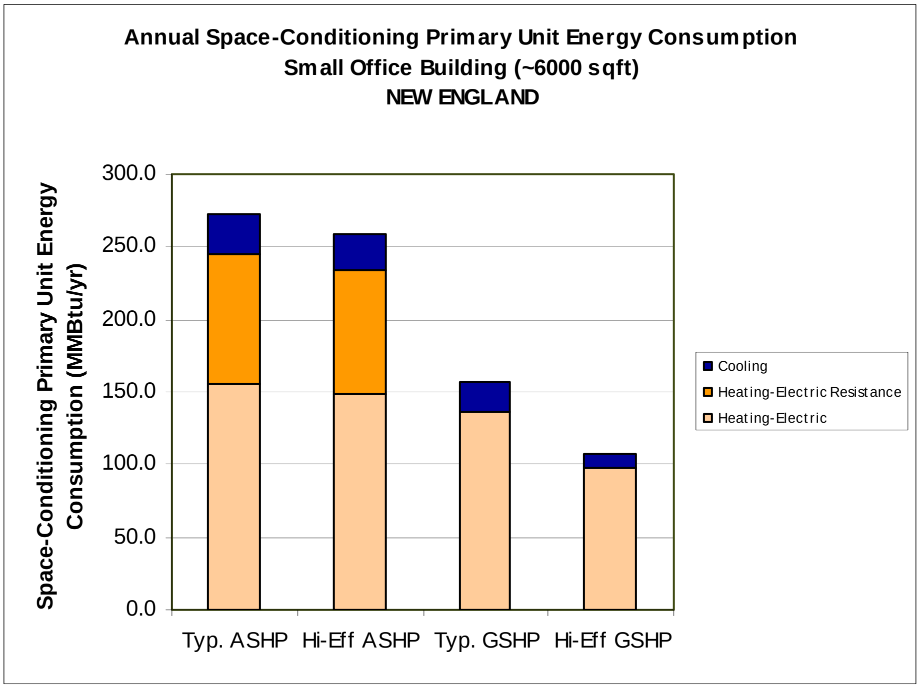


Figure 3-18: Primary Unit Energy Consumption Comparison—Middle Atlantic Commercial

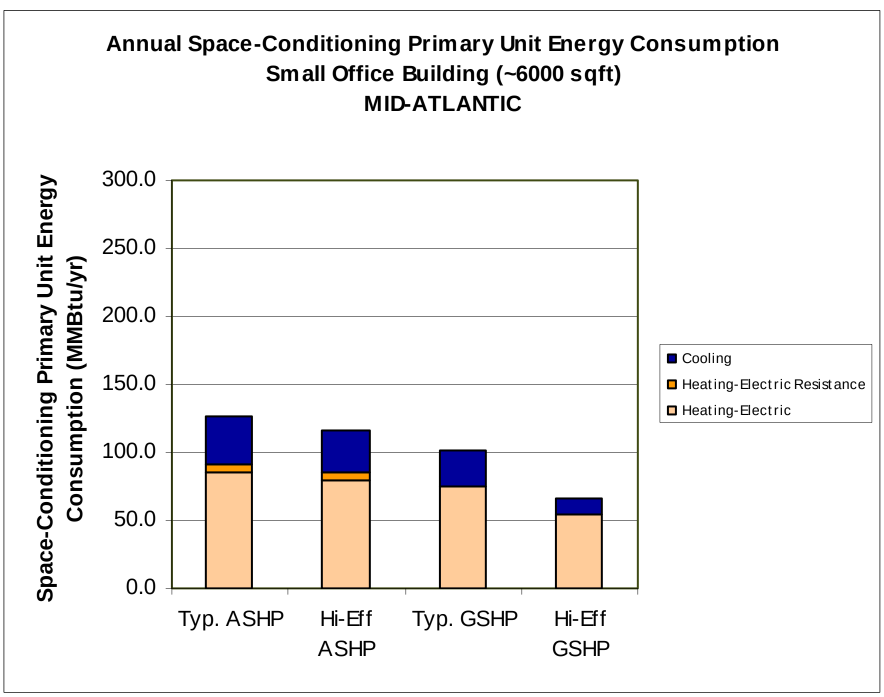


Figure 3-19 and Figure 3-20 show the resulting unit energy savings (UES) for New England and the Middle Atlantic, respectively, for the typical ASHP baseline. Appendix E contains the charts for other census regions.

Figure 3-19: Primary Unit Energy Savings Comparison—ASHP Baseline—New England Commercial

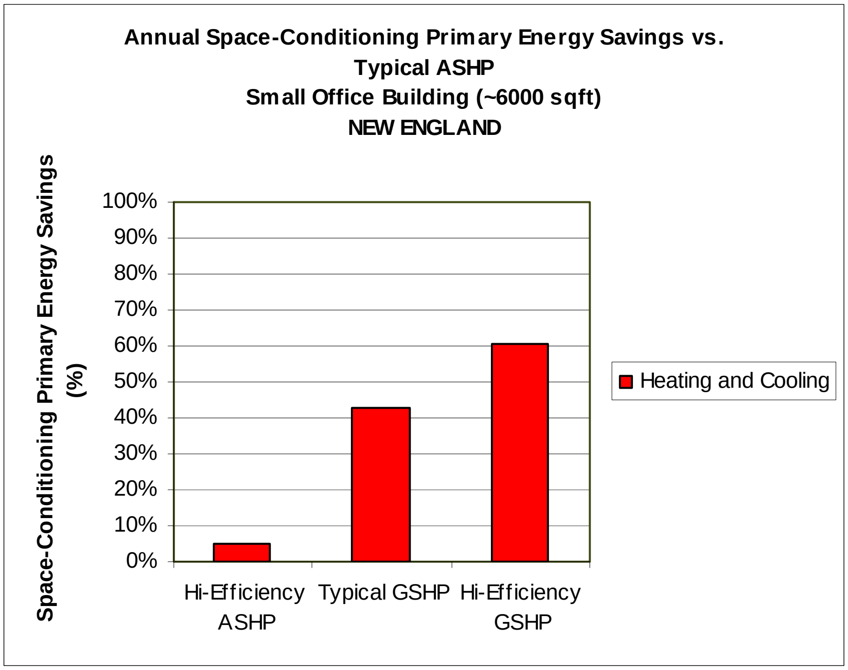
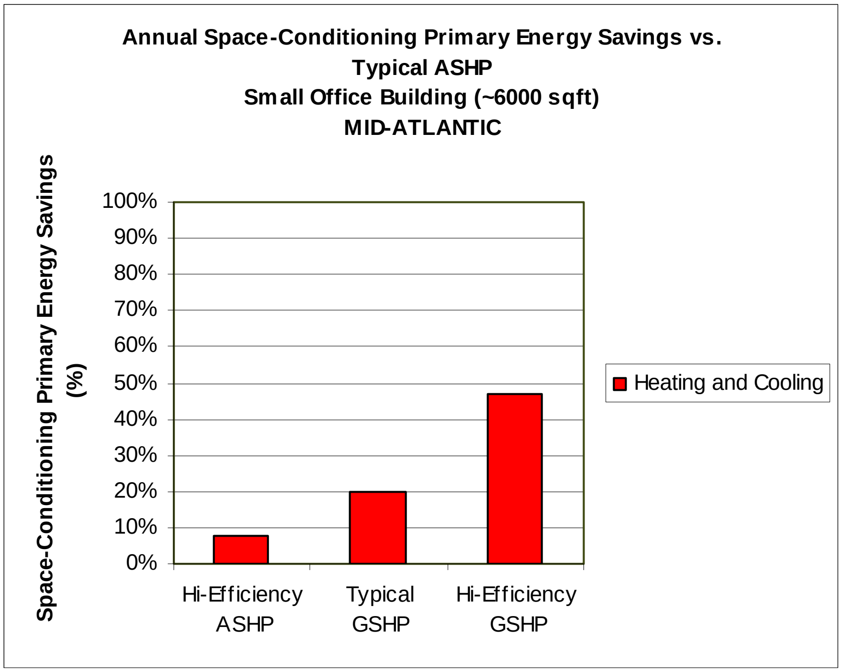


Figure 3-20: Primary Unit Energy Savings Comparison—ASHP Baseline—Middle Atlantic Commercial



Compared to typical-efficiency ASHPs, ranges of primary unit energy savings are (as a percent of space-conditioning energy consumption):

- Advanced ASHPs: 5 to 10 percent
- Typical-Efficiency GSHPs: 20 to 45 percent
- High-Efficiency GSHPs: 45 to 60 percent

In the commercial example, the "advanced" ASHP is only marginally more efficient compared to the typical ASHP, so its energy savings are less than for the residential example above. Ranges of savings for the two GSHPs are also slightly lower compared to the residential example above.

3.9 Technical Potential Primary Energy Savings

"Technical potential" refers to the theoretical primary energy savings associated with replacing 100 percent of the technically applicable baseline installations with the advanced technology. While this potential will never be achieved, it does suggest an upper limit, should the advanced technology be universally adopted. We calculate the technical potential as if all existing equipment has the efficiency of new equipment. This way, we don't double count the energy savings that will occur anyway, without further DOE action, based on normal replacement cycles.

To calculate technical potential for GSHPs rigorously, one would adjust for the number of installation sites that are not technically feasible for ground loops, such as sites having:

- Insufficient outdoor space (urban areas or densely built suburban areas)
- Unsuitable soil conditions
- Restrictive environmental regulations or ownership constraints on drilling or excavating, ground-water use, or use of glycol solutions underground.

We did not adjust technical potential for these factors, as they are difficult to quantify. Therefore, our technical potential estimates may be optimistic.

3.9.1 Residential Technical Potential.

Figure 3-21 shows the estimated technical potential primary energy savings for various advanced technologies for the typical ASHP baseline. Figure 3-22 shows the technical potential primary energy savings compared to the typical furnace and air-conditioner baseline for three furnace-fuel types. Technical potential varies by census region primarily due to differences in baseline equipment installed base, but also due to regional differences in climate and seasonal heating and cooling efficiencies. Assuming typical-efficiency GSHPs are installed, total technical potentials are about:

- Typical ASHP Baseline: 0.5 Quad
- Typical Natural-Gas Furnace and Air-Conditioner Baseline: 2.1 Quad
- Typical Fuel-Oil Furnace and Air-Conditioner Baseline: 0.3 Quad
- Typical Propane Furnace and Air-Conditioner Baseline: 0.2 Quad
- Total Technical Potential Primary Energy Savings: 3.1 Quad.

Figure 3-21: Technical Potential for Typical ASHP Baseline--Residential

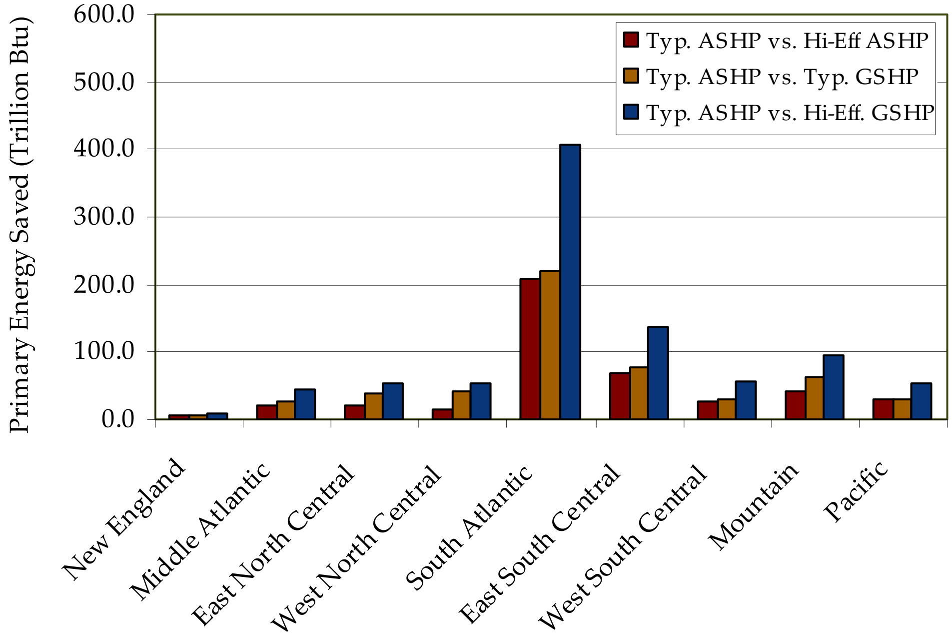
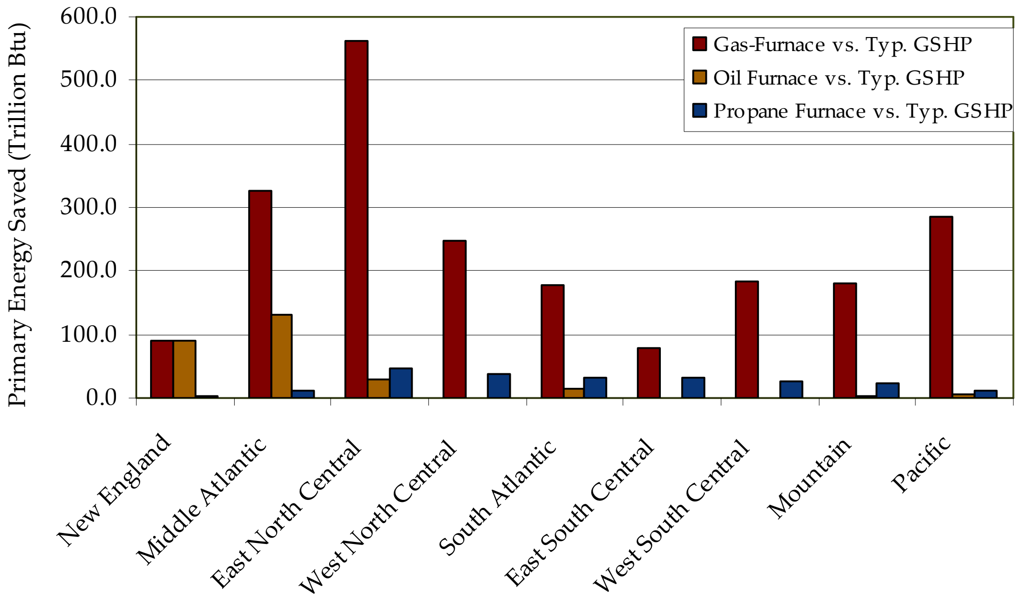


Figure 3-22: Technical Potential for Typical Furnace/AC Baseline--Residential



3.9.2 Commercial Technical Potential

We roughly estimated commercial technical potential using the following assumptions:

- Buildings under about 100,000 sq. ft. tend to use unitary packaged space-conditioning equipment and make up the primary target market for commercial GSHPs
- Roughly half the commercial space-conditioning energy consumption is associated with packaged unitary equipment.

The 2008 Buildings Energy Data Book reports that 2006 commercial space-conditioning primary energy consumption was (not including ventilation equipment):

- Space Heating: 2.17 Quad (1.18 Quad is natural gas)
- Space Cooling: 2.27 Quad (almost all electricity)
- Total: 4.44 Quad.

Based on the assumptions above, about half of this was consumed by the target market, or roughly 2 Quad. As noted above, typical GSHPs energy savings are between 20 and 45 percent, depending on climate. If we use 30 percent as a mid-range savings, commercial GSHPs could save about 0.6 Quad if applied in all unitary space-conditioning applications.

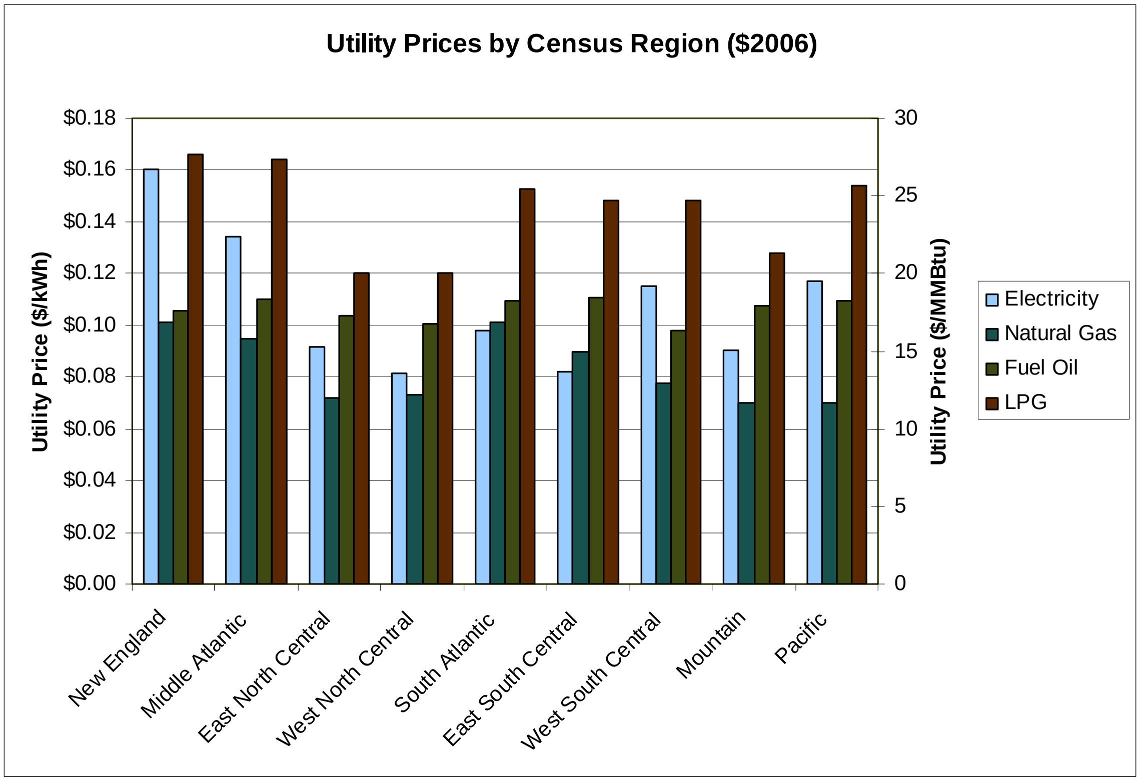
3.9.3 School Technical Potential

Public schools (K-12), a subset of commercial buildings, are a noteworthy early market for GSHPs, because they often have ample space for the ground coil and often can justify longer payback periods compared to buildings in the private sector. Schools can potentially achieve 25-50% in space-conditioning energy savings using GSHPs. We estimate the technical potential energy savings associated with schools (included in the 0.6 Quad estimate in Section 3.9.2 above) to be 0.03 Quad nationally, due to the fact that schools represent only about 2.5% of commercial floor space (DOE 2008).

3.10 Energy Prices

Figure 3-23 shows the residential utility prices used in this analysis. Prices are 2006 averages for each census region. As discussed in Section 3.6 above, we assumed that utility prices (corrected for inflation) do not change during the time period of our market projections unless a carbon tax is imposed.

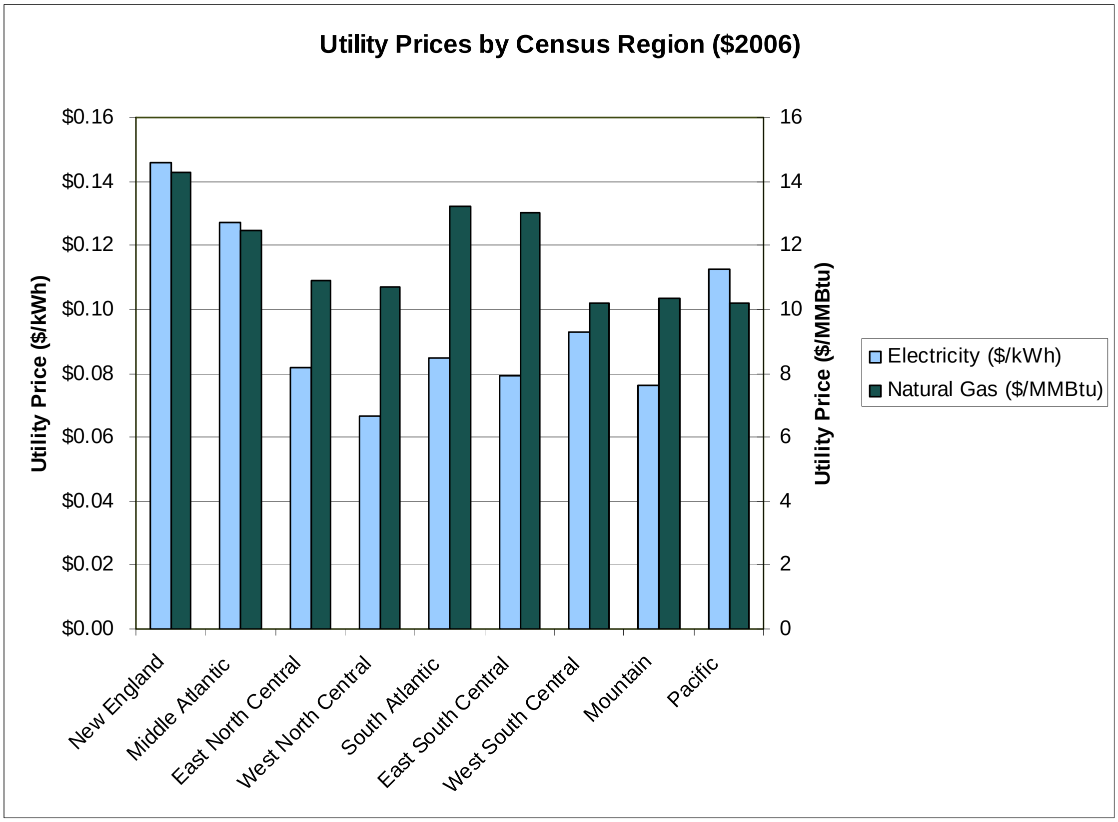
Figure 3-23: Residential Utility Rates used in Analysis



Source: Annual Energy Outlook 2008

Figure 3-24 shows the commercial utility prices used in this analysis. Prices are 2006 averages for each census region. As discussed in Section 3.6 above, we assumed that utility prices (corrected for inflation) do not change during the time period of our market projections unless a carbon tax is imposed.

Figure 3-24: Commercial Utility Rates used in Analysis



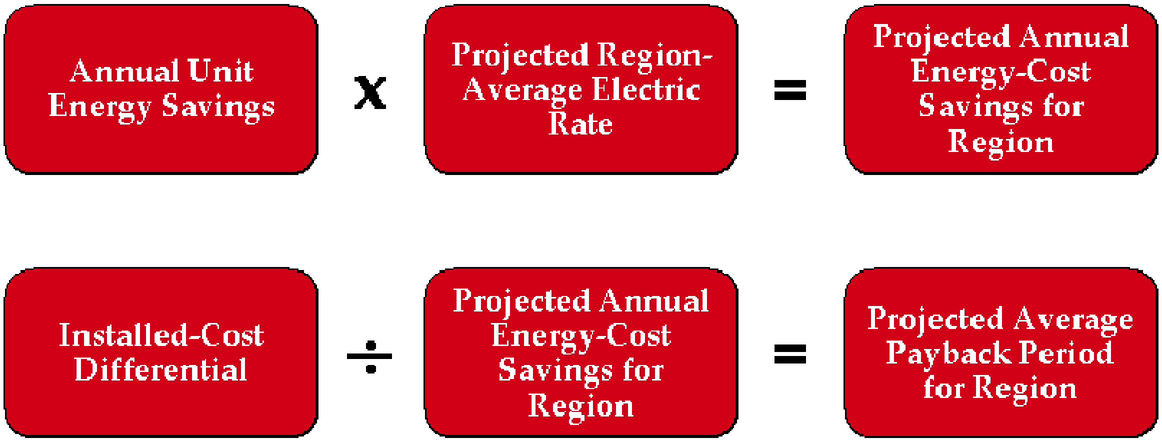
Source: Annual Energy Outlook 2008

3.11 Economic Analysis

We use simple payback period to represent the economic attractiveness of GSHPs and advanced ASHPs compared to alternative technologies. First, we estimate the allowable installed-cost differentials for selected payback periods. We then compare allowable installed-cost differentials to estimated differentials from above.

Projecting economics requires a regional approach. Figure 3-25 illustrates how we projected the economics (simple payback period) of GSHPs for each of the nine census regions in the nation. Annual energy costs used to calculate payback are shown in Appendices G and H for residential and commercial applications, respectively.

Figure 3-25: Methodology for Projecting GSHP Economics for each Region



3.11.1 Residential Fundamental Economics—Electric Baseline Technology

Figure 3-26 to Figure 3-28 show calculated simple payback periods for GSHPs and advanced ASHPs compared to typical-efficiency ASHPs.

Figure 3-26: Simple Payback Periods for Representative Single-Family Home (~3000 sq. ft.)—Advanced ASHP vs. Typical-Efficiency ASHP Baseline

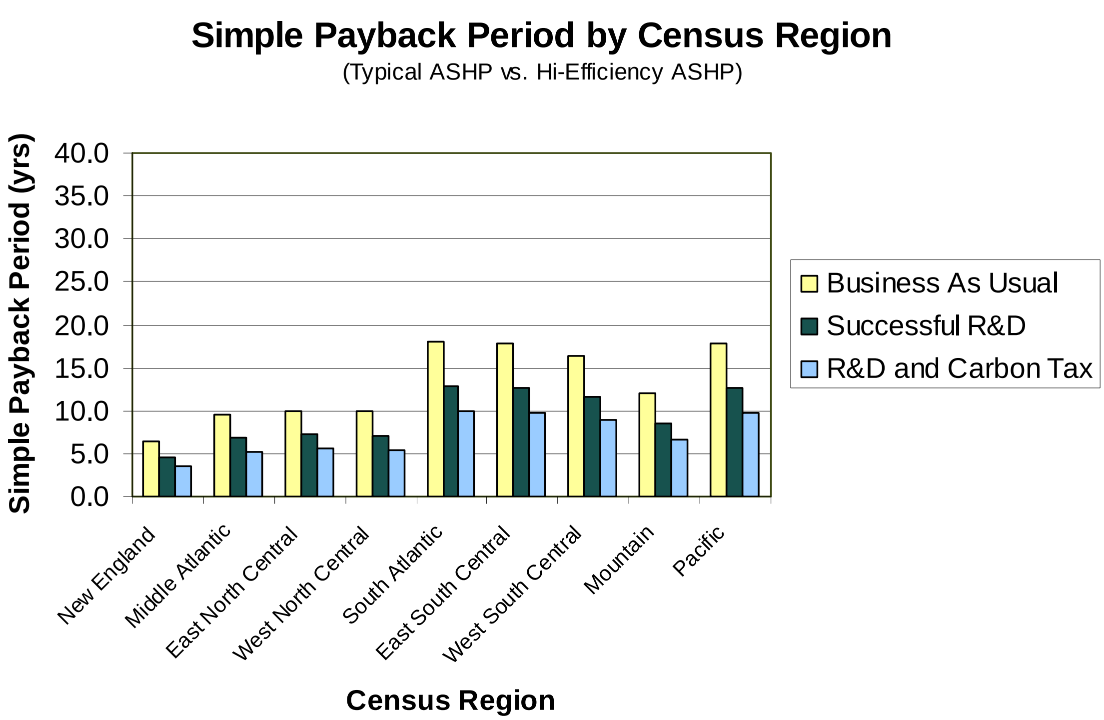


Figure 3-27: Simple Payback Periods for Representative Single-Family Home (~3000 sq. ft.)—Typical-Efficiency GSHP vs. Typical-Efficiency ASHP Baseline

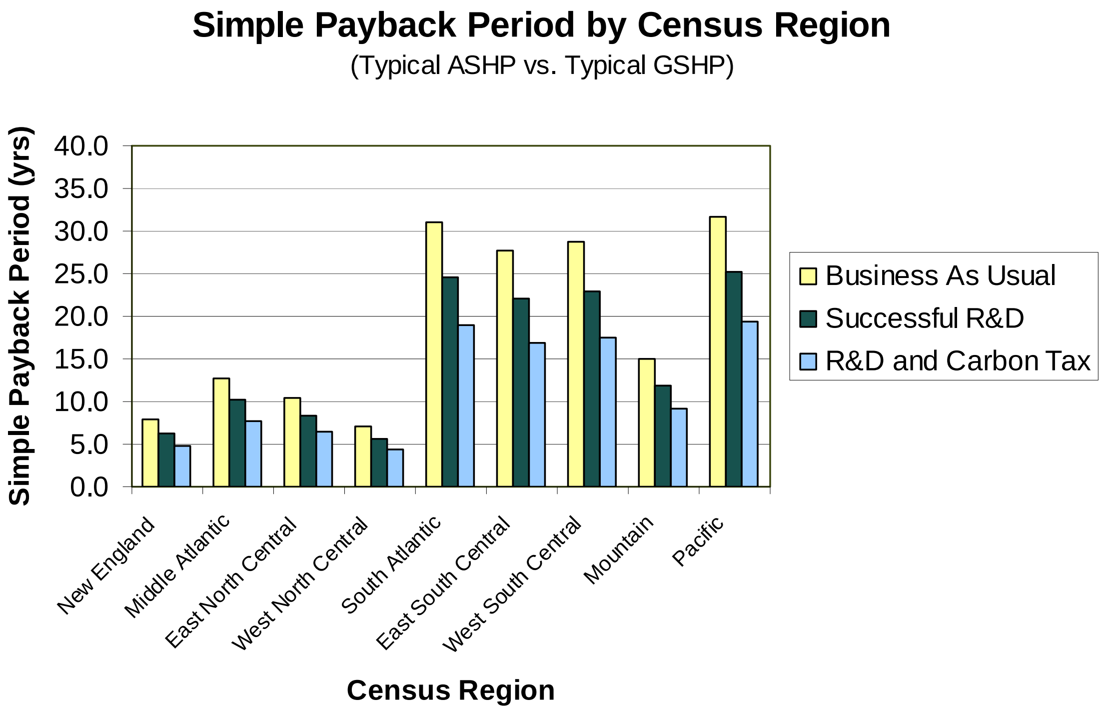
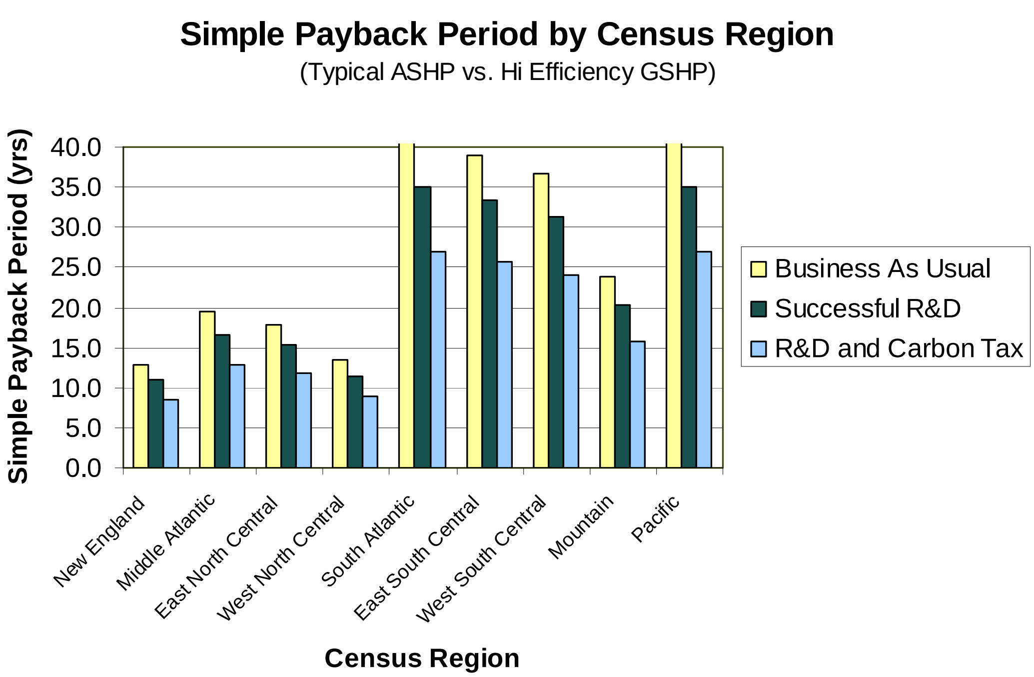


Figure 3-28: Simple Payback Periods for Representative Single-Family Home (~3000 sq. ft.)—High-Efficiency GSHP vs. Typical-Efficiency ASHP Baseline



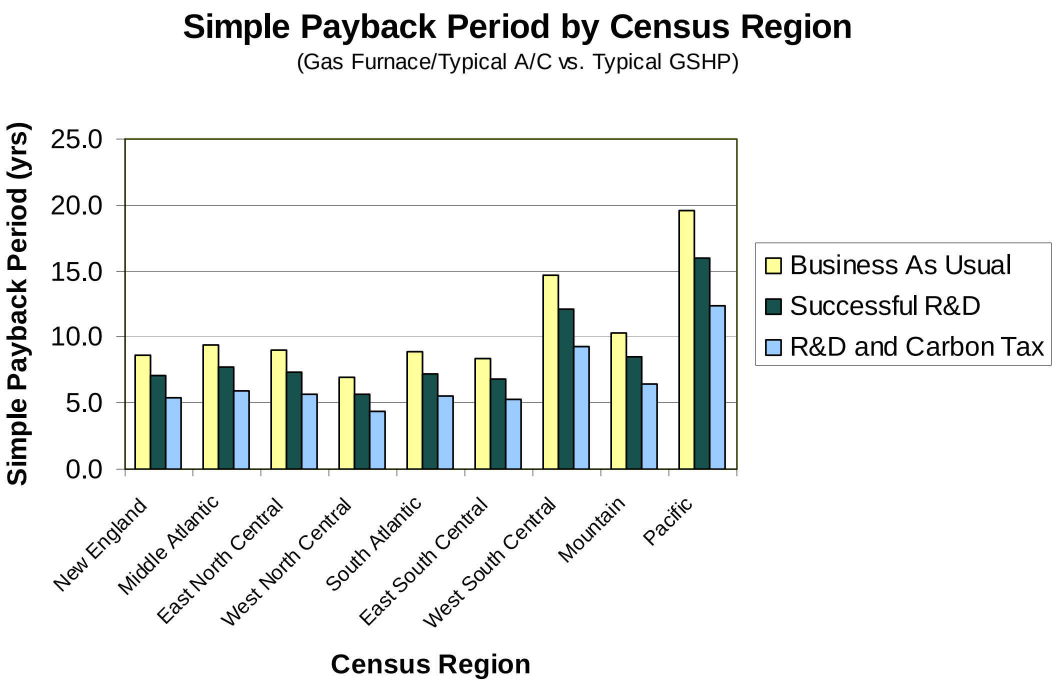
GSHPs could achieve simple payback periods of roughly 5 to 10 years in the northeast and Midwest if R&D efforts lower ground-loop installed costs and/or a significant carbon tax is imposed. The economics of advanced ASHPs are, however, as good or better compared to GSHPs. Furthermore, our analysis does not account for the improved heating-season performance of advanced ASHPs currently being developed and introduced for cold-climate applications, which would improve the economics of advanced ASHPs.

Both GSHPs and advanced ASHPs could see cost reductions as sales volumes increase. For example, GSHPs could benefit from streamlined business models for ground-loop installation. ASHPs could benefit from increased manufacturing economies of scale. (Advanced ASHPs currently sell at lower volumes than GSHPs, so have potential to achieve higher manufacturing economies of scale as sales volumes increase.)

3.11.2 Residential Fundamental Economics and Market Potential—Natural-Gas Baseline Technology

Figure 3-29 shows calculated simple payback periods for GSHPs and advanced ASHPs compared to typical-efficiency natural-gas furnaces and air conditioners. GSHPs could achieve payback periods of 5 to 10 years in most regions if R&D efforts reduce installed costs and/or a significant carbon tax is imposed.

Figure 3-29: Simple Payback Periods for Representative Single-Family Home (~3000 sq. ft.)—Typical-Efficiency GSHP vs. Typical-Efficiency Natural-Gas Furnace/AC Baseline



3.11.3 Residential Fundamental Economics and Market Potential—Fuel-Oil Baseline Technology

Figure 3-30 shows calculated simple payback periods for typical-efficiency GSHPs compared to typical-efficiency fuel-oil furnaces and air conditioners. The results suggest that GSHPs can achieve potentially attractive payback periods in some regions compared to fuel-oil furnaces. However, fuel-oil use is generally limited to the northeast, as shown in Figure 3-31. This analysis used the 2006 average price of oil by census region from the Annual Energy Outlook to calculate energy costs (AEO 2008). Although there was a 30% rise in residential fuel oil prices between 2006 and 2008, they are expected to return to 2006 levels by the end of 2009 as shown in Figure 3-32 (STEO 2009).

Figure 3-30: Simple Payback Periods for Representative Single-Family Home (~3000 sq. ft.)—Typical-Efficiency GSHP vs. Typical-Efficiency Fuel-Oil Furnace/AC Baseline

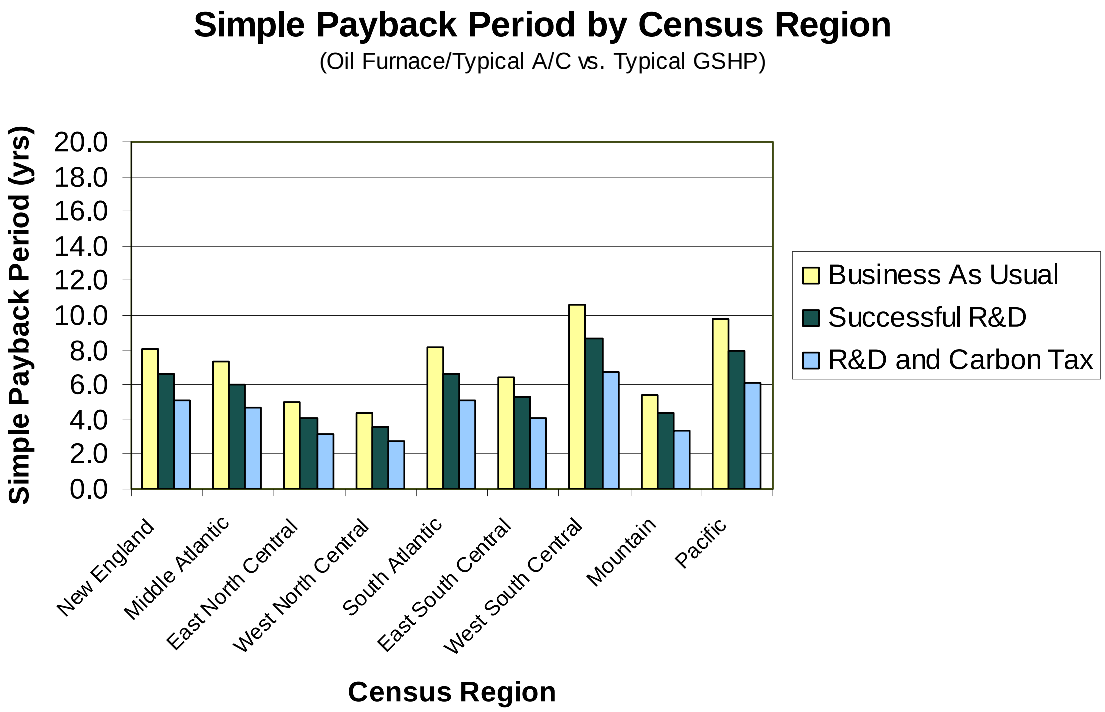
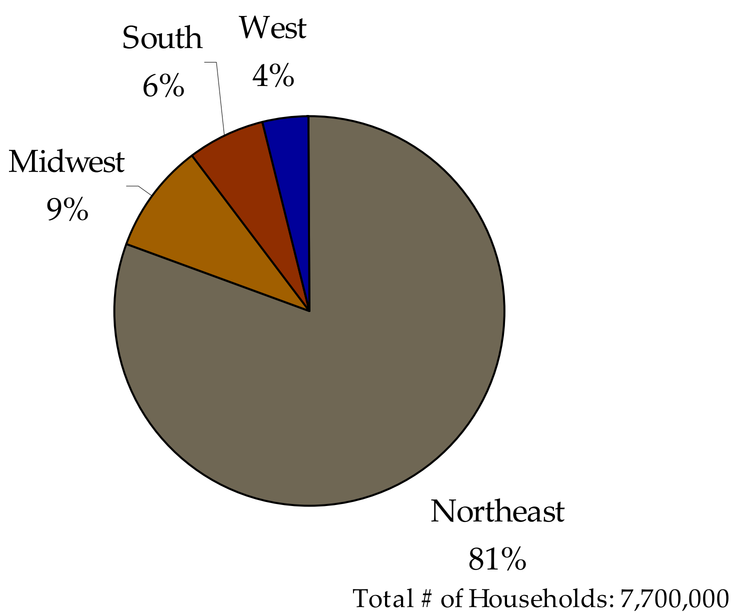
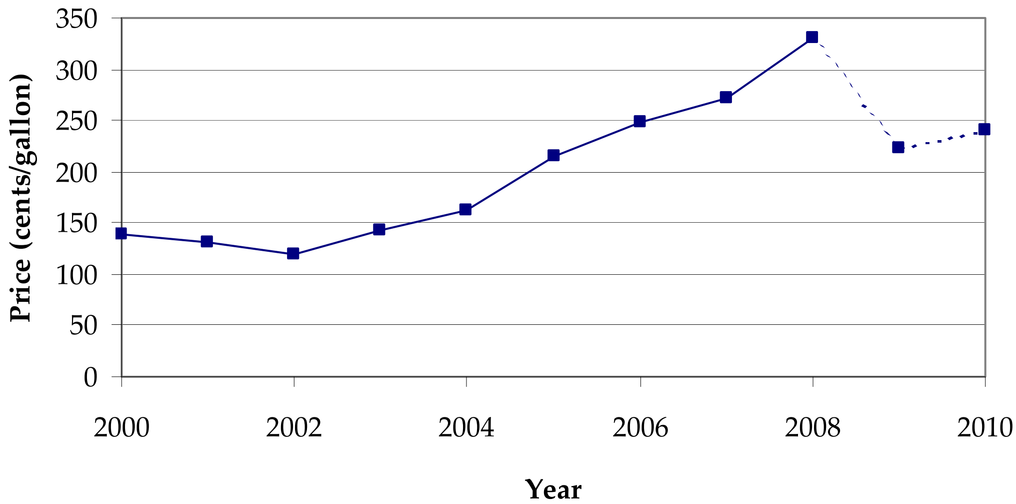


Figure 3-31: Number of Households with Fuel-Oil as Main Fuel Source



Source: RECS 2005

Figure 3-32: U.S. Energy Nominal Price for Heating Oil (Retail Price Including Taxes)

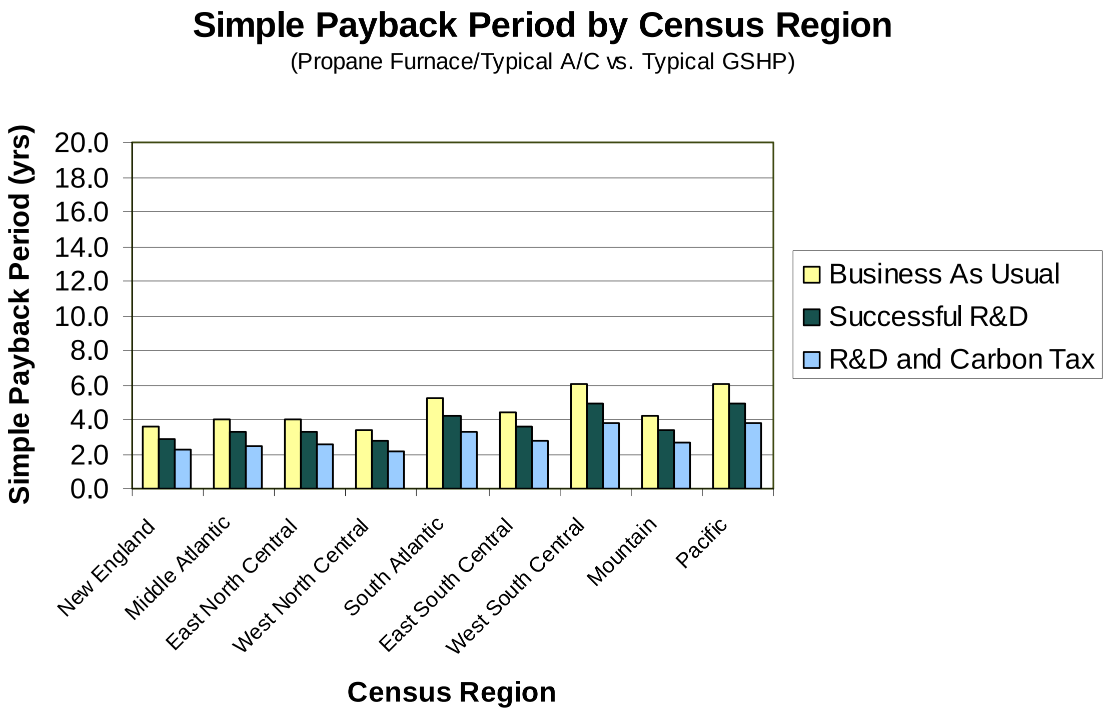


Source: EIA Short Term Energy Outlook 2009; data for 2009-2010 are projected.

3.11.4 Residential Fundamental Economics and Market Potential—Propane Baseline Technology

Figure 3-33 shows calculated simple payback periods for typical-efficiency GSHPs compared to typical-efficiency propane furnaces and air conditioners. The results suggest that GSHPs can offer fairly attractive payback periods in all regions compared to propane furnaces. However, propane use for space heating is very limited [RECS 2005].

Figure 3-33: Simple Payback Periods for Representative Single-Family Home (~3000 sq. ft.)—Typical-Efficiency GSHP vs. Typical-Efficiency Propane Furnace/AC Baseline



3.11.5 Commercial Fundamental Economics—Electric Baseline Technology

Figure 3-34 to Figure 3-36 show calculated simple payback periods for the small office example. Payback periods generally exceed ten years, except in New England. At least three factors contribute to the longer payback periods compared to the residential example.

- We used average commercial electric rates in our analysis, which are lower than residential rates
- EIA cost estimates used show installed costs per unit capacity for commercial products to be similar to those for residential applications
- Space-conditioning loads for commercial buildings are generally less weighted to the heating season than loads for single-family residences, and GSHPs provide a disproportionate benefit during the heating season.

Figure 3-34: Simple Payback Periods for Representative Small Office (~6000 sq. ft.)— Advanced ASHP vs. Typical-Efficiency ASHP

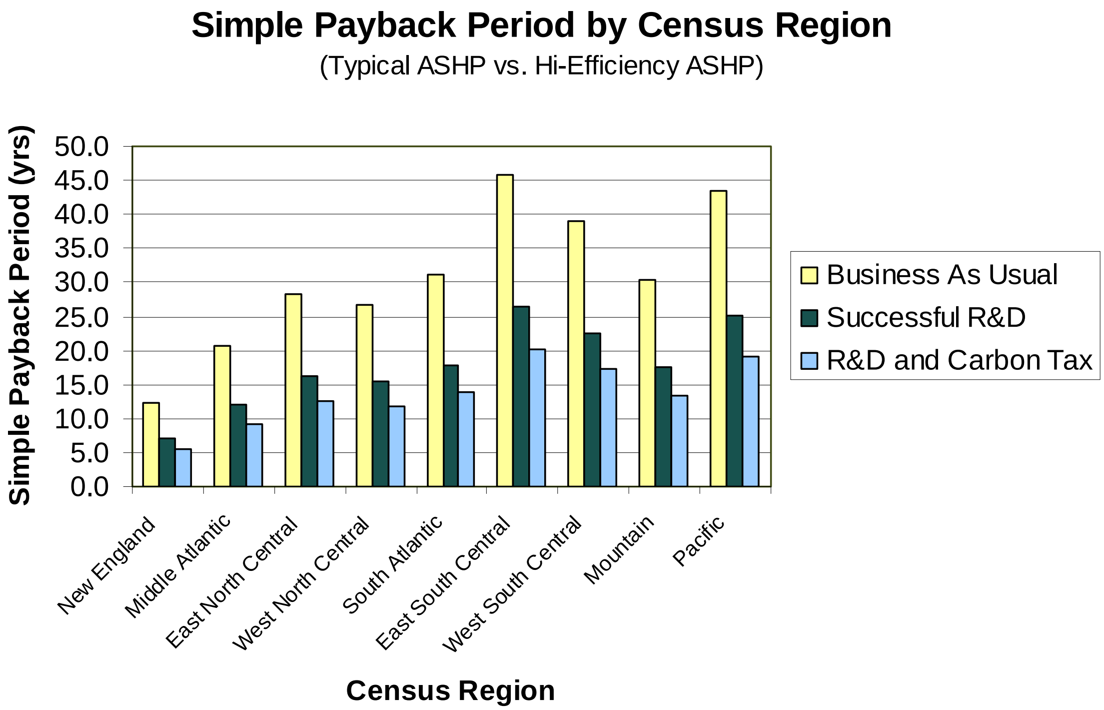


Figure 3-35: Simple Payback Periods for Representative Small Office (~6000 sq. ft.)—Typical-Efficiency GSHP vs. Typical-Efficiency ASHP

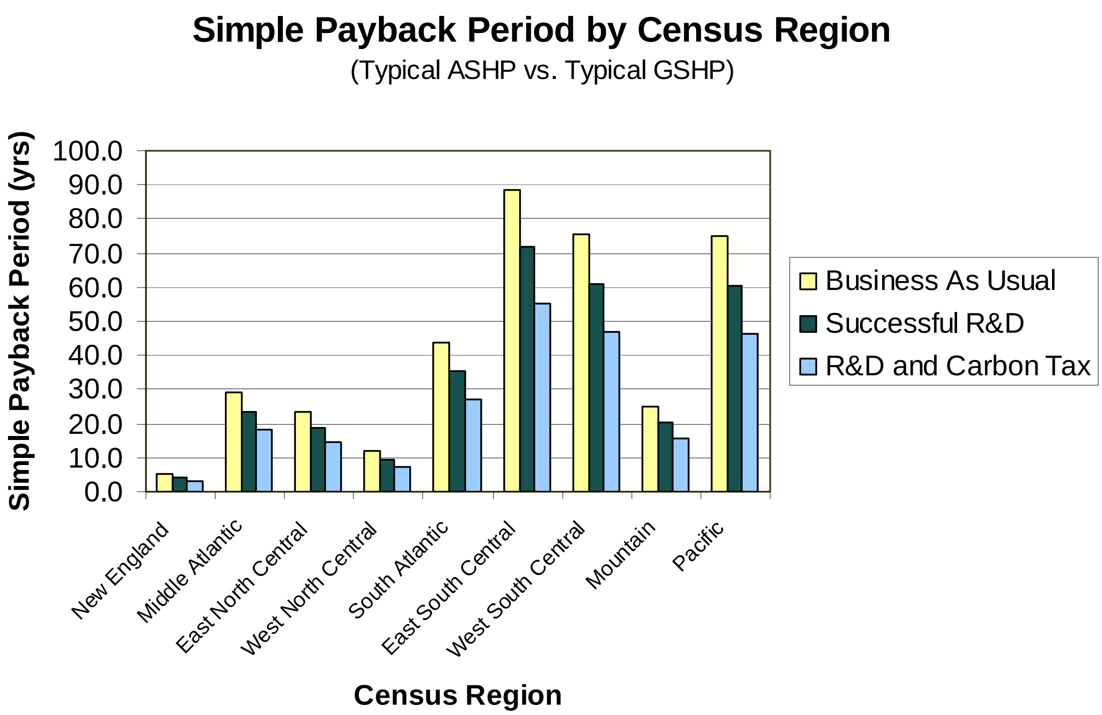
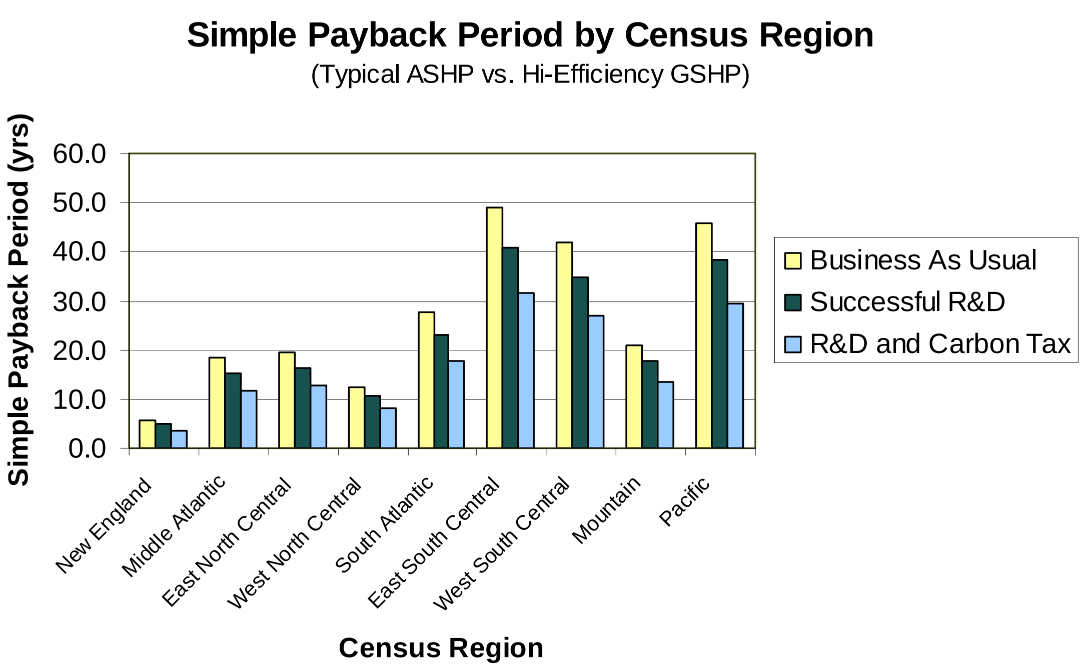


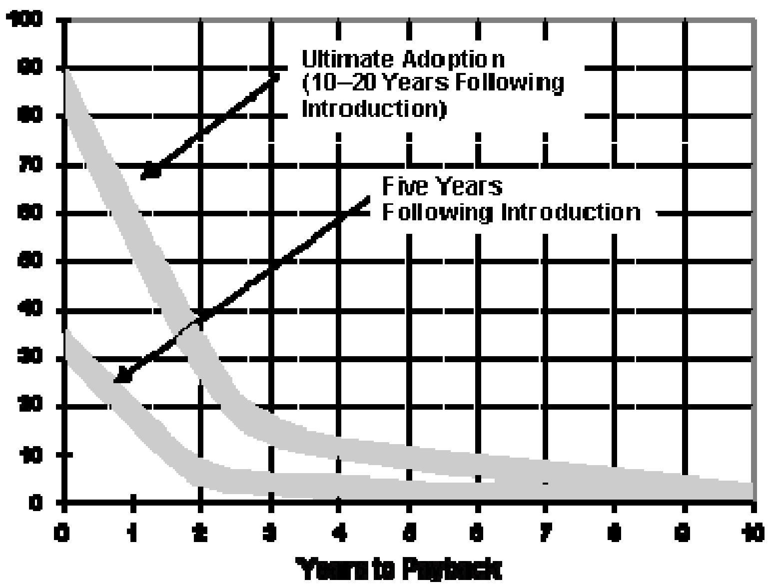
Figure 3-36: Simple Payback Periods for Representative Small Office (~6000 sq. ft.)—High-Efficiency GSHP vs. Typical-Efficiency ASHP



3.12 Projected Market Penetration

Many relationships have been developed that project market penetration of energy-saving technologies as a function of an economic parameter—usually simple payback period. One such market-penetration relationship that is commonly used in DOE analyses was developed by Arthur D. Little, Inc. (see Figure 3-37). The market-penetration curves suggest that payback periods of five years or longer lead to ultimate market penetrations under 10 percent. We consider a five-year payback as a "threshold" payback for widespread market adoption of energy-saving technologies. Payback periods of ten years suggest that applications are limited to niche markets.

Figure 3-37: Market-Penetration Relationship for Energy-Saving Building Equipment



Source: ADL 1995

Of course, actual market penetration will depend on many factors that are not specifically accounted for by simple payback period. For space-conditioning equipment, these factors may include:

- Percent increase in first cost (independent of payback)
- Degree to which well known brands are represented in the market
- Product warranties offered
- Success of marketing and promotional campaigns or branding
- Non-energy benefits such as comfort (uniformity of indoor temperature, humidity control, etc.) or noise
- Degree of disruption associated with installation (for retrofits)
- End-user desire to project a "Green image".

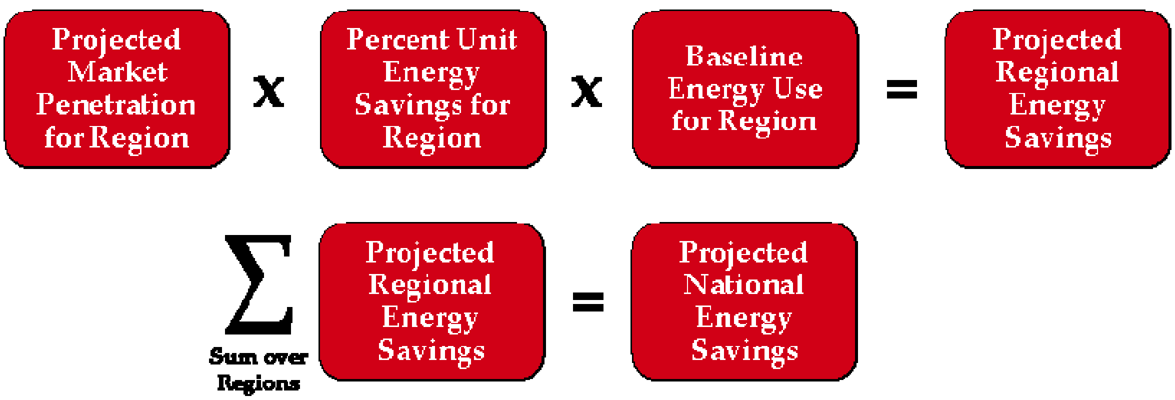
Therefore, these relationships can only be used as a general guideline for projecting market penetrations. The impact of subsidies such as utility rebates or tax credits is to shift the curves to lower payback periods.

3.13 Projected National Primary Energy Savings

As illustrated in Figure 3-38, we project national primary energy savings for each of the three scenarios based on:

- Market-penetration projections (from Section 3.7 above)
- Unit energy savings, as a percent of baseline unit energy (from Section 3.9 above)
- Regional energy consumption for the baseline technology (from Section 3.8 above).

Figure 3-38: Methodology for Projecting National Primary Energy Savings



3.13.1 Residential Applications

Table 3-7 lists the calculated ultimate market penetrations and primary energy savings for the typical ASHP baseline for New England, Middle Atlantic, and the nation as a whole for each scenario. In the northeast, advanced ASHPs achieve slightly higher market penetrations compared to typical GSHPs, but don't always achieve greater primary energy savings. Calculated national energy savings are small in all cases—well under 0.1 Quad even in our most optimistic scenario.

Table 3-7: Ultimate Market Penetrations and Primary Energy Savings for Typical ASHP Baseline—Residential

Scenario	Advanced Technology	New England		Middle Atlantic		National	
		Market Penetration	Primary Energy Savings, TBtu	Market Penetration	Primary Energy Savings, TBtu	Market Penetration	Primary Energy Savings, TBtu
Business as Usual	Advanced ASHP	7.5%	0.6	2.6%	0.9	0.5%	3
	Typical GSHP	5.1%	0.6	--	--	1%	6
	Hi-Eff. GSHP	--	--	--	--	--	--
Successful R&D	Advanced ASHP	10.6%	0.9	7.0%	2.6	3%	11
	Typical GSHP	7.8%	0.9	1.4%	0.7	3%	11
	Hi-Eff. GSHP	0.1%	--	--	--	--	--
R&D plus Carbon Tax	Advanced ASHP	12.4%	1.0	9.7%	2.6	7%	28
	Typical GSHP	10.2%	1.2	1.4%	0.7	3%	11
	Hi-Eff. GSHP	4.3%%	0.8	--	--	1%	4

Table 3-8 lists the calculated ultimate market penetrations and primary energy savings for the typical natural-gas furnace/AC for New England, Middle Atlantic, and the nation as a whole for each scenario. In this case, the dominant markets are not in the Northeast but instead in the Midwest. Compared to typical GSHPs, advanced ASHPs achieve both higher market penetrations and higher energy savings. Due to the relatively high prices of natural gas, advanced heat pumps (both GSHPs and ASHPs) show potential for significantly more impact compared to the typical ASHP baseline above—on the order of 0.1 Quad.

Table 3-8: Ultimate Market Penetrations and Primary Energy Savings for Typical Natural-Gas Furnace/AC Baseline—Residential

Scenario	Advanced Technology	New England		Middle Atlantic		National	
		Market Penetration	Primary Energy Savings, TBtu	Market Penetration	Primary Energy Savings, TBtu	Market Penetration	Primary Energy Savings, TBtu
Business as Usual	Advanced ASHP	8.5%	6.3	8.1%	22.7	6%	130
	Typical GSHP	3.9%	3.5	2.7%	8.7	3%	60
	Hi-Eff. GSHP	--	--	--	--	--	--
Successful R&D	Typical GSHP	6.5%	5.9	5.5%	18.0	5%	100
R&D plus Carbon Tax	Typical GSHP	9.3%	8.4	8.5%	27.7	8%	160

Table 3-9 lists the calculated ultimate market penetrations and primary energy savings for the typical fuel-oil furnace/AC for New England, Middle Atlantic, and the nation as a whole for each scenario. In this case, the dominant markets are clearly in the Northeast—the only region in which fuel oil is commonly used. While potentially an interesting niche market, the projected national energy savings is small—well under 0.1 Quad.

Table 3-9: Ultimate Market Penetrations and Primary Energy Savings for Typical Fuel-Oil Furnace/AC Baseline—Residential

Scenario	Advanced Technology	New England		Middle Atlantic		National	
		Market Penetration	Primary Energy Savings, TBtu	Market Penetration	Primary Energy Savings, TBtu	Market Penetration	Primary Energy Savings, TBtu
Business as Usual	Typical GSHP	4.8%	4.4	6.0%	8.0	6%	17
Successful R&D	Typical GSHP	7.3%	6.7	8.3%	10.9	8%	23
R&D plus Carbon Tax	Typical GSHP	9.8%	9.0	10.6%	14.0	11%	29

Table 3-10 lists the calculated ultimate market penetrations and primary energy savings for the typical propane furnace/AC baseline for New England, Middle Atlantic, and the nation as a whole for each scenario. In this case, the dominant markets are in the Midwest. While potentially an interesting niche market, the projected national energy savings is small—well under 0.1 Quad.

Table 3-10: Ultimate Market Penetrations and Primary Energy Savings for Typical Propane Furnace/AC Baseline—Residential

Scenario	Advanced Technology	New England		Middle Atlantic		National	
		Market Penetration	Primary Energy Savings, TBtu	Market Penetration	Primary Energy Savings, TBtu	Market Penetration	Primary Energy Savings, TBtu
Business as Usual	Typical GSHP	12.4%	0.5	11.7%	1.3	11%	25
Successful R&D	Typical GSHP	13.5%	0.5	12.9%	1.4	12%	28
R&D plus Carbon Tax	Typical GSHP	23.7%	0.9	16.4%	1.8	16%	37

3.13.2 Commercial Applications

Table 3-11 lists the calculated ultimate market penetrations and primary energy savings for the typical ASHP baseline for New England for each scenario.

Payback periods on the order of five years result in projected market penetrations of around 10 percent. National energy savings can approach 0.1 Quad.

Table 3-11: Ultimate Market Penetrations and Primary Energy Savings for Typical ASHP Baseline—Commercial

Scenario	Advanced Technology	New England	
		Market Penetration	Primary Energy Savings, TBtu
Business as Usual	Advanced ASHP	--	--
	Typical GSHP	9%	54
	Hi-Eff. GSHP	9%	73
Successful R&D	Advanced ASHP	7%	5
	Typical GSHP	11%	64
	Hi-Eff. GSHP	10%	86
R&D plus Carbon Tax	Advanced ASHP	9%	7
	Typical GSHP	13%	74
	Hi-Eff. GSHP	12%	100

4 Other Benefits of GSHPs (not included in Economic Analysis)

There are a number of additional benefits associated with GSHPs relative to advanced ASHPs that are not reflected in our economic/energy-impact analysis. These include:

- Actual economics may be substantially better if variable-electric rate structures are considered, such as:
    - Commercial: Demand charges and time-of-use rates penalize peak power consumption, which is substantially lower with GSHPs than with ASHPs or standard air conditioners
    - Residential: Current/upcoming time-dependent rate structures will make energy savings at peak times (e.g. summer afternoons) very valuable.
- Reduction in peak electric demand from GSHPs is significantly greater than for ASHPs, which would benefit electric utilities and could be used as a justification for offering substantial subsidies.
- Noise reduction (no outdoor fan)
- For GSHPs using secondary loops (or open loops), the refrigeration system can be factory packaged, leading to much lower chances of refrigerant leaks, improper charging, or refrigerant-system contamination
- Life of the ground loop will most likely exceed the life of an ASHP outdoor unit. Once a GSHP has been installed, replacing the system (excluding the ground loop, which should last almost indefinitely) may be less expensive than replacing an ASHP
- Lower temperature lift should improve compressor reliability and life
- No unsightly outdoor unit (that also takes up space)
- No requirement to clean an outdoor, air-cooled heat exchanger
- No shipping size/weight restrictions that limit the outdoor-unit coil size/efficiency in an ASHP
- Successful branding of GSHPs as a renewable energy technology may encourage greater adoption and greater availability of incentives.

5 Key Barriers to GSHP's in the U.S.

The key barriers to increased use of GSHPs in the U.S. are discussed below. This includes technological, market, institutional, regulatory, and other barriers.

5.1 Technological Barriers

There are several key technological barriers to widespread adoption of GSHPs, including:

- The need for a ground loop adds significant complexity, cost, and risk:
  - Adds site-specific design considerations, which are particularly significant for single-family residential applications. Geological conditions can vary significantly even within a given neighborhood [Proffer 2008]
  - Site-evaluation costs can be high.
  - Creates risks and uncertainties in cost estimating. It is difficult for installers to provide quotes, unless prices are inflated to cover uncertainties/risks
- Generally requires installation-specific design and engineering of the ground loop
- Pumping parasitics can be high if the system is not properly designed
- Seasonal variations in ground temperature in the vicinity of ground loop keep temperature lifts higher than in theory, limiting efficiency gains
- GSHPs can be difficult and costly to install in retrofit applications

Other technological barriers include:

- Direct-exchange systems (refrigerant circuit in direct contact with the ground), while less popular today compared to secondary-loop alternatives, pose unique challenges, including:
  - May be difficult to ensure adequate refrigerant-oil return
  - Increased difficulty in maintaining refrigeration-loop integrity and cleanliness
  - High cost of copper or aluminum refrigeration tubing/piping
  - High refrigerant cost
  - System repair and maintenance challenges (i.e., more difficult to recover charge and re-charge system)
  - Detecting charge loss or repairing leaks can be problematic

Market Barriers

GSHPs also face several market challenges:

- High installation costs result in poor payback compared to ASHPs, and limit energy savings compared to ultra-high-efficiency ASHPs, which costs less to install
- Space constraints in many urban areas
- Limited production volumes lead to higher costs
- Operating cost is dependent upon electricity price (high in NE)
- Advances in ASHPs are "raising the bar" (high-efficiency, cold climate)
- Longer project duration for installing a GSHP relative to an ASHP or furnace (which can be completed in less than one day), along with the excavation mess, is a disincentive for some customers.

5.2 Institutional, Regulatory, and Other Barriers

GSHPs face additional barriers, including:

- Environmental regulations in some regions restrict re-injection of ground water.
- Potential for glycol leaks can be a barrier
- Low market awareness among consumers
- Limited number of qualified, trained installers
- Need codes to ensure proper design and installation of ground loop and pump selection (pump parasitics issue)

6 Applicability to Zero-Energy Homes and Buildings

Advanced ASHPs are currently available in efficiency ranges suitable for zero-energy homes (ZEH). Advanced ASHPs are available in capacity ranges of 1.5 - 2 tons of cooling capacity, which is the range required for ZEHs. GSHPs in this capacity range, if available at all, are likely to be very expensive compared to ASHPs due to the fixed costs associated with ground-loop installation. On the other side, ZEHs can utilize lower-capacity GSHPs, which will reduce the first-cost barrier compared to conventional homes.

Space-conditioning loads for zero-energy buildings (ZEBs) will generally be less weighted to the heating season than loads for conventional commercial buildings. This results because internal heat loads (which are generally fixed)become a greater percentage of the overall space-cooling load when increased insulation and reduced infiltration lower overall space-conditioning loads. Since GSHPs provide a disproportionate benefit during the heating season, ZEBs using GSHPs may not see the same percentage reduction in space-conditioning loads as do conventional buildings. On the other side, ZEBS will be able to utilize smaller-capacity heat pumps, which will lower the first-cost barrier.

7 Summary/Conclusions

A summary, observations and conclusions follow.

7.1 Summary

We conducted this investigation to:

- Summarize the status of GSHP technology and market penetration globally
- Estimate the energy saving potential of GSHPs in the U.S.
- Identify and describe the key market barriers that are inhibiting wider market adoption of GSHPs
- Recommend initiatives that can be implemented or facilitated by the DOE to accelerate market adoption.

We used information/data obtained from:

- Available literature related to GSHPs
- Interviews with selected industry experts
- A spreadsheet analysis to evaluate the energy savings and economics by U.S. census region for representative residential and commercial applications.

Our energy-savings and economics analysis compares two high-efficiency technologies (GSHPs and advanced ASHPs) to two standard-efficiency baseline systems (conventional ASHPs and furnaces with air conditioners). We used general relationships between economics and market penetration to project ultimate market penetrations of GSHPs and associated national primary energy savings.

7.2 General Observations/Conclusions

Some general observations and conclusions about the potential for GSHPs are summarized below.

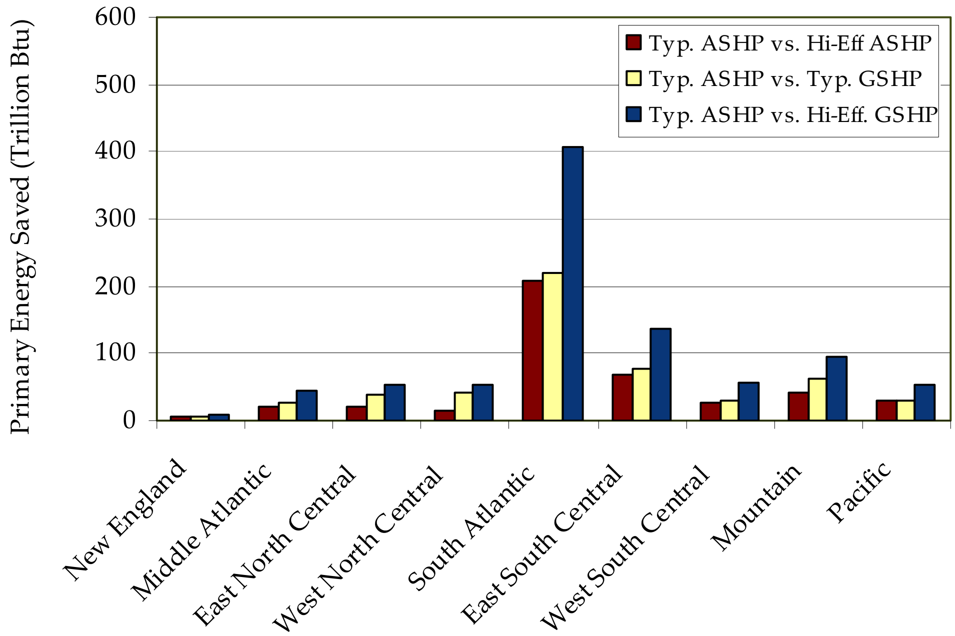
7.2.1 Fundamental Economics and Market Potential

Based on this analysis, both GSHPs and advanced ASHPs show potential for significant unit energy savings (per-installation savings) when displacing typical-efficiency ASHPs. While GSHPs generally have efficiency advantages, advanced ASHPs tend to be somewhat more economical (as measured by simple payback period). While the GSHP market may continue to expand for many years, GSHPs are unlikely to capture a major share of the heat-pump market.

7.2.2 Potential for National Energy Savings

The technical potential primary energy savings associated with GSHPs is shown in Table 8-1.

Table 8-1: Potential National Primary Energy Savings



7.2.3 Key Benefits of GSHPs

In addition to high energy efficiency, GSHPs offer two key benefits:

- Can have factory-packaged refrigeration loop
- Reduces peak electric demand.

7.2.4 Key Barriers to Widespread Application of GSHPs

GSHPs face three key barriers:

- Cost and difficulty of evaluating the suitability of individual installation sites.
- Generally requires installation-specific design and engineering of the ground loop
- Space requirements for ground coupling can be problematic in densely built areas

7.2.5 Key Lessons Learned from Global GSHP Experience

Beyond the U.S., the GSHP market is booming in Europe and starting to accelerate in Asia. Europe has a more extensive supply of published market data than the U.S., making it easier for policy-makers to analyze the trends and for manufacturers to plan for the future. Although the Asian market has only recently blossomed, China, Japan, and Korea all participate in the IEA Heat Pump Conferences and have made important contributions to the research effort. It is important to continue the international cooperation as the industry continues to mature.

The European heat pump market suffered a major blow in the late 1980's and early 1990's after booming initially during the oil crisis of the 1970's. The lack of skilled installers and poor equipment quality damaged the reputation of the technology. It is in the best interest of the GSHP industry that the U.S. maintain high quality and service through periods of growth.

Since the late 1990's, the European industry has been reborn with the help of various government and utility programs as well as rising energy prices. Programs and policies vary by country. Sweden has been most successful at penetrating the new and retrofit markets.

7.3 Observations/Conclusions for Residential Applications

Our analysis of a representative single-family residential application (about 3000 sq. ft.) suggests the following.

7.3.1 Residential Unit Energy Savings

Compared to typical-efficiency ASHPs, ranges of unit energy savings are (as a percent of space-conditioning energy consumption):

- Advanced ASHPs: 20 to 30 percent
- Typical-Efficiency GSHPs: 25 to 50 percent
- High-Efficiency GSHPs: 50 to 70 percent

Compared to typical-efficiency furnaces (natural gas, propane or fuel oil) and air conditioners, ranges of unit energy savings are (as a percent of space-conditioning energy consumption):

- Advanced ASHPs: 20 to 30 percent
- Typical-Efficiency GSHPs: 25 to 30 percent
- High-Efficiency GSHPs: 50 to 60 percent

These ranges are narrower than reported above for the typical-efficiency-ASHP baseline because there is less regional variation in heating-season performance compared to ASHPs.

7.3.2 Residential Fundamental Economics and Market Potential—Electric Baseline Technology

Table 7-1 shows approximate ranges of simple payback periods for GSHPs and advanced ASHPs compared to typical-efficiency ASHPs.

Table 7-1: Approximate Simple Payback Periods for Representative Single-Family Home (~3000 sq. ft.)—Typical-Efficiency ASHP Baseline

Scenario	Advanced Technology	Payback Range by Major Census Region (Years)			
		Northeast	Midwest	South	West
Business as Usual	Advanced ASHP	6 - 10	8 - 12	15 - 20	10 - 20
	Typical GSHP	8 - 15	7 - 11	25 - 35	15 - 35
	High-Efficiency GSHP	10 - 20	10 - 20	35 - 40	25 - 40
Successful R&D	Advanced ASHP	Same as "Business as Usual"[a]			
	Typical GSHP	6 - 10	6 - 8	20 - 25	10 - 25
	High-Efficiency GSHP	10 - 20	10 - 15	30 - 35	20 - 35
R&D plus Carbon Tax	Advanced ASHP	4 - 5	5 - 6	9 - 10	7 - 10
	Typical GSHP	5 - 8	4 - 6	15 - 20	9 - 20
	High-Efficiency GSHP	8 - 15	9 - 12	25 - 30	15 - 30

a) Successful R&D assumed to impact the GSHP ground loop only, so this scenario won't change the economics of the advanced ASHP.

Generalized market-penetration curves suggest that payback periods of five years or longer lead to ultimate market penetrations under 10 percent. Payback periods of ten years suggest that applications are limited to niche markets. GSHPs approach threshold economics for widespread adoption in the northeast and Midwest if R&D efforts lower ground-loop installed costs and/or a significant carbon tax is imposed on electricity. The economics of advanced ASHPs are, however, as good or better compared to GSHPs. And, our analysis does not account for the improved heating-season performance of advanced ASHPS currently being developed and introduced for cold-climate applications, which would improve the economics of advanced ASHPs.

Projected payback periods are sensitive to installed-cost estimates. However, using installed-cost estimates from another researcher would result in even longer payback periods.

Both GSHPs and advanced ASHPs could see cost reductions as sales volumes increase. For example, GSHPs could benefit from streamlined business models for ground-loop installation. ASHPs could also benefit from increased manufacturing economies of scale.

7.3.3 Residential Fundamental Economics and Market Potential—Natural-Gas Baseline Technology

Table 7-2 shows approximate ranges of simple payback periods for GSHPs and advanced ASHPs compared to two typical-efficiency natural-gas furnaces and air conditioners.

Table 7-2: Approximate Simple Payback Periods for Representative Single-Family Home (~3000 sq. ft.)—Typical-Efficiency Natural-Gas Furnace and Air-Conditioner Baseline

Scenario	Advanced Technology	Payback Range by Major Census Region (Years)			
		Northeast	Midwest	South	West
Business as Usual	Advanced ASHP	5 - 6	4 - 6	5 - 9	7 - 12
	Typical GSHP	8 - 10	7 - 9	8 - 15	10 - 20
	High-Efficiency GSHP	12 - 15	12 - 15	15 - 20	15 - 30
Successful R&D	Typical GSHP	7 - 8	5 - 7	7 - 12	8 - 15
R&D plus Carbon Tax	Typical GSHP	5 - 10	4 - 6	5 - 9	6 - 12

GSHPs approach threshold economics for widespread adoption only if R&D efforts reduce installed costs and/or a significant carbon tax is imposed. The economics of advanced ASHPs are, however, are generally better compared to GSHPs. As stated above, our analysis does not account for the improved heating-season performance of advanced ASHPS currently being developed and introduced for cold-climate applications, which would improve the economics of advanced ASHPs. Our analysis also does not incorporate the potential economic advantages of lower peak demand from GSHPs, which is very valuable to utilities and can be passed on to consumers as residential variable rate pricing becomes more widespread.

7.3.4 Residential Fundamental Economics and Market Potential—Fuel-Oil Baseline Technology

Table 7-3 shows approximate ranges of simple payback periods for typical-efficiency GSHPs compared to typical-efficiency fuel-oil furnaces and air conditioners.

Table 7-3: Approximate Simple Payback Periods for Representative Single-Family Home (~3000 sq. ft.)—Typical-Efficiency Fuel-Oil Furnace and Air-Conditioner Baseline

Scenario	Advanced Technology	Payback Range by Major Census Region (Years) Northeast[a]
Business as Usual	Typical GSHP	7 - 8
Successful R&D		6 - 7
R&D plus Carbon Tax		4 - 5

a) Only the Northeast is listed because other regions use very little fuel oil.

The results suggest that GSHPs can be economically competitive in the northeast compared to fuel-oil furnaces.

7.3.5 Residential Fundamental Economics and Market Potential—Propane Baseline Technology

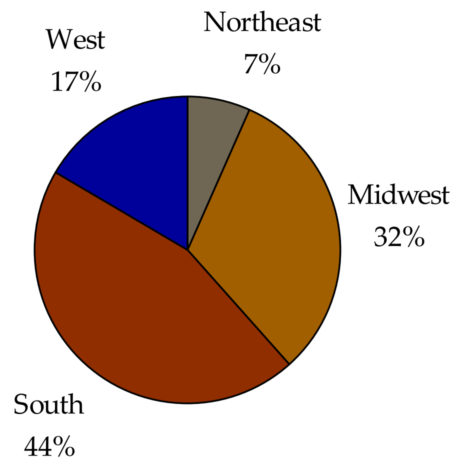
Table 7-4 shows approximate ranges of simple payback periods for typical-efficiency GSHPs compared to typical-efficiency propane furnaces and air conditioners.

Table 7-4: Approximate Simple Payback Periods for Representative Single-Family Home (~3000 sq. ft.)—Typical-Efficiency Propane Furnace and Air-Conditioner Baseline

Scenario	Advanced Technology	Payback Range by Major Census Region (Years)			
		Northeast	Midwest	South	West
Business as Usual	Typical GSHP	3 - 4	3 - 4	4 - 6	4 - 6
Successful R&D		~3	2.5 – 3	3 - 5	3 - 5
R&D plus Carbon Tax		2 – 2.5	2 – 2.5	3 - 4	2.5 - 4

The results suggest that GSHPs can be economically competitive in all regions compared to propane furnaces. However, propane use for space heating is limited to 6% of households nationally (see
Figure 7-1 for regional distribution of propane-heated households).

Figure 7-1: Distribution of U.S. Households using Propane as the Main Space-Heating Fuel



Source: RECS 2005

7.3.6 Potential National Primary Energy Savings—Residential

While the technical potential energy savings for residential applications of GSHPs is about 3.1 Quad, our economic analysis suggests that could achieve a national primary energy savings of about 0.1 Quad. While homes having propane and fuel-oil furnaces may offer an attractive target market for residential GSHPs, they are not likely to provide significant national energy impacts.

7.3.7 Zero-Energy Homes

Advanced ASHPs are currently available in efficiency ranges suitable for zero-energy homes (ZEH). Advanced ASHPs are available in capacity ranges of 1.5 - 2 tons of cooling capacity, which is the range required for ZEHs. GSHPs in this capacity range, if available at all, are likely to be very expensive compared to ASHPs due to the fixed costs associated with ground-loop installation. On the other side, ZEHs can utilize lower-capacity GSHPs, which will reduce the first-cost barrier compared to conventional homes.

7.4 Observations/Conclusions for Commercial/Institutional Applications

Compared to typical-efficiency ASHPs, ranges of primary unit energy savings are (as a percent of space-conditioning energy consumption):

- Advanced ASHPs: 5 to 10 percent
- Typical-Efficiency GSHPs: 20 to 45 percent
- High-Efficiency GSHPs: 45 to 60 percent

The technical potential primary energy savings in commercial buildings is roughly 0.6 Quad, of which about XXQuad is associated with public grade schools. However, the results of our analyses of a representative small office building application (about 6000 sq. ft.) generally show calculated payback periods over ten years, except in New England. At least three factors contribute to the longer payback periods compared to the residential example.

- We used average commercial electric rates in our analysis, which are lower than residential rates
- EIA cost estimates used show installed costs per unit capacity for commercial products to be similar to those for residential applications
- Space-conditioning loads for commercial buildings are generally less weighted to the heating season than loads for single-family residences, and GSHPs provide a disproportionate benefit during the heating season.

Various industry experts report, however, that real-world economics tend to be better for commercial or institutional buildings compared to residential applications. We expect that real-world pricing generally results in a cost reduction per unit capacity as capacity increases; however, we have no representative installed-cost data to confirm this.

While we did not analyze a natural-gas furnace and conditioner baseline, if the economics are similar to the typical ASHP baseline, GSHPs could ultimately achieve roughly 10 percent penetration of this market. This would result in on the order of 0.05 Quad national primary energy savings.

7.4.1 Zero-Energy Buildings

Space-conditioning loads for ZEBs will generally be less weighted to the heating season than loads for conventional commercial buildings. This results because internal heat loads (which are generally fixed) become a greater percentage of the overall space-cooling load when increased insulation and reduced infiltration lower overall space-conditioning loads. Since GSHPs provide a disproportionate benefit during the heating season, ZEBs using GSHPs may not see the same percentage reduction in space-conditioning loads as do conventional buildings. On the other side, ZEBS will be able to utilize smaller-capacity heat pumps, which will lower the first-cost barrier.

7.5 Observations/Conclusions for Community Applications

New-construction, planned communities may offer significantly improved economics for GSHPs. Various GSHP systems could be considered, all providing significant installed-cost reductions compared to individual installations:

- Large GSHP installation providing a district heating and cooling system to the community
- Large ground loop providing a thermal source or sink to individual water-source heat pumps in the community
- Individual GSHPS for each building/home, but installed en masse at the time of building/home construction to lower installation costs

While potentially an attractive niche market, new-construction, planned communities represent a small portion of the national building stock and, therefore, will have modest impacts on national energy consumption for quite some time.

8 Recommended Initiatives to Accelerate Market Adoption of GSHPs

W**e recommend that DOE support advanced heat pumps in general, rather than supporting only one type (such as GSHP)**. Based on our investigation, all types of heat pumps (GSHPs, ASHPs, and possibly hybrid systems) can play important roles helping DOE pursue its energy-efficiency objectives. Incentives such as federal tax credits or utility rebates can be based on energy efficiency achieved, rather than type of heat pump. R&D projects can be pursued based on the individual merit of each prospective project, rather than type of heat pump. This will require close coordination between the Geothermal Technologies Group (which is responsible for GSHPs) and Building Technologies Group (which is responsible for ASHPs). This coordination will help ensure that both types of heat pumps are developed, evaluated, and promoted in a way that ensures that apples-to-apples comparisons are made and that duplication of effort is avoided to the extent possible.

8.1 Additional Evaluations

Additional evaluations will help determine the likely impacts of R&D efforts to lower costs and to identify promotional projects that may be of interest to stakeholders. We recommend that GT and BT pursue the following evaluation activities.

8.1.1 Potential for GSHP Cost Reductions

Evaluate the potential for first-cost reductions for GSHPs , including potential economies of scale, alternative business models, and potential partnering relationships. Working with industry stakeholders, identify concepts to lower ground-loop installation costs then estimate their likely cost impacts. Potential concepts may include:

- Reducing the need for, and/or cost of, evaluating ground conditions (soil type/mix, thermal conductivity, water content/ground-water depth)
- For new construction, maximizing use of excavation required for the building foundation, including coupling ground loop to the foundation
- Hybrid systems using air-cooled condensers or possibly cooling towers to reduce ground-loop size while still meeting peak cooling requirements
- Additives to enhance soil conductivity in the vicinity of the ground loop
- Heat-exchanger designs, or extended surfaces that then attach to ground loops, that can be hammered into soil
- Low-cost drilling/excavation equipment, including water-jet technology.

8.1.2 Potential for ASHP Cost Reductions and Heating-Season Performance Improvements

Evaluate the potential for first-cost reductions for advanced ASHPs , including potential economies of scale. Include ASHPs developed specifically for cold climates that improve heating-season efficiency, as poor heating-season performance is the "Achilles' Heel" of ASHPs. While cold-climate ASHPs are currently available from a limited number of suppliers, the products are generally expensive, designs may be immature, and performance/reliability may not be sufficiently demonstrated.

8.1.3 Detailed Performance and Energy-Benefits Modeling

Since we did not conduct detailed performance modeling, our investigation does not consider:

- Potential improvements in economics due to using variable electricity rates, such as:
  - Commercial: Demand charges and time-of-use rates
  - Residential: Current/upcoming time-dependent rate structures
- Benefits of reducing peak electric demand. Understanding the peak demand reduction benefits of GSHPs is essential to justifying utility rebates that could substantially accelerate market adoption of GSHPs.

We recommend detailed performance modeling to estimate these impacts, which could significantly improve the economics of GSHPs.

In addition, as noted above, the national benefits modeling described in this report was necessarily based on many estimates and simplifications, as the project scope did not permit detailed models such as hourly load modeling. A more rigorous modeling process would better quantify the potential national benefits of GSHPs and could better target DOE activities to accelerate market adoption.

8.1.4 Schools and Other Government Buildings

Schools and other government buildings (with assistance from energy services companies) have proven to be attractive, early market niches for GSHP installations. We did not specifically examine these opportunities in this analysis. A 1998 DOE study found GSHP systems in schools to reduce energy use for space conditioning by 25-50% compared to traditional systems, with payback periods of 2-8 years (MacMillan 2007). Our analysis of technical potential has produced similar results, and we estimate that U.S. public schools (K-12) have the potential to save 0.03 Quad collectively by using GSHPs for space-conditioning. We recommend further analysis, documentation, and publication of the energy savings, economics, reliability, comfort, installation and operational lessons learned, etc., associated with schools and other government buildings. Having this knowledge and experience available will help facilitate GSHP market growth in other building applications.

8.1.5 *Promotional Programs with Stakeholders*

Contact stakeholders to identify interest in a joint DOE promotional program. Arrange meetings with interested stakeholders to compare information, identify common interests, agree on priorities, and outline a joint collaboration effort, as appropriate. Stakeholders potentially interested in a DOE partnership to promote GSHPs may include:

- Electric utilities and the Consortium for Energy Efficiency (CEE)
- GSHP Manufacturers
- American Council for an Energy Efficient Economy (ACEEE)
- Geothermal Heat Pump Consortium, Inc.
- International Energy Agency, Heat Pump Program
- International Ground Source Heat Pump Association
- Canadian GeoExchange Coalition
- Geo-Heat Center, Oregon Institute of Technology
- South Dakota State University
- Leadership in Energy and Environmental Design.

8.2 *Research and Development*

Depending on the results of the additional analyses outlined above, we recommend that GT and BT consider the following R&D projects.

8.2.1 *Ground-Loop Cost Reduction*

After developing and evaluating various concepts for lowering ground-loop cost, develop prototype designs for the more promising concepts. Laboratory test or field test, as appropriate.

8.2.2 *Cold-Climate ASHP Development/Cost Reduction*

Depending on the results of the investigation outlined in Section 9.1.2 above, perform additional development and laboratory testing to reduce cost and ensure good reliability and performance of cold-climate ASHPs.

8.3 *Field Testing and Verification*

We recommend that GT and BT pursue the following field-testing and performance-verification activities.

8.3.1 *Ground-Loop Testing/Evaluation*

Researchers have demonstrated that the ground loop has significant impacts on ground temperature in the vicinity of the ground loop. Also, soil characteristics vary dramatically, and have significant influence on ground-loop design and performance, and even the suitability of the site for a GSHP. Further, space constraints for some installations may not permit optimal sizing of the ground loop or spacing of bore holes.

8.3.2 *Rigorous Performance Verification and Comparison to ASHP*

DOE should evaluate and document the energy-savings potential of GSHPs compared to alternatives (advanced ASHPs and furnaces) through field testing and demonstrations. One option is to install both a GSHP and an ASHP (or furnace and air conditioner) in a test home and alternate use of each system. Adjust results for weather conditions and compare performance. Careful instrumentation of the ground loop is important to understand the impacts of seasonal ground-temperature variation (due to heat extraction in the winter and heat rejection in the summer).

8.3.3 *Gathering Data to Support Improved Design/Installation Guidelines*

Working with interested manufacturers and installers, DOE could encourage that

8.4 Promotion

We recommend that GT and BT pursue several advanced heat-pump promotional activities as outlined below.

8.4.1 *Installation Codes*

DOE test procedures are used for measuring WSHP energy efficiency for ENERGY STAR® ratings.[9] Because a WSHP is factory or laboratory tested, the DOE test procedure uses a formula to estimated ground-loop pump-power requirements. Unfortunately, this does not provide assurance that the GSHP, as installed, will use an energy-efficient pump, nor a ground-loop design and glycol flow rate that ensures optimum balance between heat-transfer performance and pumping power requirements. We recommend that DOE work with state and local governments, manufacturers, and installers to develop model codes that state and local governments can utilize to ensure in-field performance is consistent with good design practice. The model codes should provide (or reference) appropriate ground-loop design and pump-selection guidelines for various installation conditions and ground-loop types. It should include

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[9] DOE test procedures reference the following industry test procedures: ARI 320 – Water Source Heat Pumps; ARI 325 – Groundwater Source Heat Pumps; ARI 330 – Ground Source Heat Pumps

functional performance testing requirements, if appropriate, to ensure that the system works as intended once installed.

8.4.2 *Guidelines for Selecting/Designing Advanced Heat Pumps*

There are many factors to consider when selecting the appropriate heat-pump technology for a given installation, including:

- Site conditions
- Available space
- Climate
- Building type/construction
- End-user economic criteria
- End-user preferences.

Adequate tools are lacking for selecting the appropriate technology and designing the system to optimize cost and performance. DOE should work with interested stakeholders to develop, disseminate and support these tools.

8.4.3 *Community-Based Systems*

GSHPs, WSHPs, and even hybrid systems can offer significant cost and performance advantages when considered for communities. There are substantial opportunities for creative combinations with other types of community systems, such as:

- Combined Heat and Power (CHP) systems
- District heating or cooling systems, including lake-water cooling systems
- Heat recovery systems, including sources such as sewage, anaerobic digesters, or industrial waste-heat streams.

For example, WSHPs or hybrid systems installed at individual customer sites may be effective in reducing the capacity requirements for district heating and cooling systems, when a few, peak hours or days may otherwise dictate sizing requirements. Also, community-based systems provide a scale that may interest energy service companies or third-party owner/operators, helping to surmount the first-cost barrier.

8.4.4 *Other Promotional Activities*

Promotional activities should include:

- Support training for designers and installers (including drillers and excavators)
- Consider partnerships to create new business models to reduce drilling/trenching costs
- Support regional information-dissemination programs

- Work with local governments, utilities, developers, manufacturers and installers to consider community-based GSHP systems when constructing planned communities. These are especially attractive for communities that have access to lake, pond, or ocean water where, in many cases, direct cooling is possible for much or all of the cooling season.

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Appendix A: Scope of Work

The project will begin with a kickoff teleconference with DOE to confirm the objectives, approach, and deliverables anticipated for the project. The tasks planned for the project are explained below.

Task 1. Review Status of Global GSHP markets

In this task, we will provide an overview of the global market for GSHPs, focusing primarily on Asia and Europe. To the extent that data are available, we will provide estimates of market size in key regions and explain the types of GSHPs that are prevalent worldwide. We will also review available information on incentives that are available for GSHPs in key regions. We will examine where GSHPs have been successful and the apparent reasons for their success, as well as whether any of the lessons learned abroad may be applicable in the U.S.

Task 2. Estimate Energy Savings Potential for GSHPs in the U.S.

In task 2, we will estimate the energy savings potential of GSHPs in the U.S. under a few different scenarios, likely including optimistic, pessimistic, and "business as usual". The factors that might create these scenarios will also be discussed. A simplified cost-benefit analysis based on simple payback periods will be documented, and both new construction and retrofits will be considered.

Task 3. Examine Key Market Barriers to GSHPs in the U.S.

In task 3, we will identify and explain the most important barriers that are inhibiting growth of the GSHP market in the U.S. These may include market, technological, institutional, regulatory, or other barriers. Although we will examine these issues on a national basis, we will pay particular attention to the Northeast, where the high cost of heating oil and propane might provide an opening for GSHPs. The opportunities and barriers associated with a community loop arrangement will also be considered.

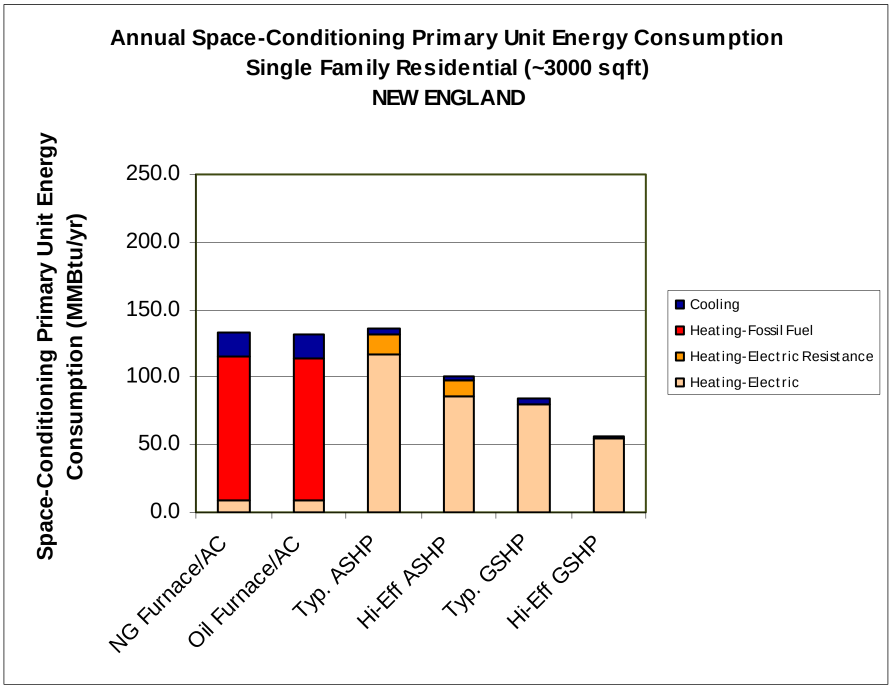
Task 4. Recommend Initiatives to Accelerate Market Adoption of GSHPs

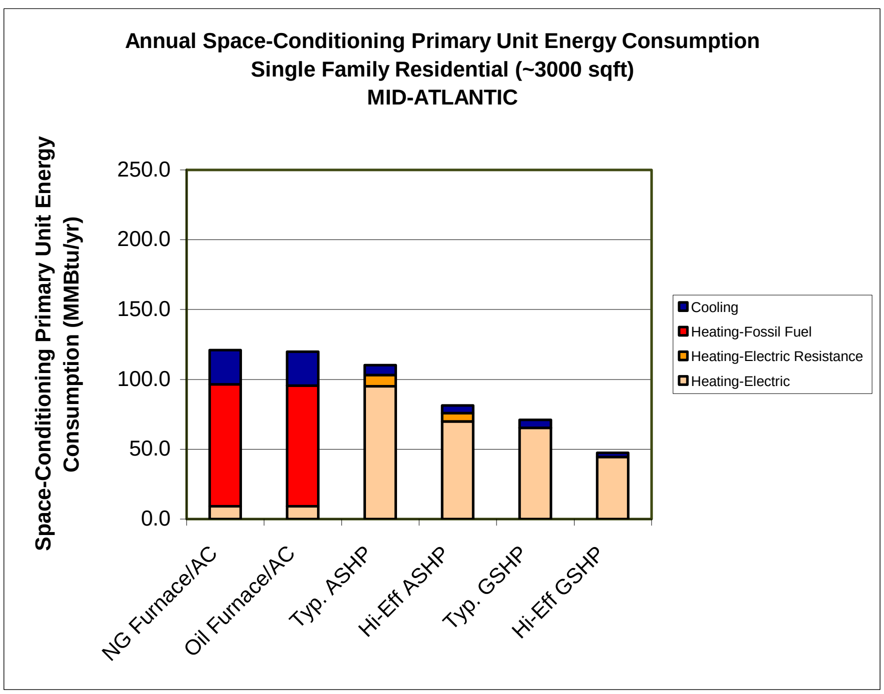
Based on the findings of task 3, as well as any lessons learned from abroad in task 1, we will recommend initiatives that the DOE could undertake or facilitate to accelerate market adoption of GSHPs in the U.S. and particularly in the Northeast. These initiatives could be undertaken by DOE alone or in partnership with other stakeholders such as states, utilities, manufacturers, or others

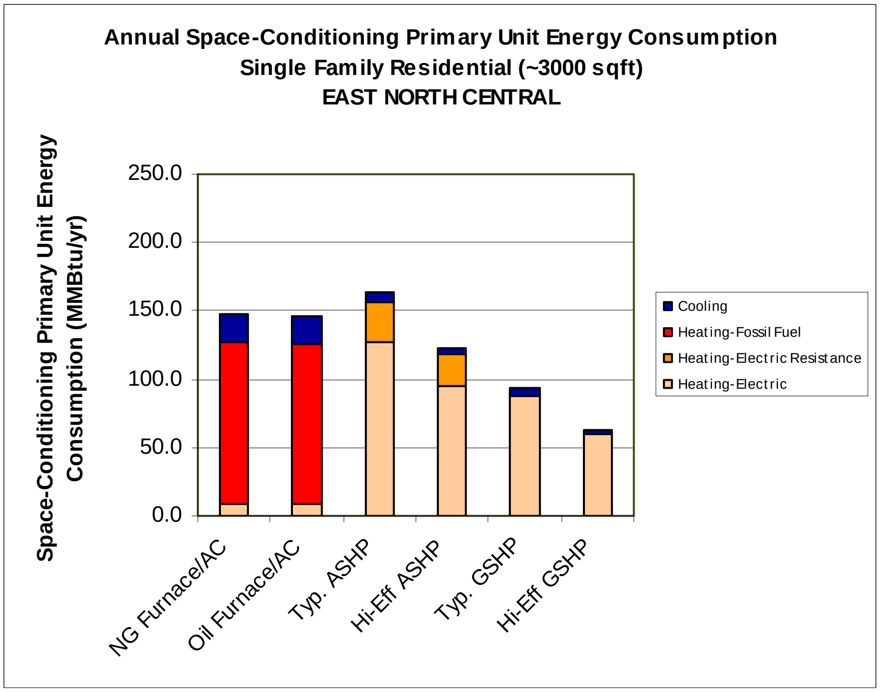
Deliverables and Schedule

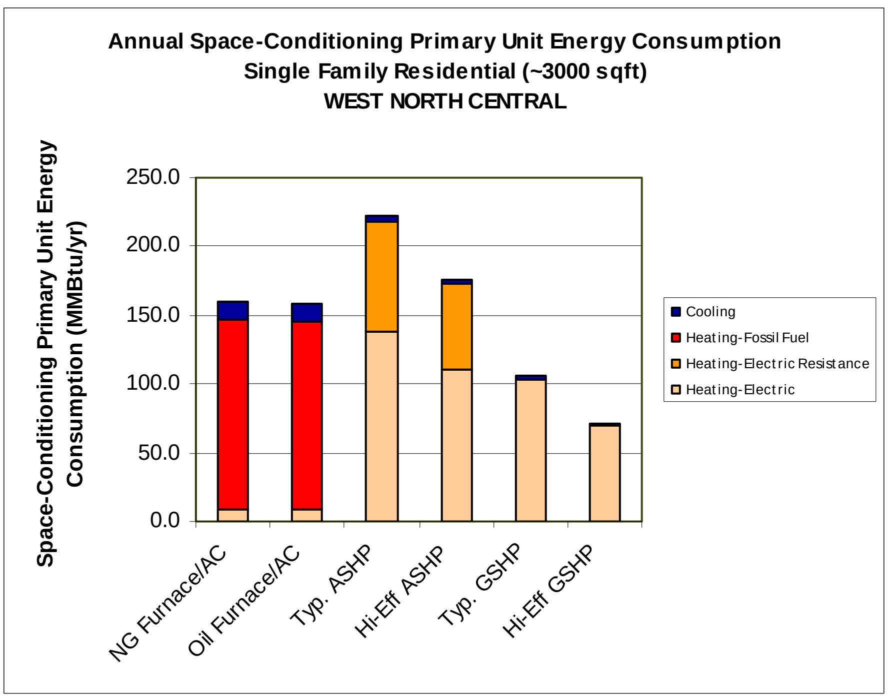
Our findings will be summarized in a draft final report approximately 2 months from the date of subcontract award. The revised final report will be submitted within two weeks after receipt and resolution of any comments on the draft report.

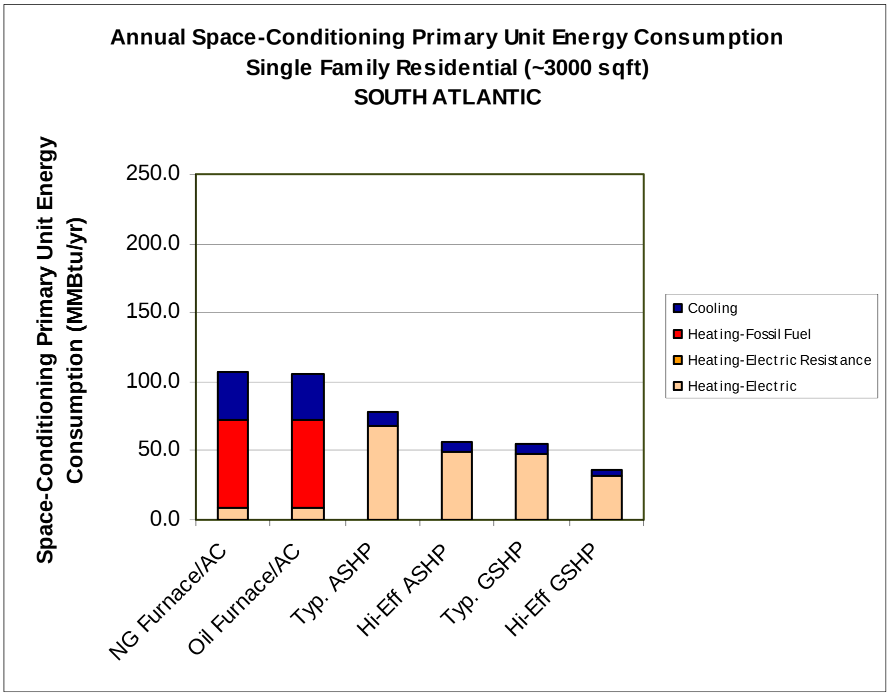
Appendix B: Residential Unit Energy Consumptions



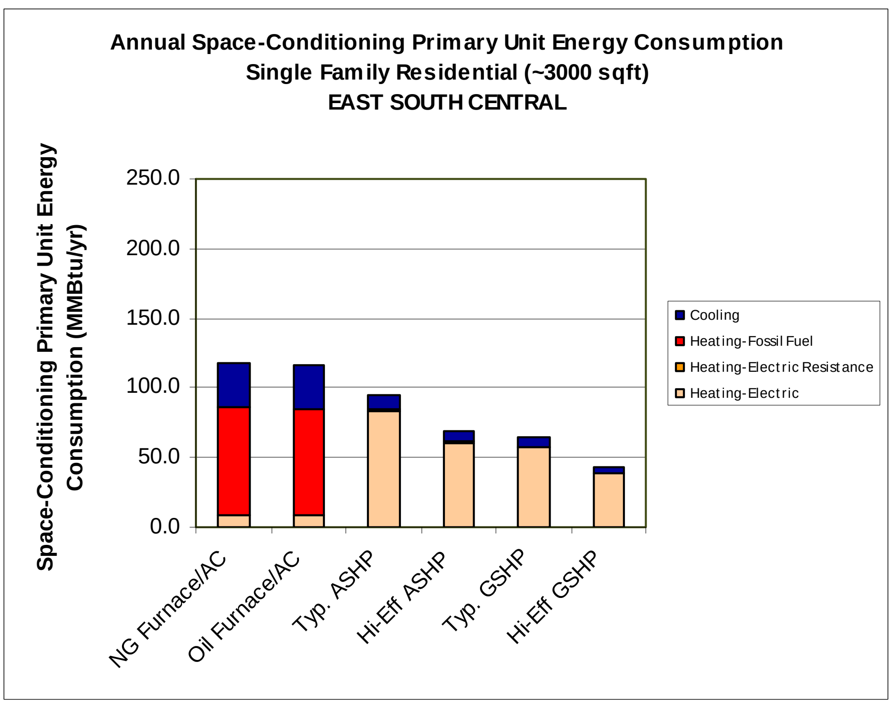



Annual Space-Conditioning Primary Unit Energy Consumption
Single Family Residential (~3000 sqft)
EAST NORTH CENTRAL
Space-Conditioning Primary Unit Energy Consumption (MMBtu/yr)
250.0
200.0
150.0
100.0
50.0
0.0
NG Furnace/AC
Oil Furnace/AC
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling
Heating-Fossil Fuel
Heating-Electric Resistance
Heating-Electric

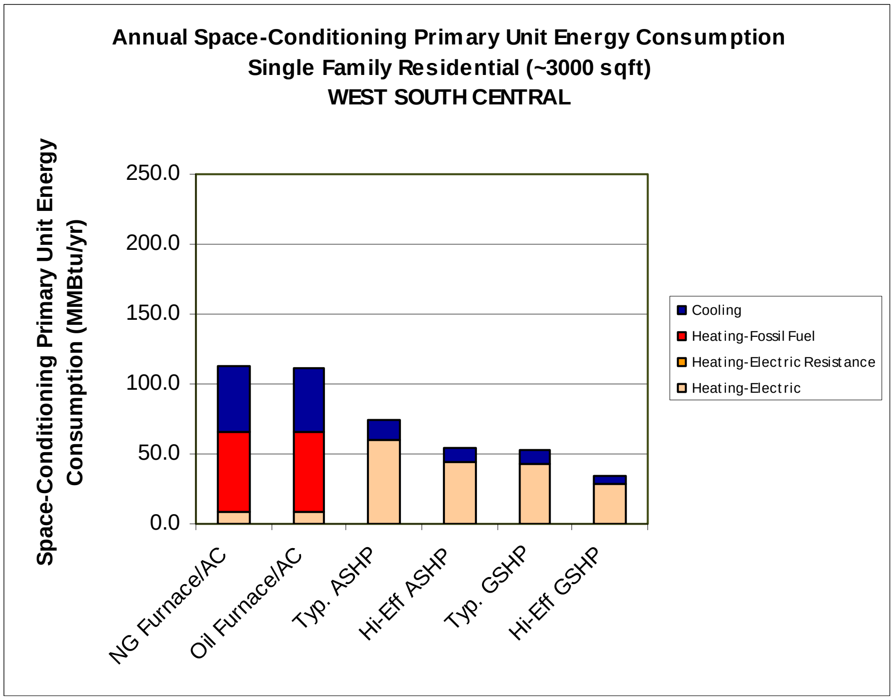

Annual Space-Conditioning Primary Unit Energy Consumption
Single Family Residential (~3000 sqft)
WEST NORTH CENTRAL
Space-Conditioning Primary Unit Energy Consumption (MMBtu/yr)
250.0
200.0
150.0
100.0
50.0
0.0
NG Furnace/AC
Oil Furnace/AC
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling
Heating-Fossil Fuel
Heating-Electric Resistance
Heating-Electric

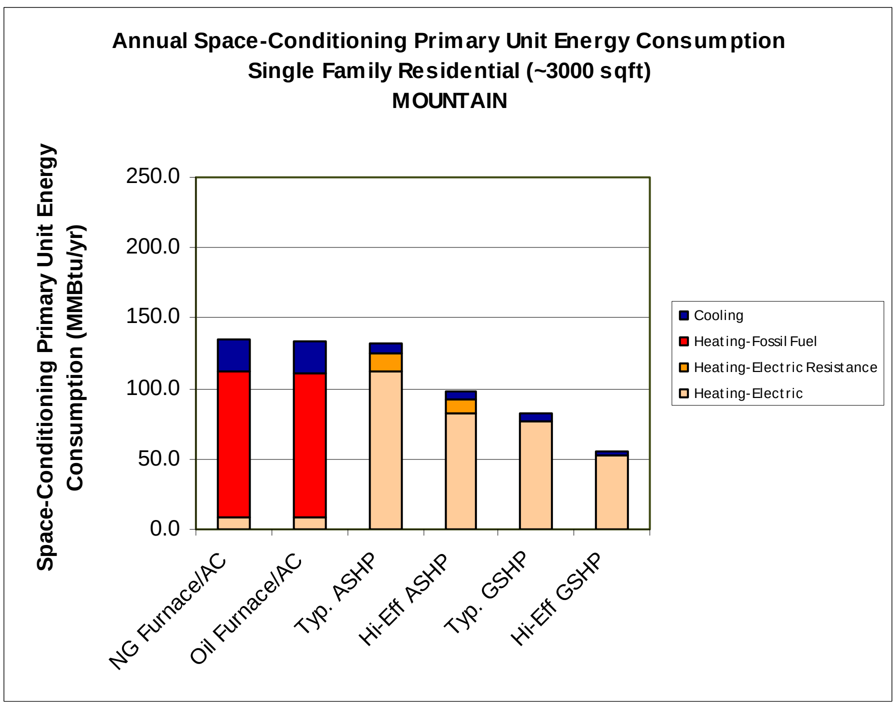


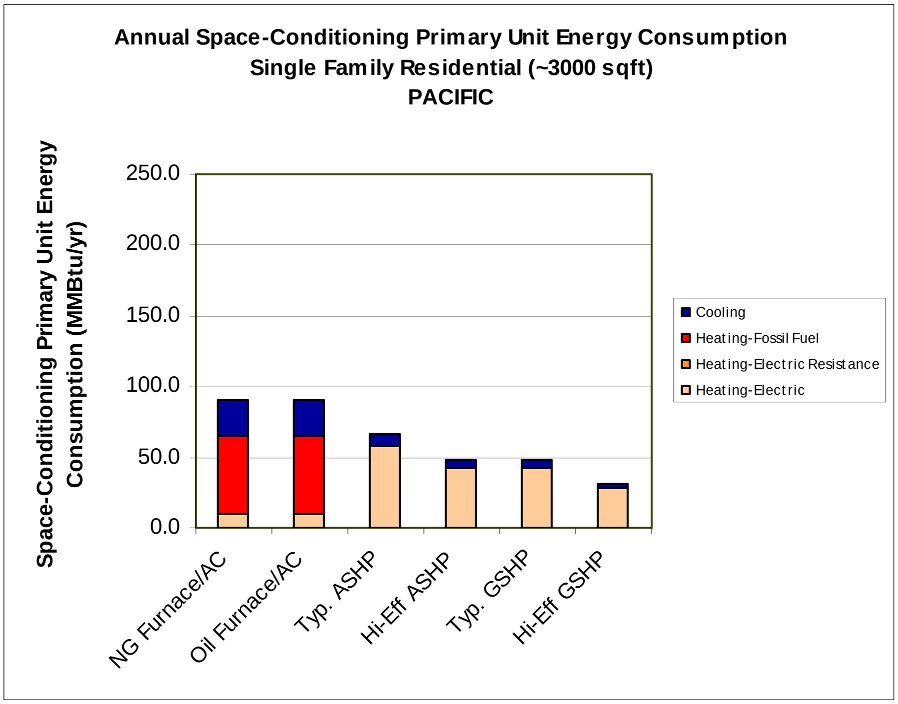
Annual Space-Conditioning Primary Unit Energy Consumption
Single Family Residential (~3000 sqft)
SOUTH ATLANTIC
Space-Conditioning Primary Unit Energy Consumption (MMBtu/yr)
250.0
200.0
150.0
100.0
50.0
0.0
NG Furnace/AC
Oil Furnace/AC
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling
Heating-Fossil Fuel
Heating-Electric Resistance
Heating-Electric



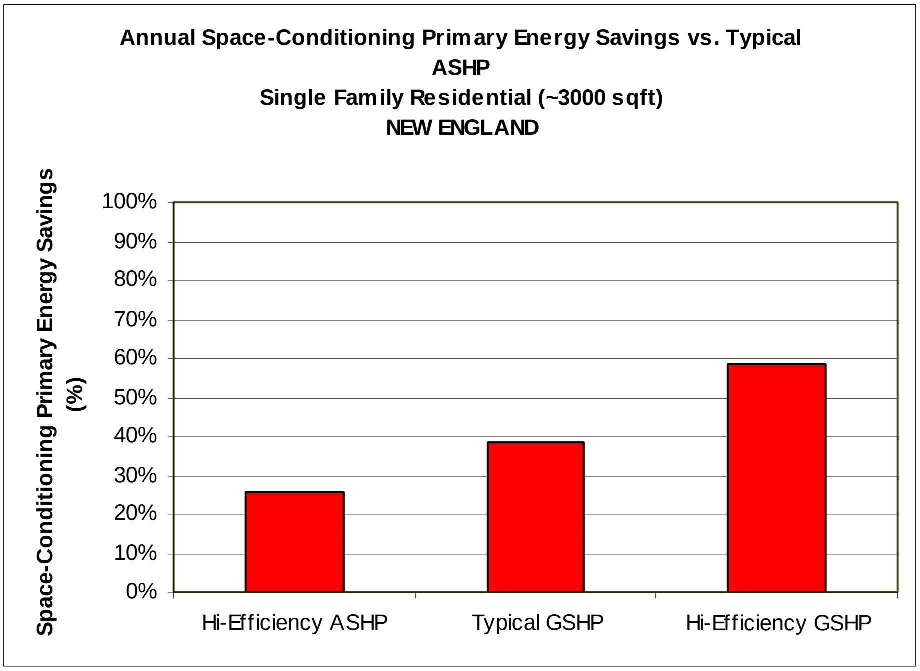
Annual Space-Conditioning Primary Unit Energy Consumption
Single Family Residential (~3000 sqft)
EAST SOUTH CENTRAL
Space-Conditioning Primary Unit Energy Consumption (MMBtu/yr)
250.0
200.0
150.0
100.0
50.0
0.0
NG Furnace/AC
Oil Furnace/AC
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling
Heating-Fossil Fuel
Heating-Electric Resistance
Heating-Electric

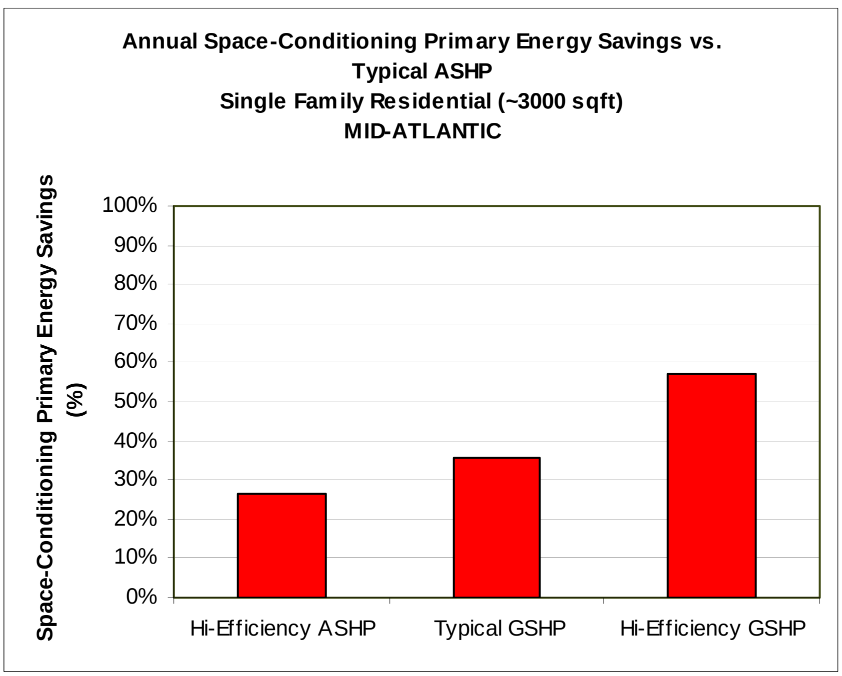

Annual Space-Conditioning Primary Unit Energy Consumption
Single Family Residential (~3000 sqft)
WEST SOUTH CENTRAL
Space-Conditioning Primary Unit Energy Consumption (MMBtu/yr)
250.0
200.0
150.0
100.0
50.0
0.0
NG Furnace/AC
Oil Furnace/AC
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling
Heating-Fossil Fuel
Heating-Electric Resistance
Heating-Electric

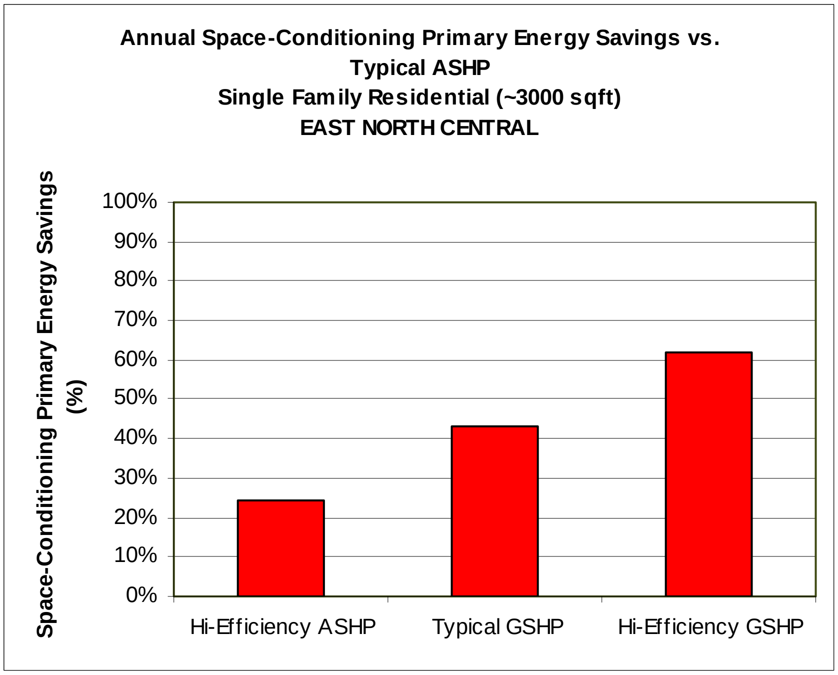

Annual Space-Conditioning Primary Unit Energy Consumption
Single Family Residential (~3000 sqft)
MOUNTAIN
Space-Conditioning Primary Unit Energy Consumption (MMBtu/yr)
250.0
200.0
150.0
100.0
50.0
0.0
NG Furnace/AC
Oil Furnace/AC
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling
Heating-Fossil Fuel
Heating-Electric Resistance
Heating-Electric

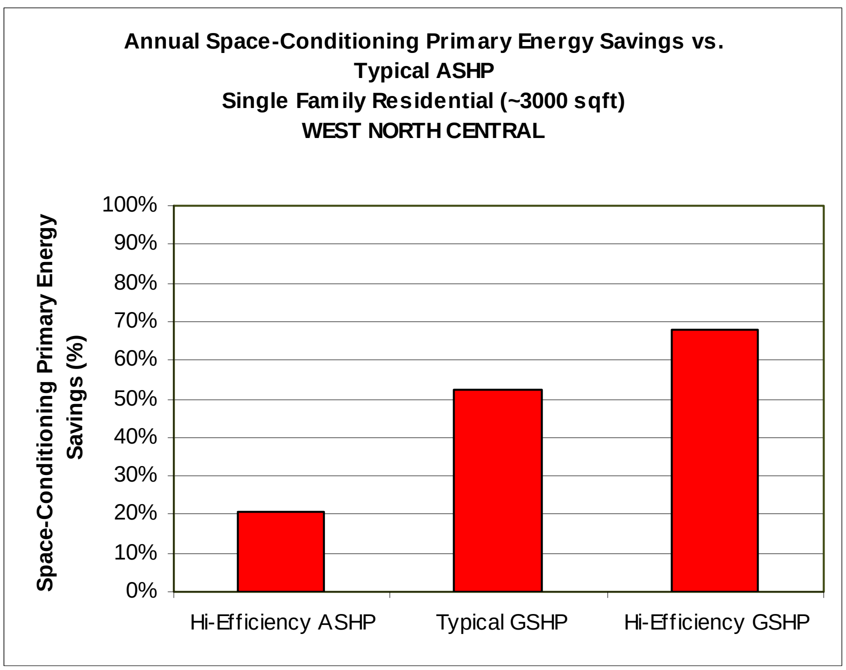

Annual Space-Conditioning Primary Unit Energy Consumption
Single Family Residential (~3000 sqft)
PACIFIC
Space-Conditioning Primary Unit Energy Consumption (MMBtu/yr)
250.0
200.0
150.0
100.0
50.0
0.0
NG Furnace/AC
Oil Furnace/AC
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling
Heating-Fossil Fuel
Heating-Electric Resistance
Heating-Electric

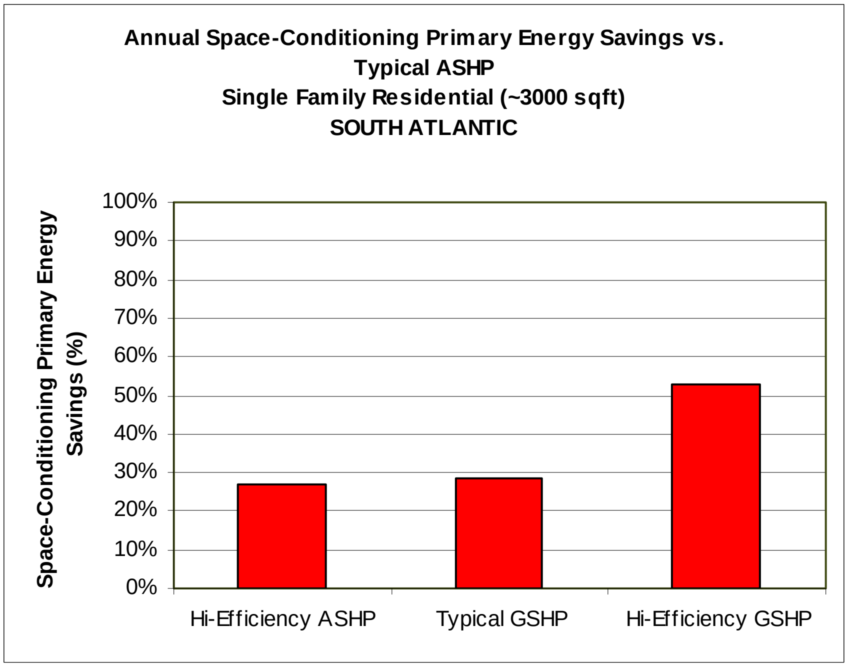
Appendix C: Residential Unit Energy Savings

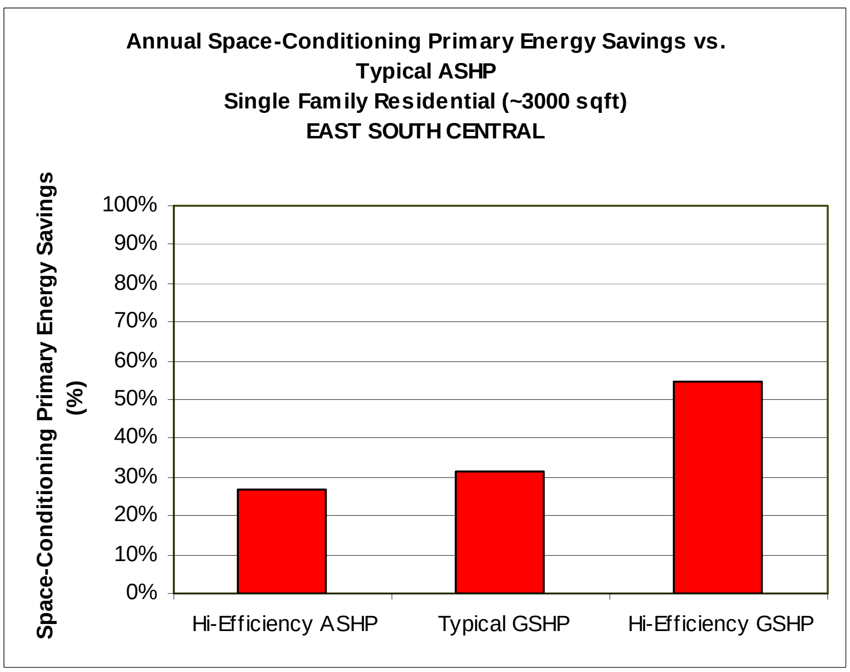


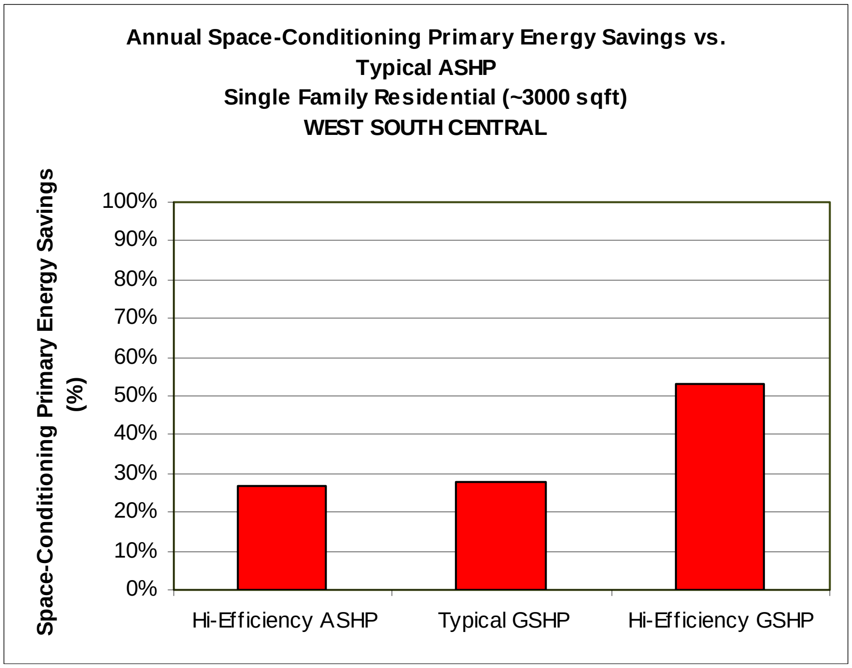


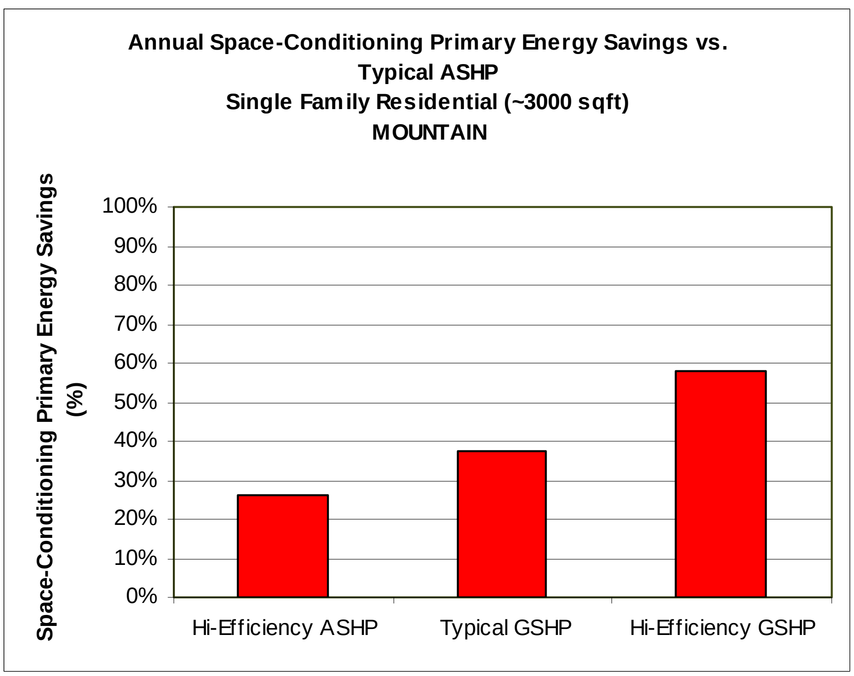

Annual Space-Conditioning Primary Energy Savings vs.
Typical ASHP
Single Family Residential (~3000 sqft)
EAST NORTH CENTRAL
Space-Conditioning Primary Energy Savings (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency ASHP
Typical GSHP
Hi-Efficiency GSHP

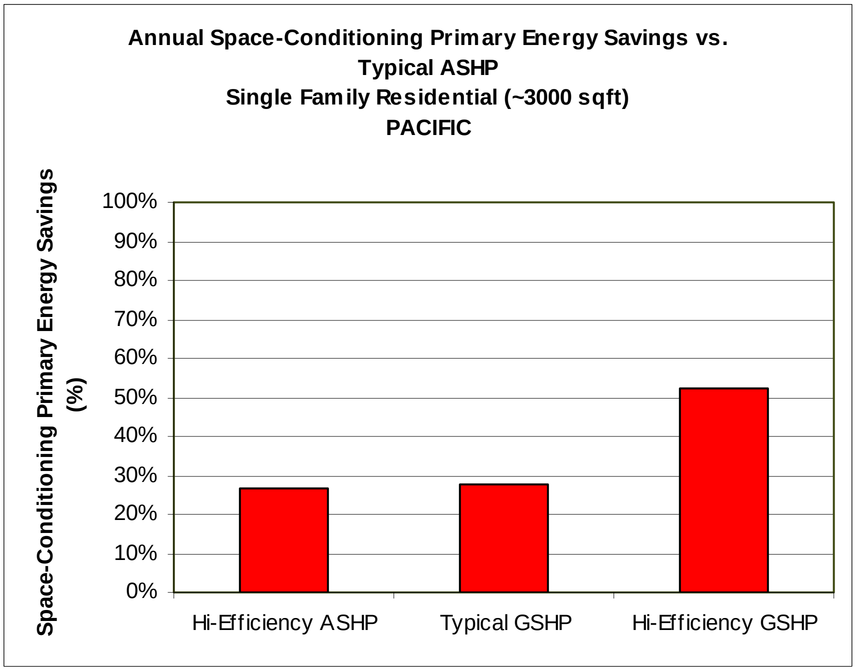

Annual Space-Conditioning Primary Energy Savings vs.
Typical ASHP
Single Family Residential (~3000 sqft)
WEST NORTH CENTRAL
Space-Conditioning Primary Energy Savings (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency ASHP
Typical GSHP
Hi-Efficiency GSHP

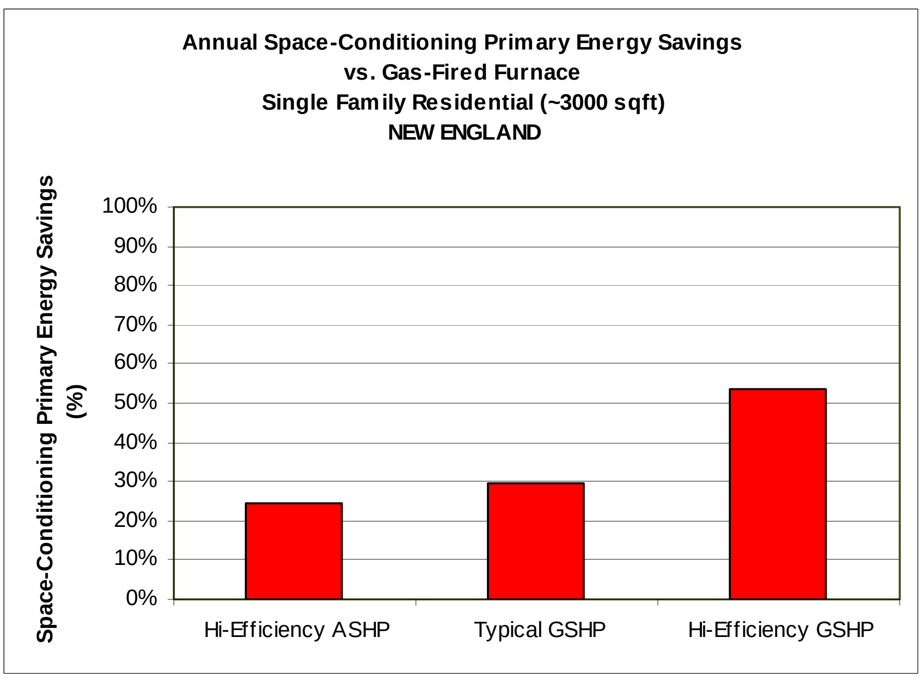

Annual Space-Conditioning Primary Energy Savings vs.
Typical ASHP
Single Family Residential (~3000 sqft)
SOUTH ATLANTIC
Space-Conditioning Primary Energy Savings (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency ASHP
Typical GSHP
Hi-Efficiency GSHP

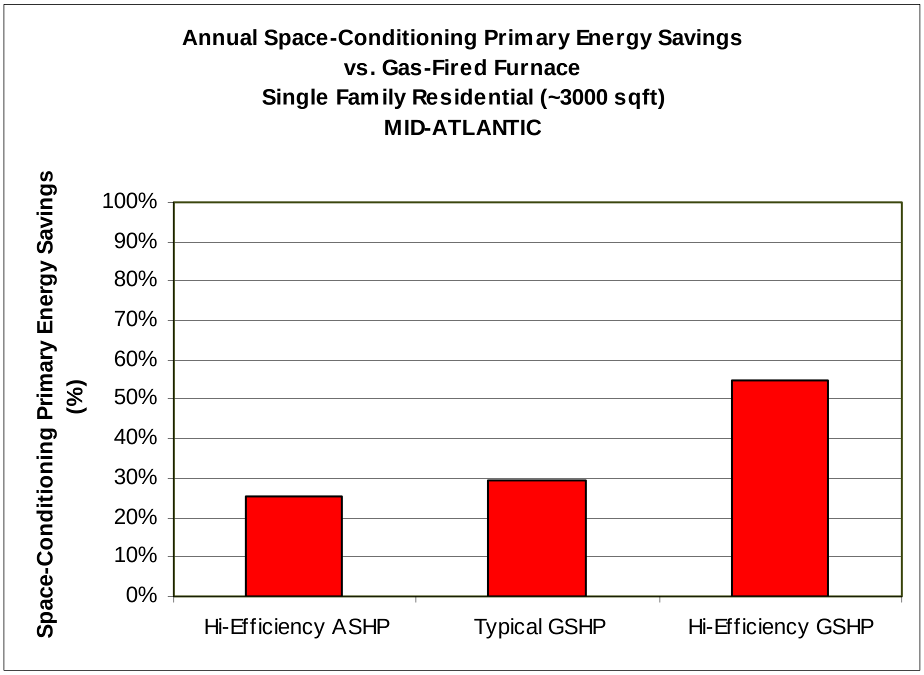

Annual Space-Conditioning Primary Energy Savings vs.
Typical ASHP
Single Family Residential (~3000 sqft)
EAST SOUTH CENTRAL
Space-Conditioning Primary Energy Savings (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency ASHP
Typical GSHP
Hi-Efficiency GSHP

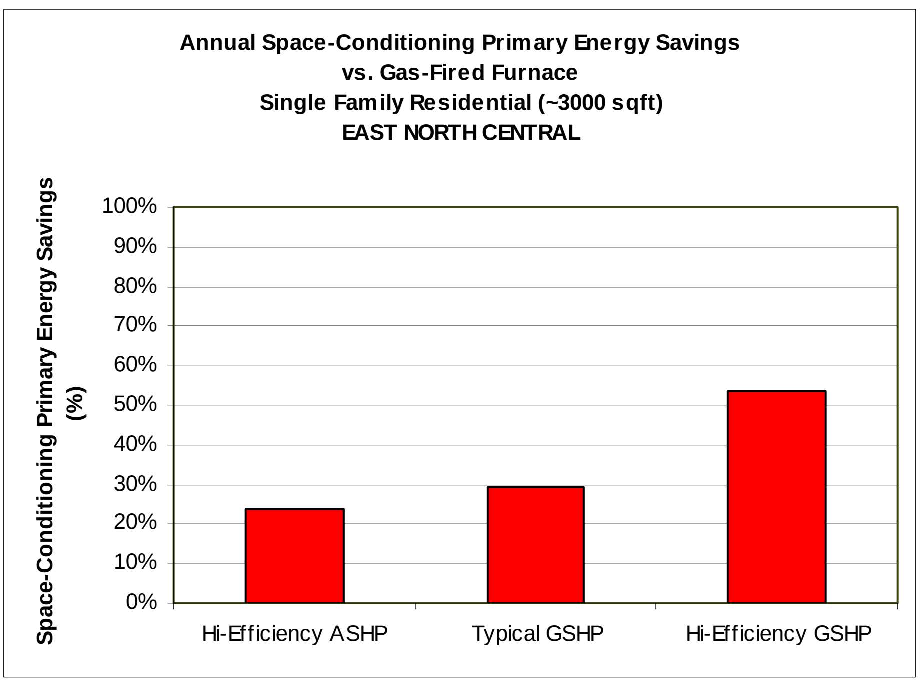

Annual Space-Conditioning Primary Energy Savings vs.
Typical ASHP
Single Family Residential (~3000 sqft)
WEST SOUTH CENTRAL
Space-Conditioning Primary Energy Savings
(%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency ASHP
Typical GSHP
Hi-Efficiency GSHP

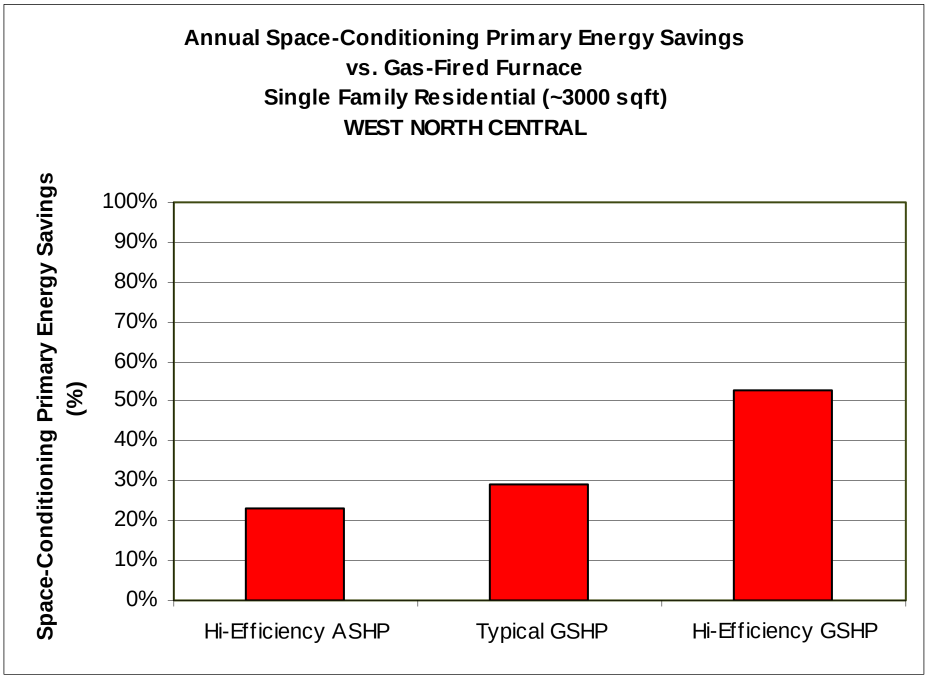

Annual Space-Conditioning Primary Energy Savings vs.
Typical ASHP
Single Family Residential (~3000 sqft)
MOUNTAIN
Space-Conditioning Primary Energy Savings
(%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency ASHP
Typical GSHP
Hi-Efficiency GSHP

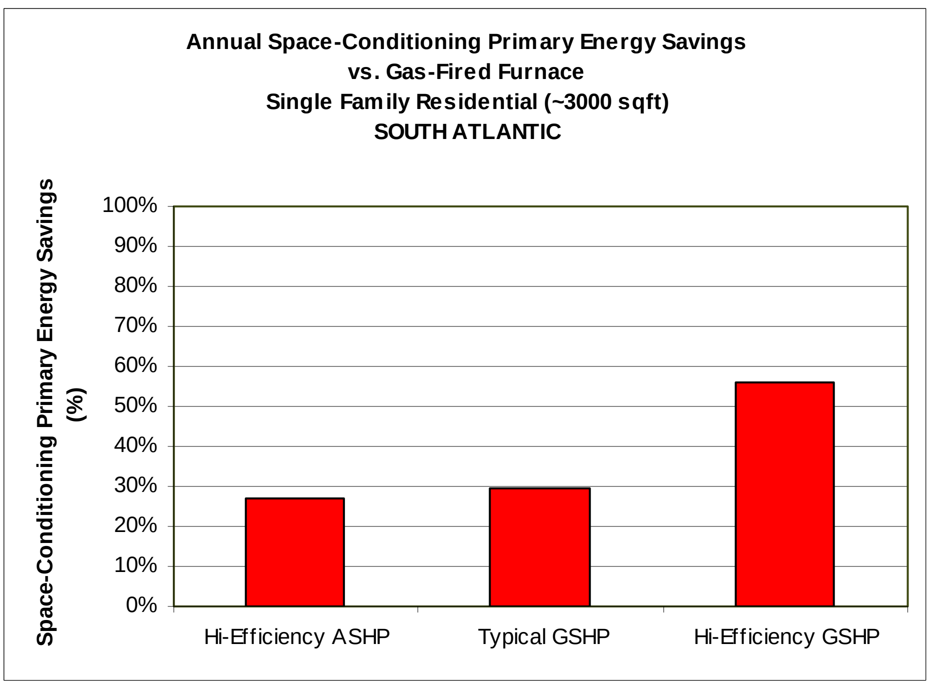

Annual Space-Conditioning Primary Energy Savings vs.
Typical ASHP
Single Family Residential (~3000 sqft)
PACIFIC
Space-Conditioning Primary Energy Savings
(%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency ASHP
Typical GSHP
Hi-Efficiency GSHP

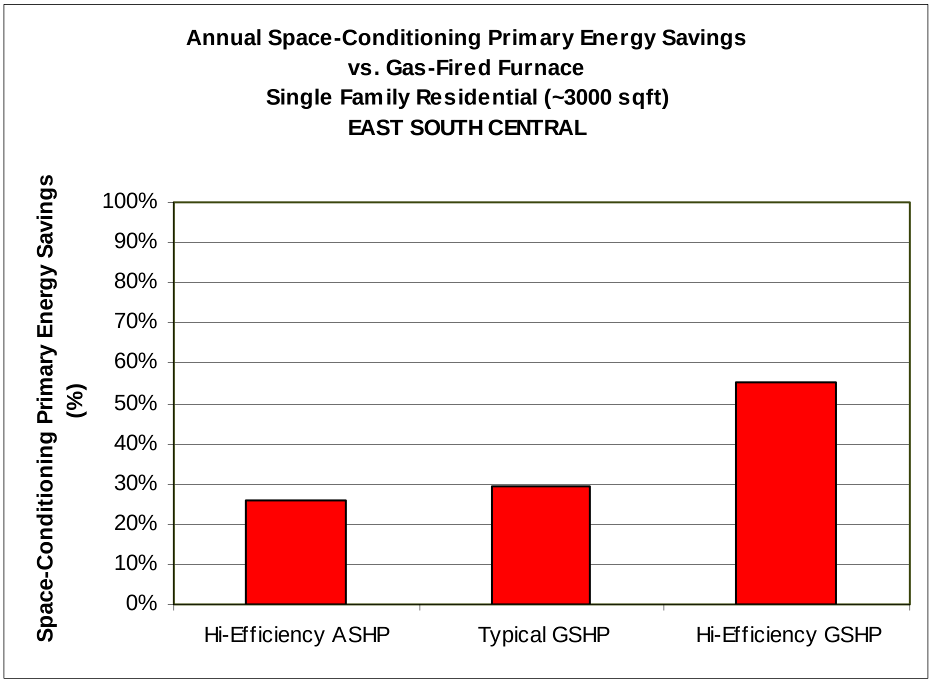

Annual Space-Conditioning Primary Energy Savings
vs. Gas-Fired Furnace
Single Family Residential (~3000 sqft)
NEW ENGLAND
Space-Conditioning Primary Energy Savings
(%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency ASHP
Typical GSHP
Hi-Efficiency GSHP

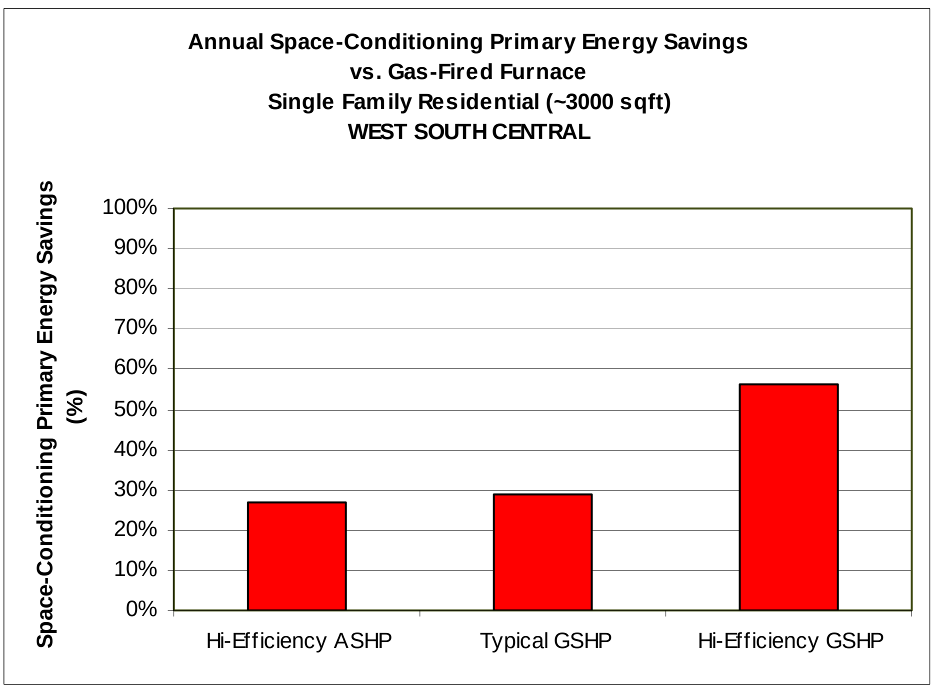

Annual Space-Conditioning Primary Energy Savings
vs. Gas-Fired Furnace
Single Family Residential (~3000 sqft)
MID-ATLANTIC
Space-Conditioning Primary Energy Savings
(%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency ASHP
Typical GSHP
Hi-Efficiency GSHP

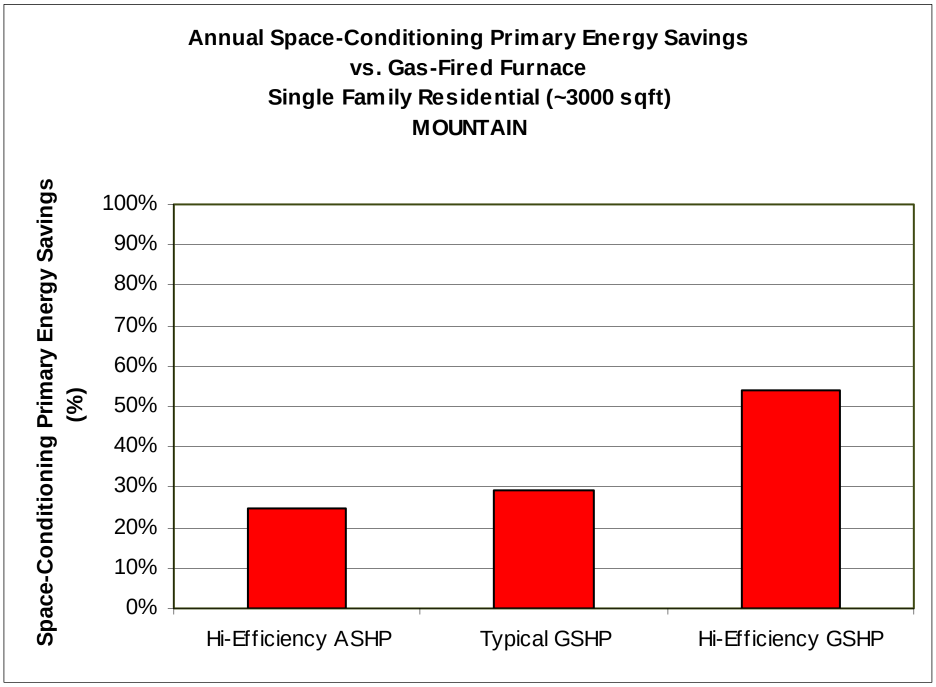

Annual Space-Conditioning Primary Energy Savings
vs. Gas-Fired Furnace
Single Family Residential (~3000 sqft)
EAST NORTH CENTRAL
Space-Conditioning Primary Energy Savings
(%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency ASHP
Typical GSHP
Hi-Efficiency GSHP

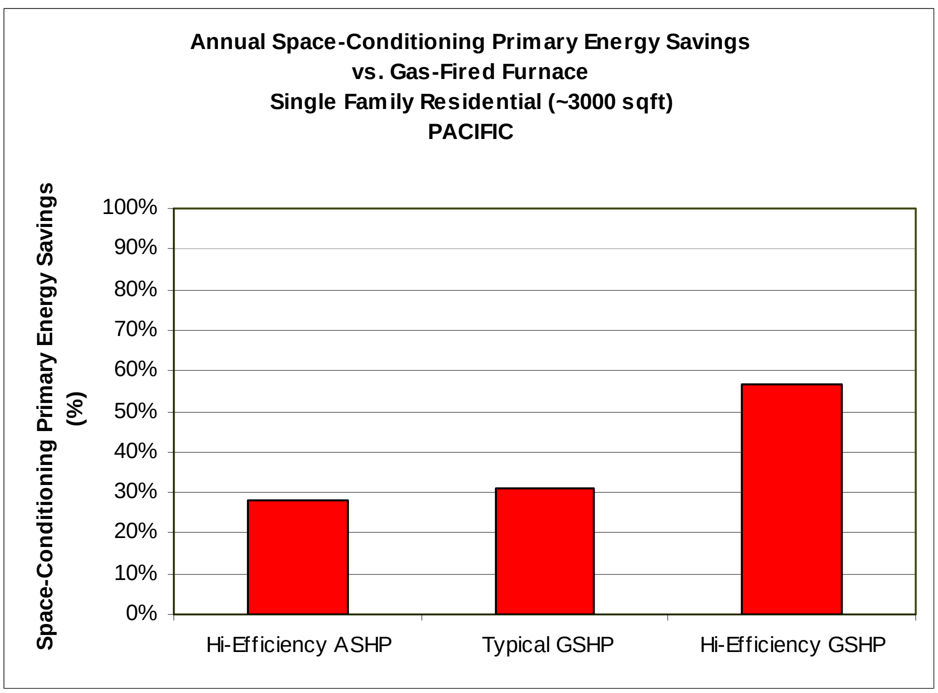

Annual Space-Conditioning Primary Energy Savings
vs. Gas-Fired Furnace
Single Family Residential (~3000 sqft)
WEST NORTH CENTRAL
Space-Conditioning Primary Energy Savings (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency ASHP
Typical GSHP
Hi-Efficiency GSHP


Annual Space-Conditioning Primary Energy Savings
vs. Gas-Fired Furnace
Single Family Residential (~3000 sqft)
SOUTH ATLANTIC
Space-Conditioning Primary Energy Savings (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency ASHP
Typical GSHP
Hi-Efficiency GSHP

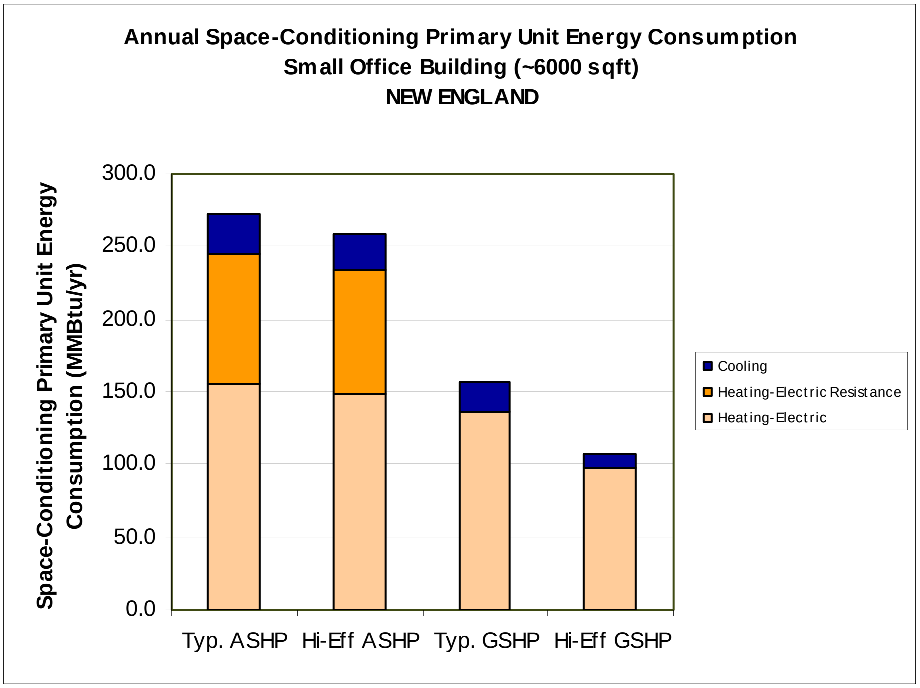

Annual Space-Conditioning Primary Energy Savings
vs. Gas-Fired Furnace
Single Family Residential (~3000 sqft)
EAST SOUTH CENTRAL
Space-Conditioning Primary Energy Savings (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency ASHP
Typical GSHP
Hi-Efficiency GSHP

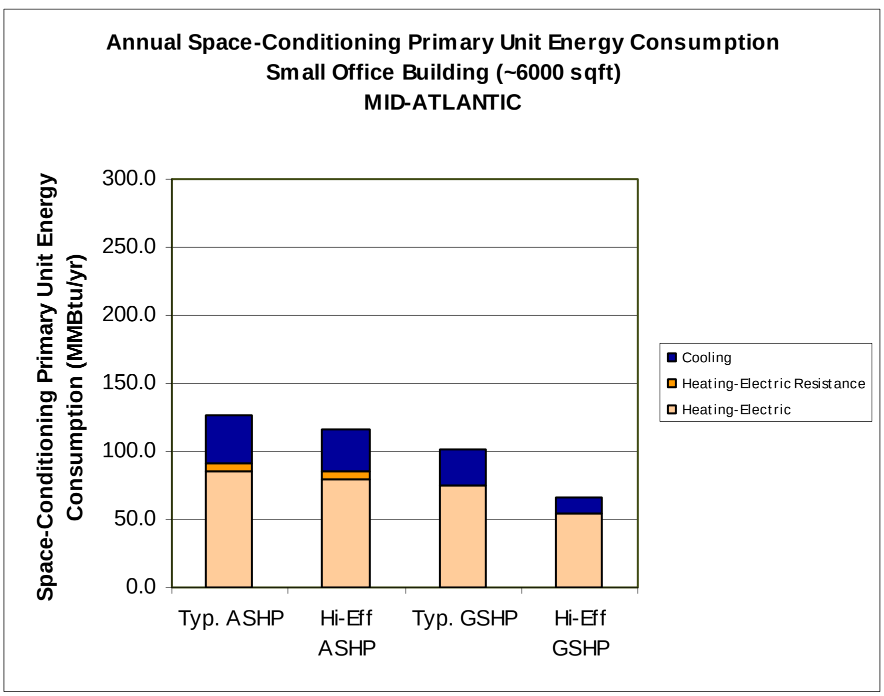

Annual Space-Conditioning Primary Energy Savings
vs. Gas-Fired Furnace
Single Family Residential (~3000 sqft)
WEST SOUTH CENTRAL
Space-Conditioning Primary Energy Savings (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency ASHP
Typical GSHP
Hi-Efficiency GSHP

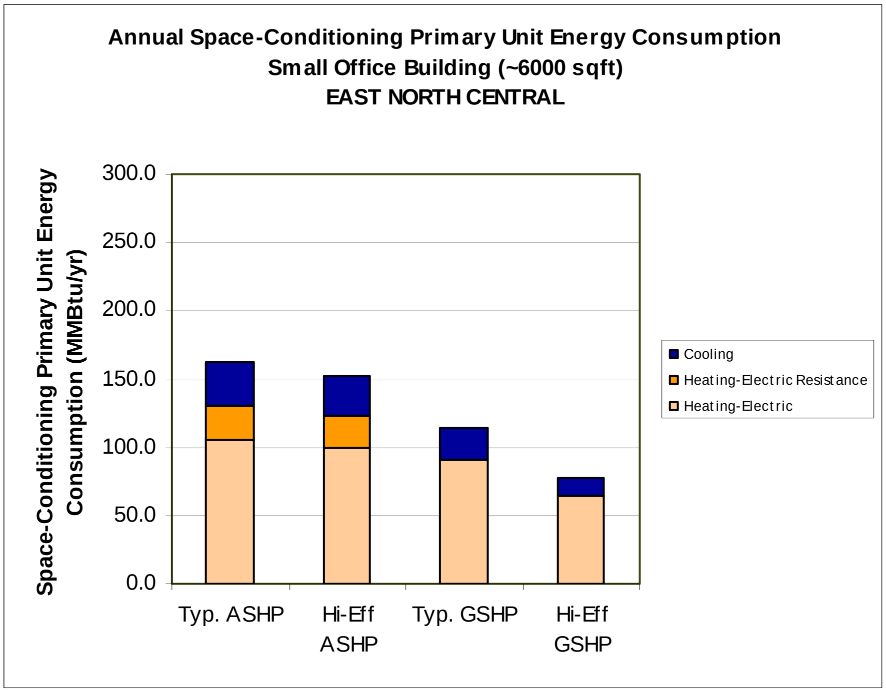

Annual Space-Conditioning Primary Energy Savings
vs. Gas-Fired Furnace
Single Family Residential (~3000 sqft)
MOUNTAIN
Space-Conditioning Primary Energy Savings (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency ASHP
Typical GSHP
Hi-Efficiency GSHP

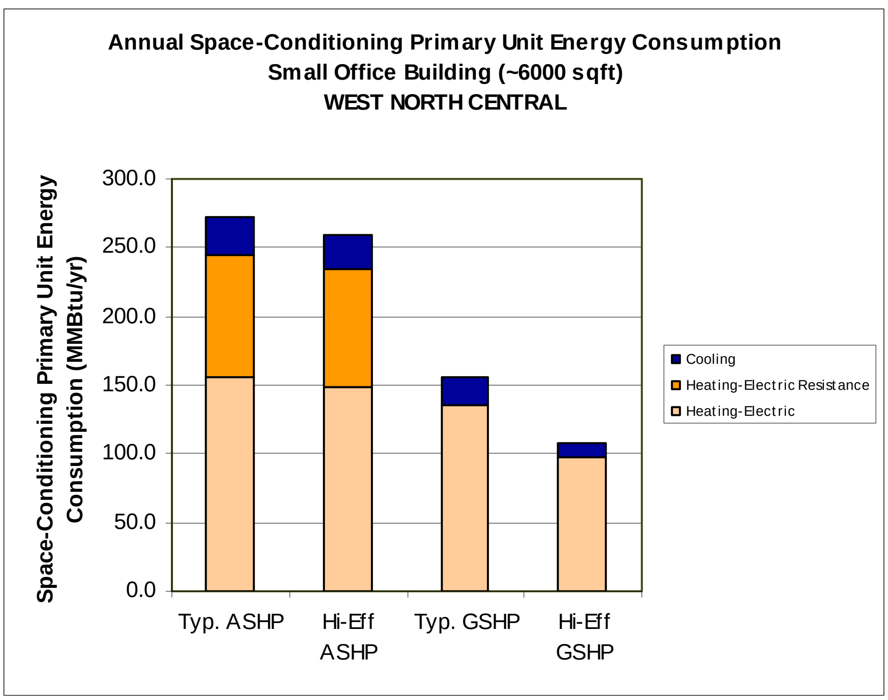

Annual Space-Conditioning Primary Energy Savings
vs. Gas-Fired Furnace
Single Family Residential (~3000 sqft)
PACIFIC
Space-Conditioning Primary Energy Savings (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency ASHP
Typical GSHP
Hi-Efficiency GSHP

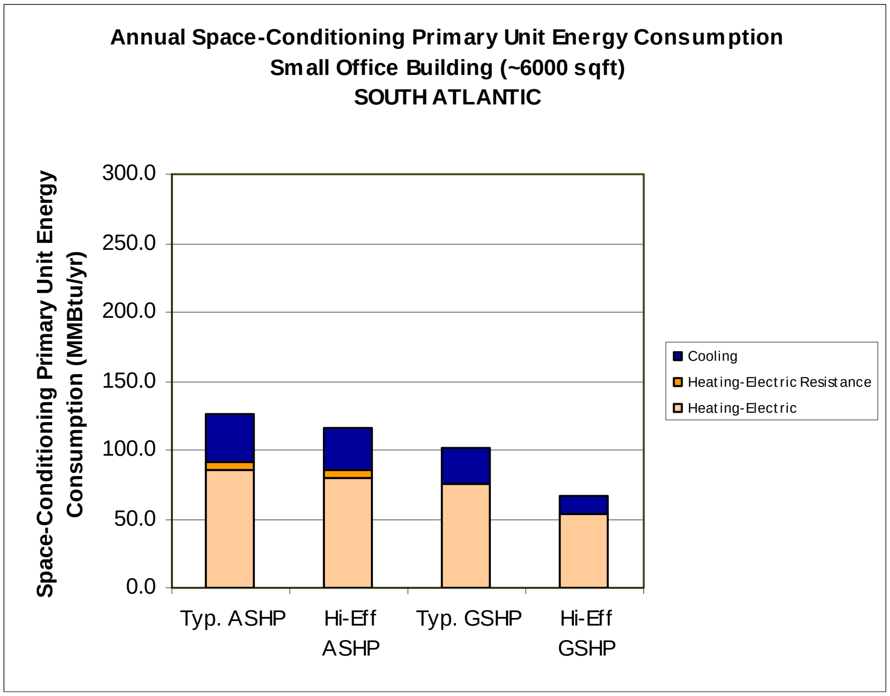
Appendix D: Commercial Unit Energy Consumptions

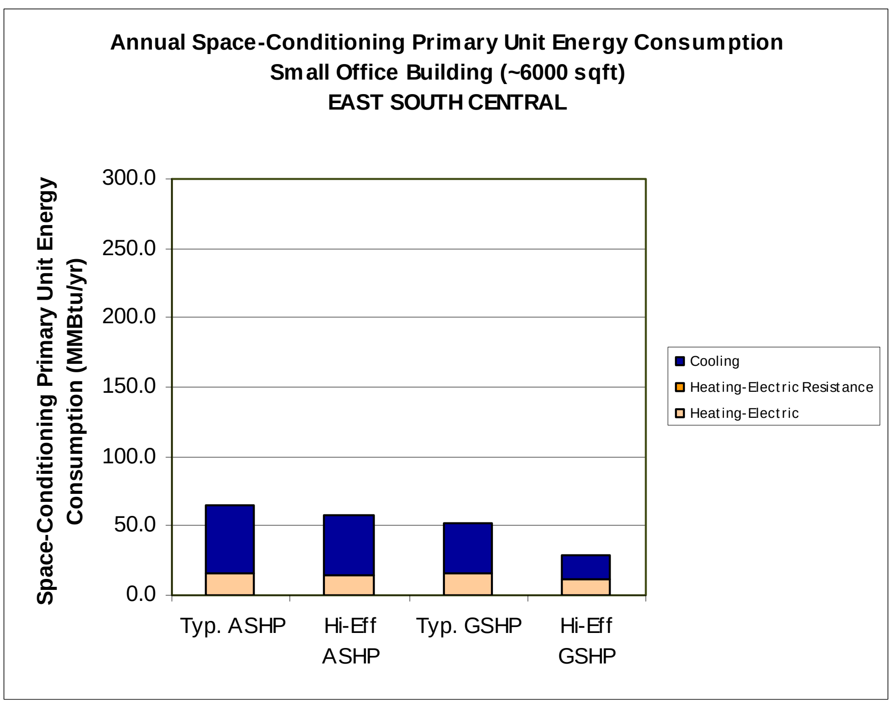


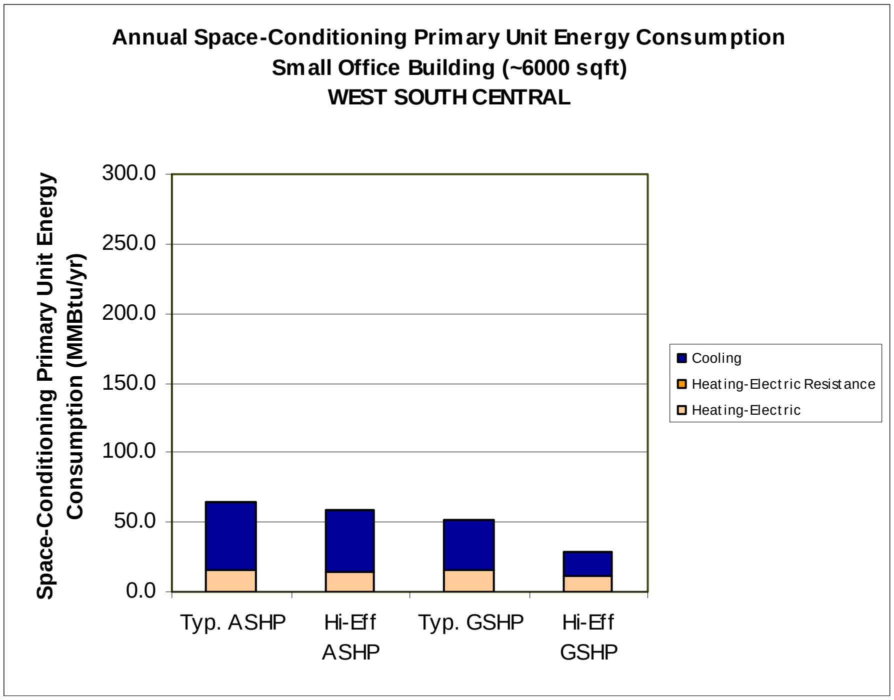


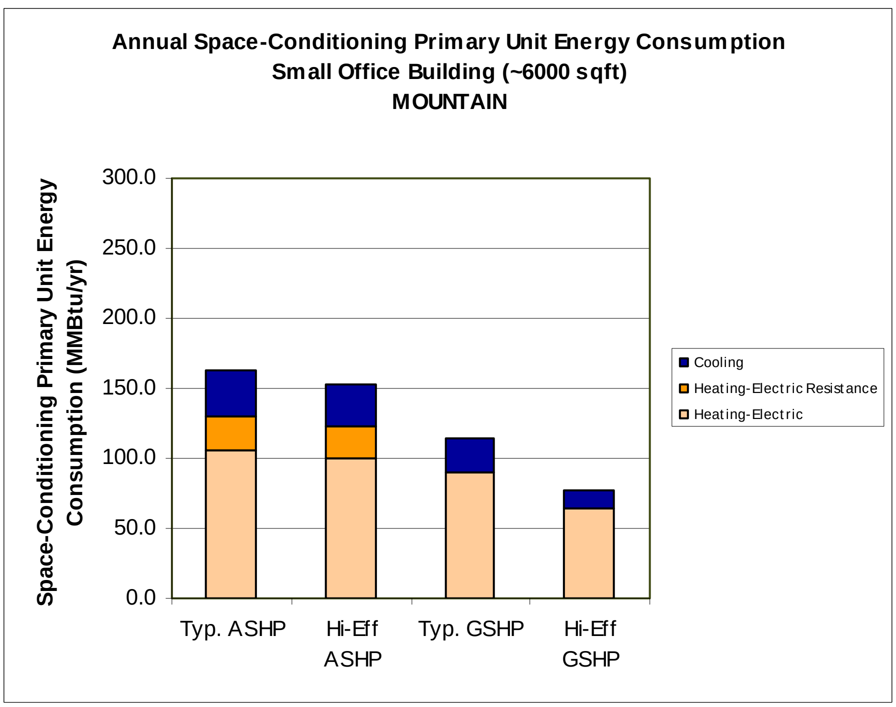

Annual Space-Conditioning Primary Unit Energy Consumption
Small Office Building (~6000 sqft)
EAST NORTH CENTRAL
Space-Conditioning Primary Unit Energy Consumption (MMBtu/yr)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling
Heating-Electric Resistance
Heating-Electric

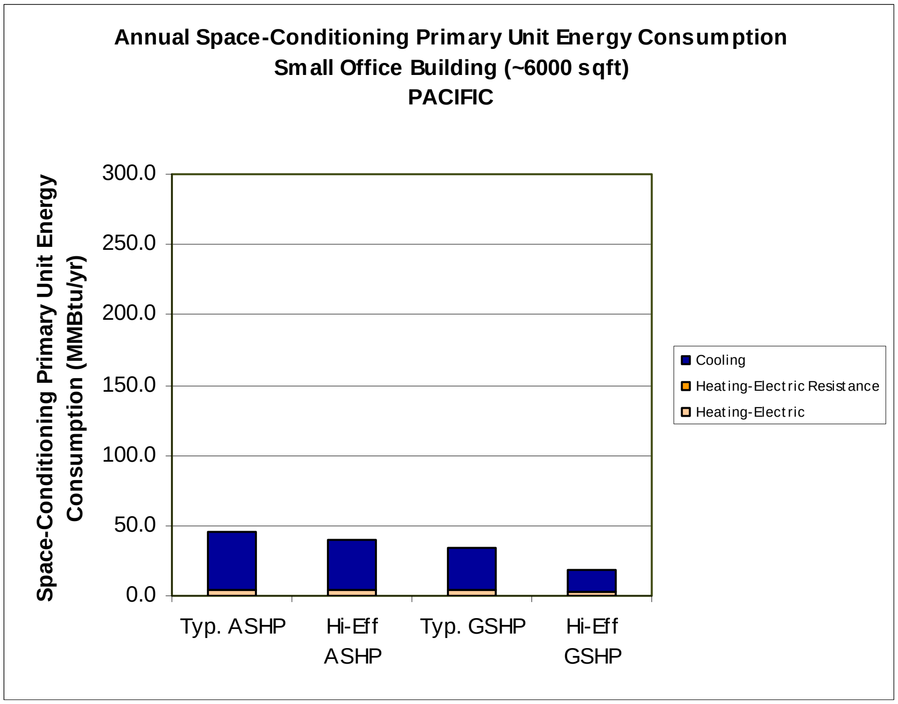

Annual Space-Conditioning Primary Unit Energy Consumption
Small Office Building (~6000 sqft)
WEST NORTH CENTRAL
Space-Conditioning Primary Unit Energy Consumption (MMBtu/yr)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling
Heating-Electric Resistance
Heating-Electric


Annual Space-Conditioning Primary Unit Energy Consumption
Small Office Building (~6000 sqft)
SOUTH ATLANTIC
Space-Conditioning Primary Unit Energy Consumption (MMBtu/yr)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling
Heating-Electric Resistance
Heating-Electric

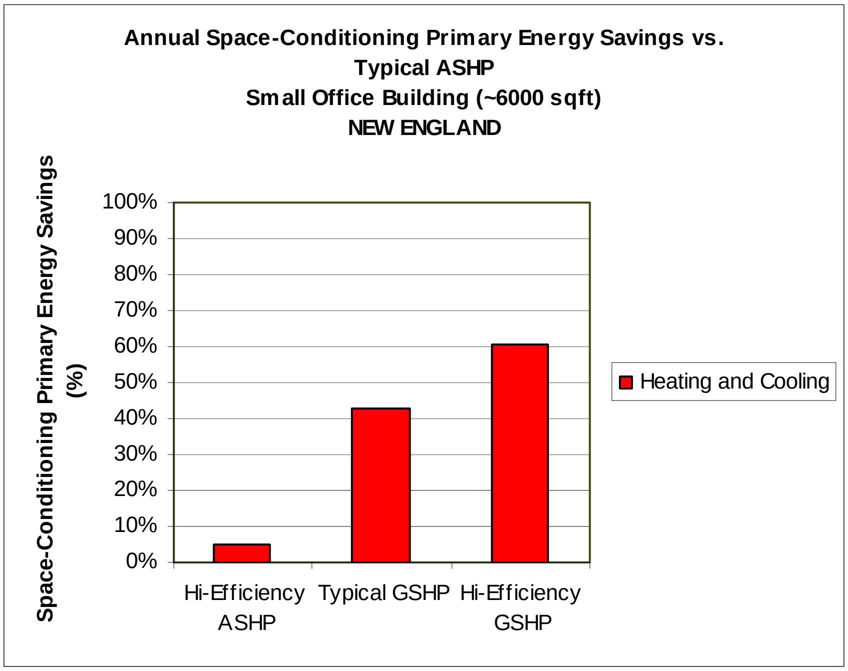

Annual Space-Conditioning Primary Unit Energy Consumption
Small Office Building (~6000 sqft)
EAST SOUTH CENTRAL
Space-Conditioning Primary Unit Energy Consumption (MMBtu/yr)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling
Heating-Electric Resistance
Heating-Electric

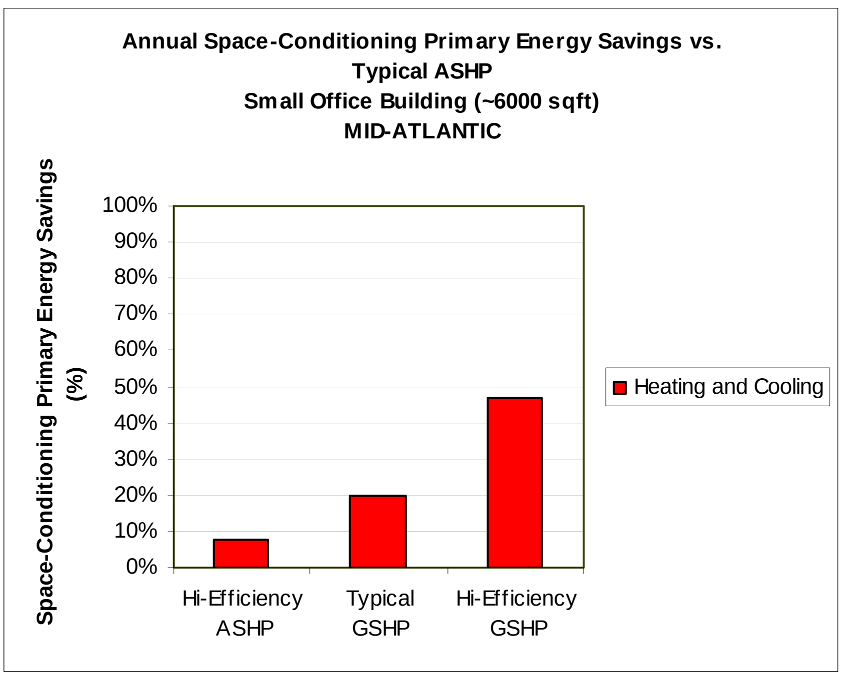

Annual Space-Conditioning Primary Unit Energy Consumption
Small Office Building (~6000 sqft)
WEST SOUTH CENTRAL
Space-Conditioning Primary Unit Energy Consumption (MMBtu/yr)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling
Heating-Electric Resistance
Heating-Electric

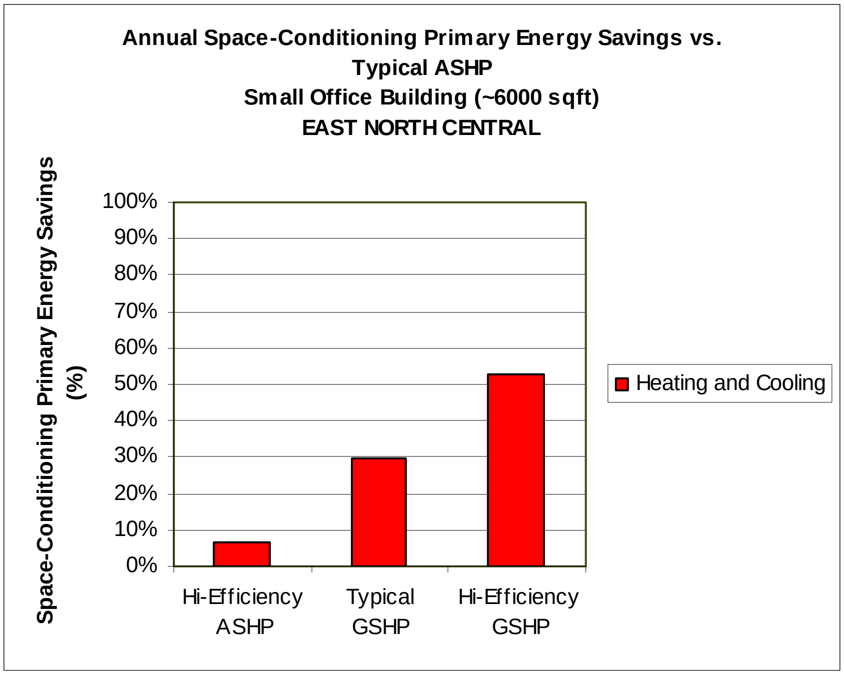

Annual Space-Conditioning Primary Unit Energy Consumption
Small Office Building (~6000 sqft)
MOUNTAIN
Space-Conditioning Primary Unit Energy Consumption (MMBtu/yr)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling
Heating-Electric Resistance
Heating-Electric

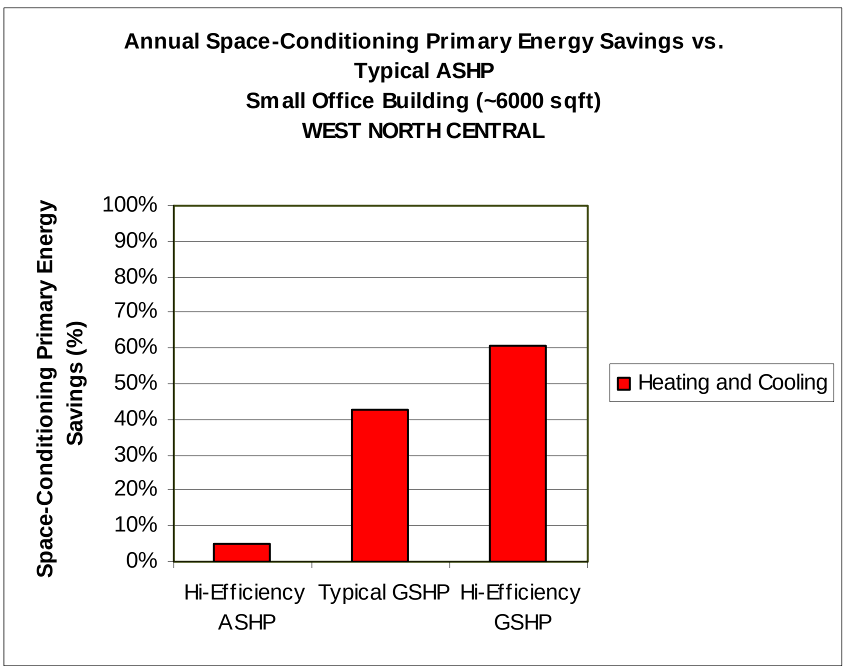

Annual Space-Conditioning Primary Unit Energy Consumption
Small Office Building (~6000 sqft)
PACIFIC
Space-Conditioning Primary Unit Energy Consumption (MMBtu/yr)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling
Heating-Electric Resistance
Heating-Electric

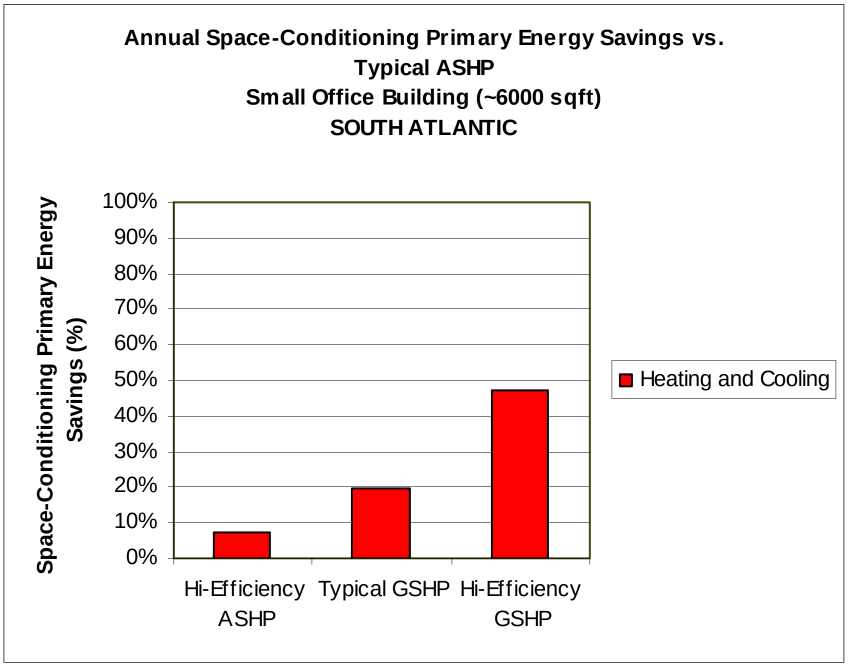
Appendix E: Commercial Unit Energy Savings

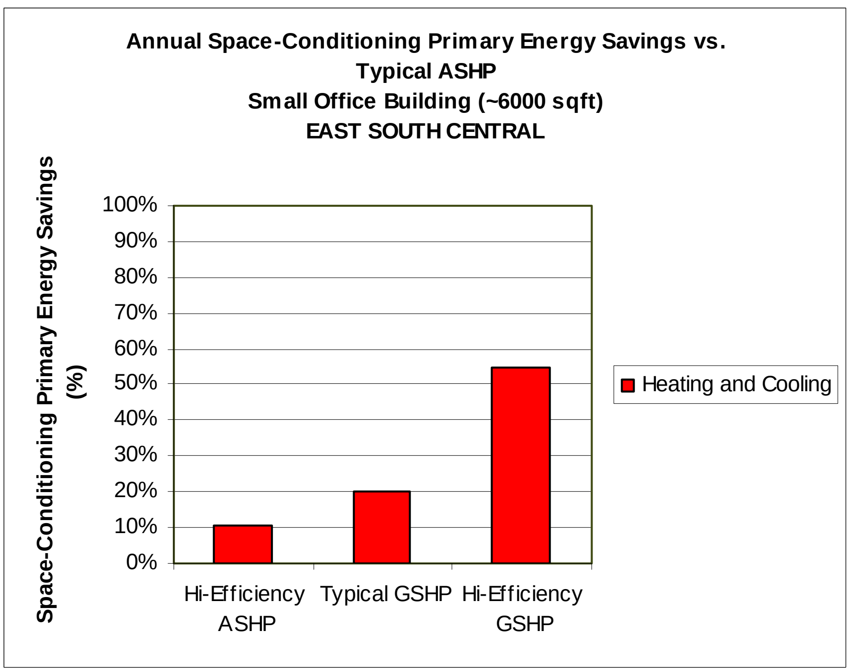


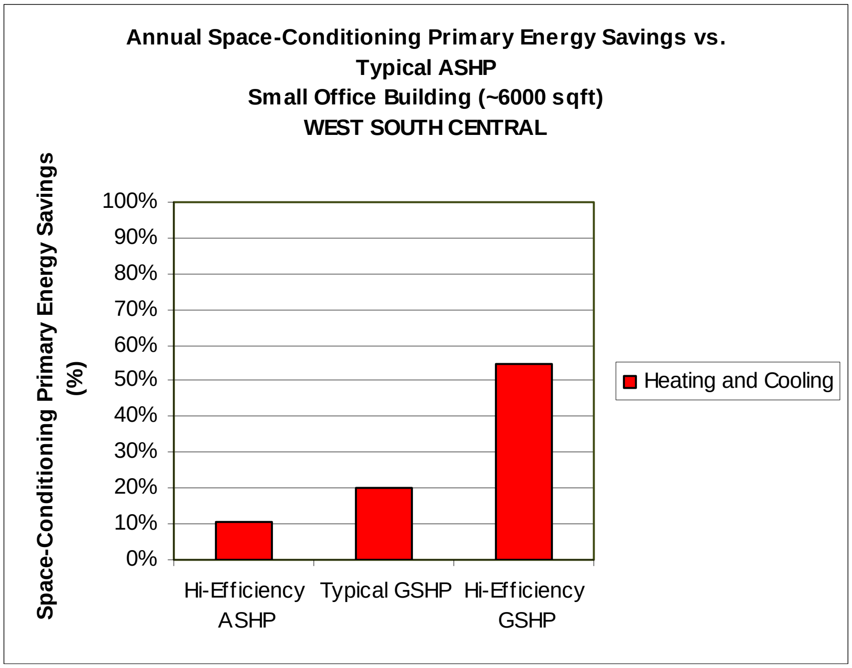


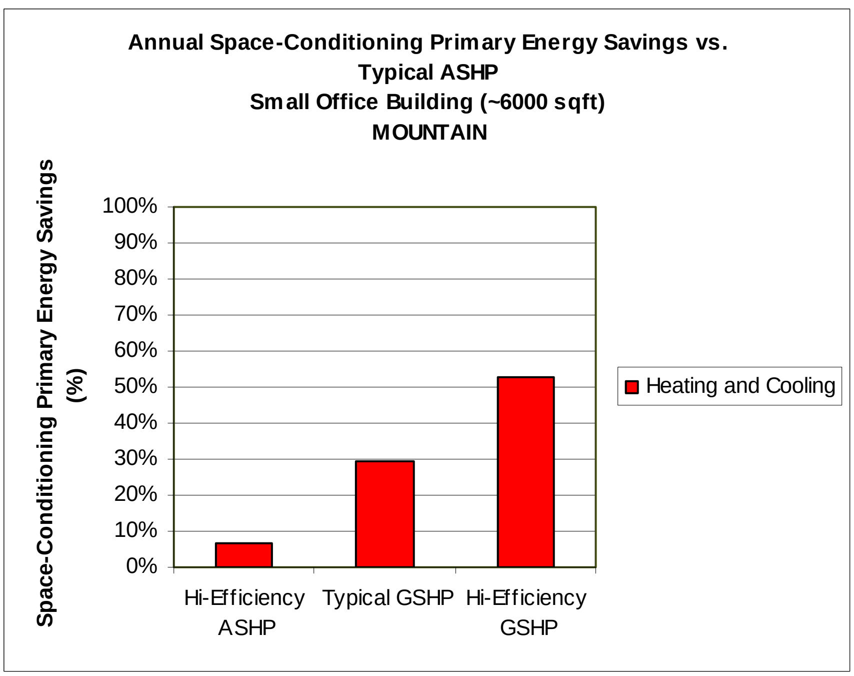

Annual Space-Conditioning Primary Energy Savings vs.
Typical ASHP
Small Office Building (~6000 sqft)
EAST NORTH CENTRAL
Space-Conditioning Primary Energy Savings (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency ASHP
Typical GSHP
Hi-Efficiency GSHP
Heating and Cooling

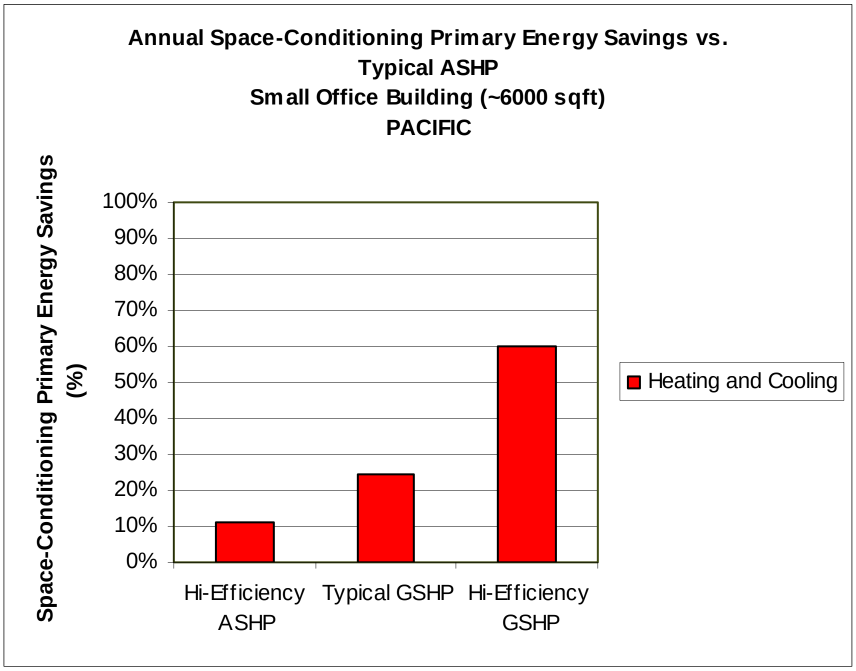

Annual Space-Conditioning Primary Energy Savings vs.
Typical ASHP
Small Office Building (~6000 sqft)
WEST NORTH CENTRAL
Space-Conditioning Primary Energy Savings (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency ASHP
Typical GSHP
Hi-Efficiency GSHP
Heating and Cooling


Annual Space-Conditioning Primary Energy Savings vs.
Typical ASHP
Small Office Building (~6000 sqft)
SOUTH ATLANTIC
Space-Conditioning Primary Energy Savings (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency ASHP
Typical GSHP
Hi-Efficiency GSHP
Heating and Cooling


Annual Space-Conditioning Primary Energy Savings vs.
Typical ASHP
Small Office Building (~6000 sqft)
EAST SOUTH CENTRAL
Space-Conditioning Primary Energy Savings (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency ASHP
Typical GSHP
Hi-Efficiency GSHP
Heating and Cooling


Annual Space-Conditioning Primary Energy Savings vs.
Typical ASHP
Small Office Building (~6000 sqft)
WEST SOUTH CENTRAL
Space-Conditioning Primary Energy Savings (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency ASHP
Typical GSHP
Hi-Efficiency GSHP
Heating and Cooling


Annual Space-Conditioning Primary Energy Savings vs.
Typical ASHP
Small Office Building (~6000 sqft)
MOUNTAIN
Space-Conditioning Primary Energy Savings (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency ASHP
Typical GSHP
Hi-Efficiency GSHP
Heating and Cooling



Annual Space-Conditioning Primary Energy Savings vs.
Typical ASHP
Small Office Building (~6000 sqft)
PACIFIC
Space-Conditioning Primary Energy Savings
(%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hi-Efficiency
ASHP
Typical GSHP
Hi-Efficiency
GSHP
Heating and Cooling

Appendix F: Electricity Price Projections

As illustrated in Figures F-1 and F-2, EIA projections through 2030 for residential and commercial electricity prices vary relatively little from 2006 actual prices for each of the cases considered (high price, low price, and reference case), when correcting for inflation. Figures F-3 and F-4 illustrate that these trends hold true on a regional basis, too. Therefore, we concluded that our economic analyses could be based on 2006 electricity prices and still represent the economics for future years.

Figure F-1: Residential Electricity Price Projections

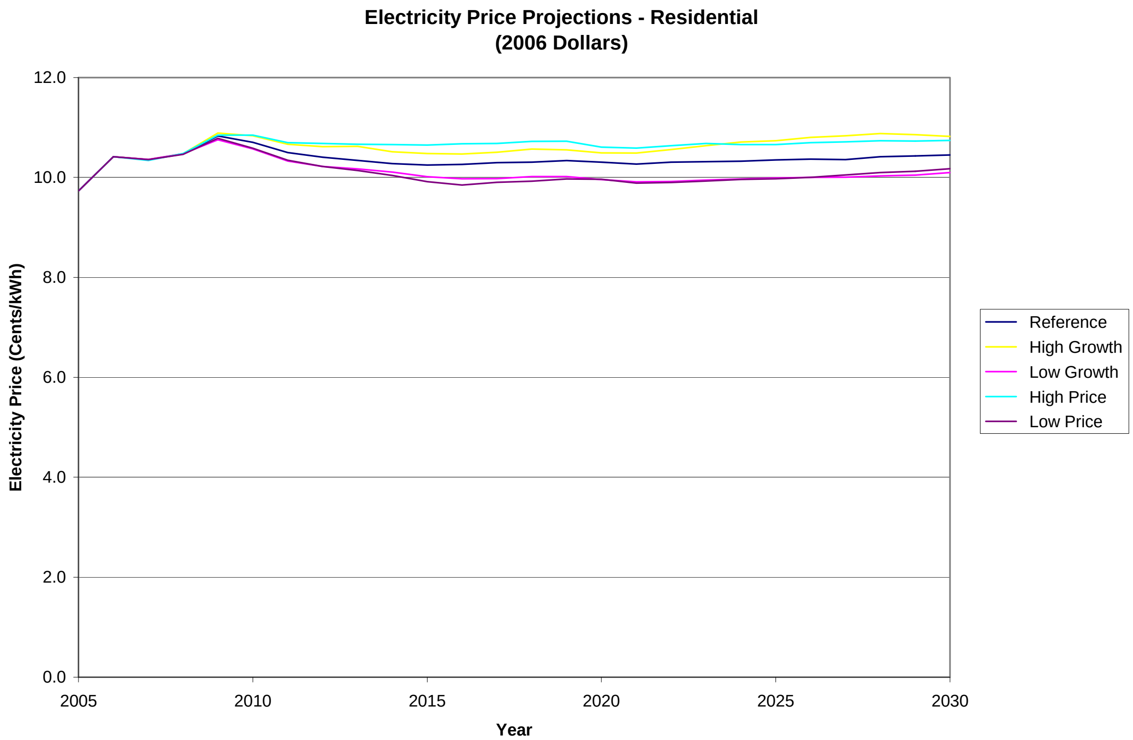


Figure F-2: Commercial Electricity Price Projections

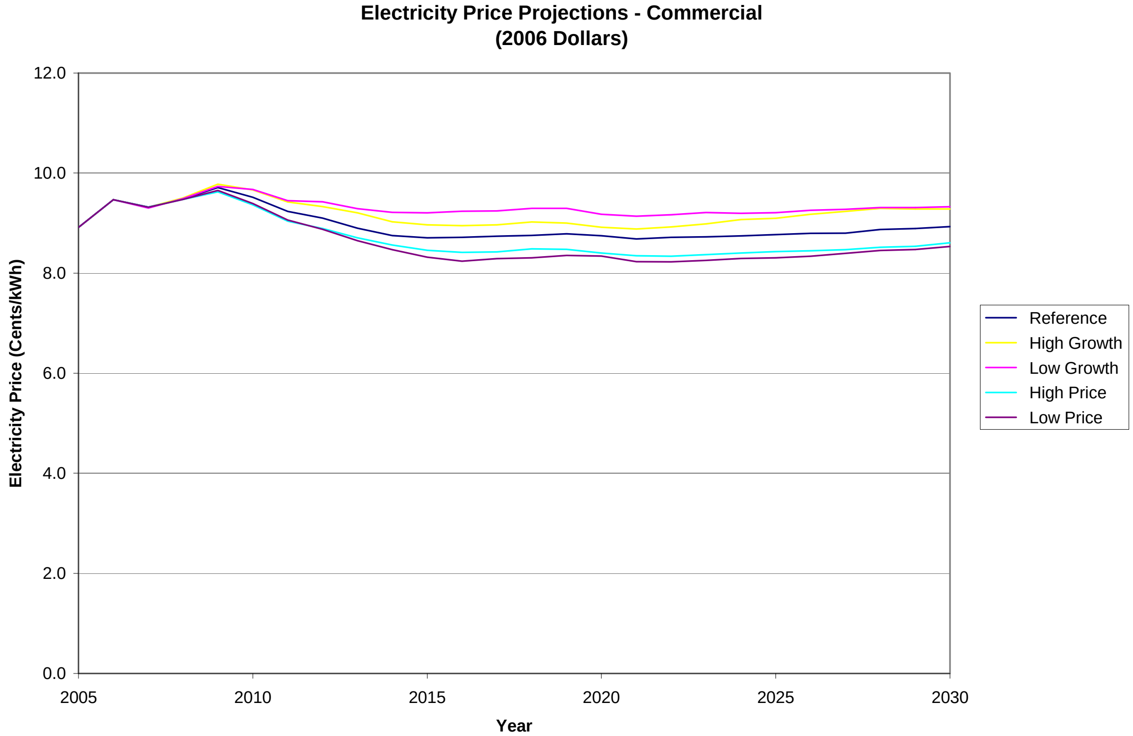


Figure F-3: Residential Electricity Price Projections by Census Region

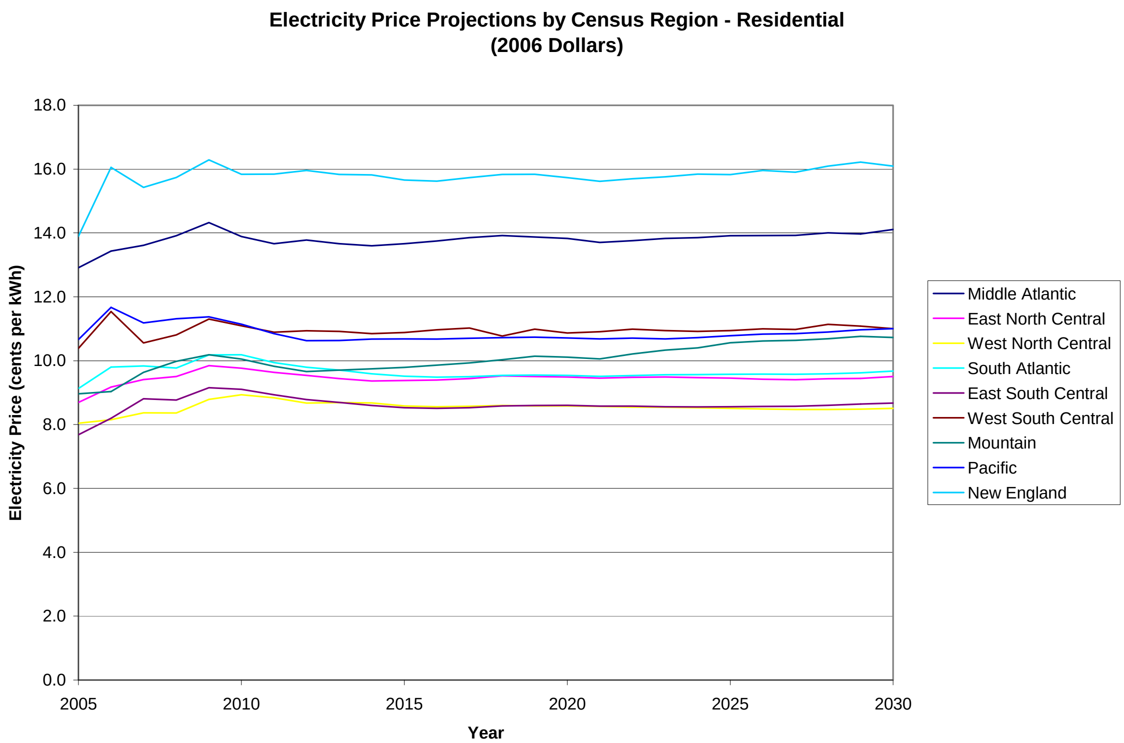
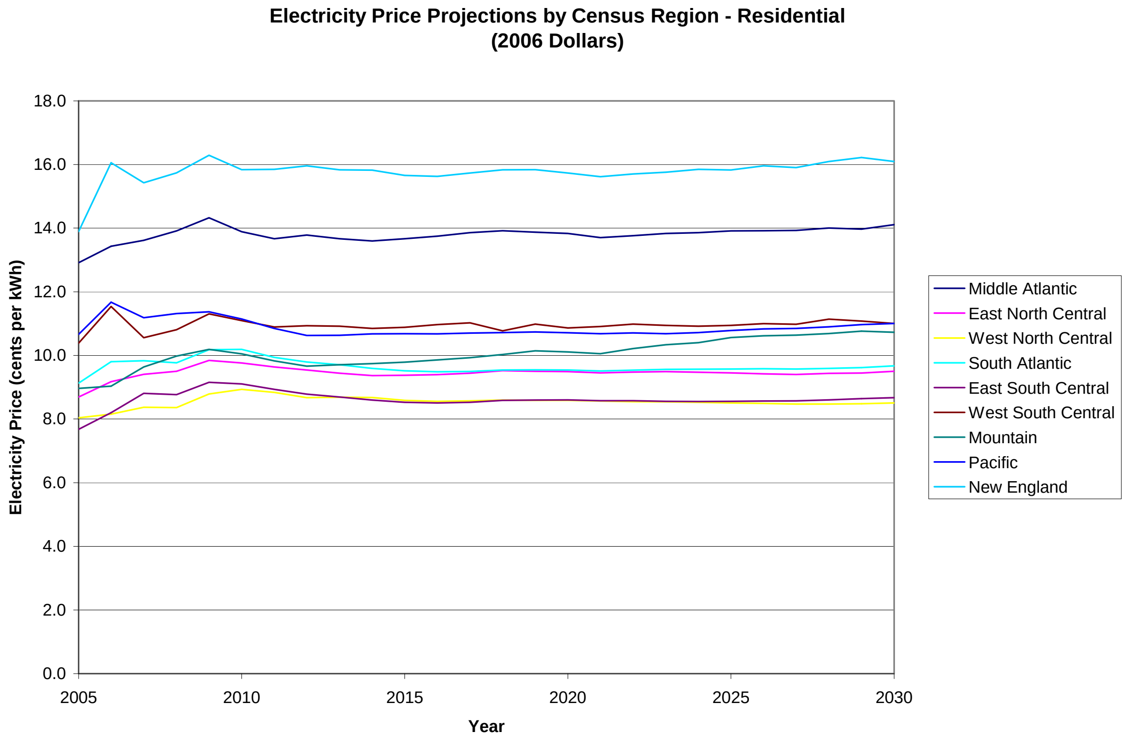
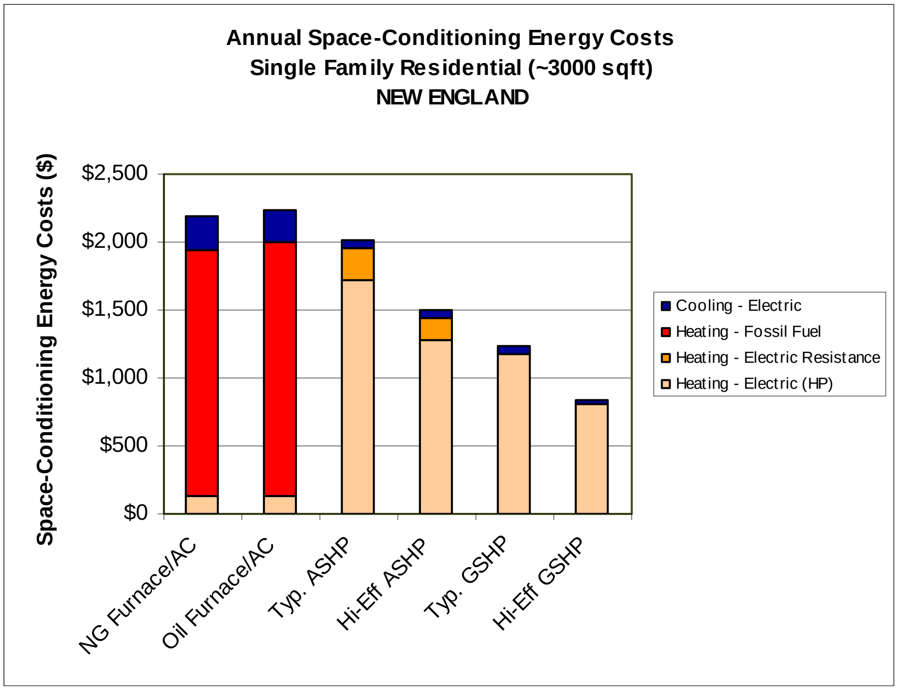
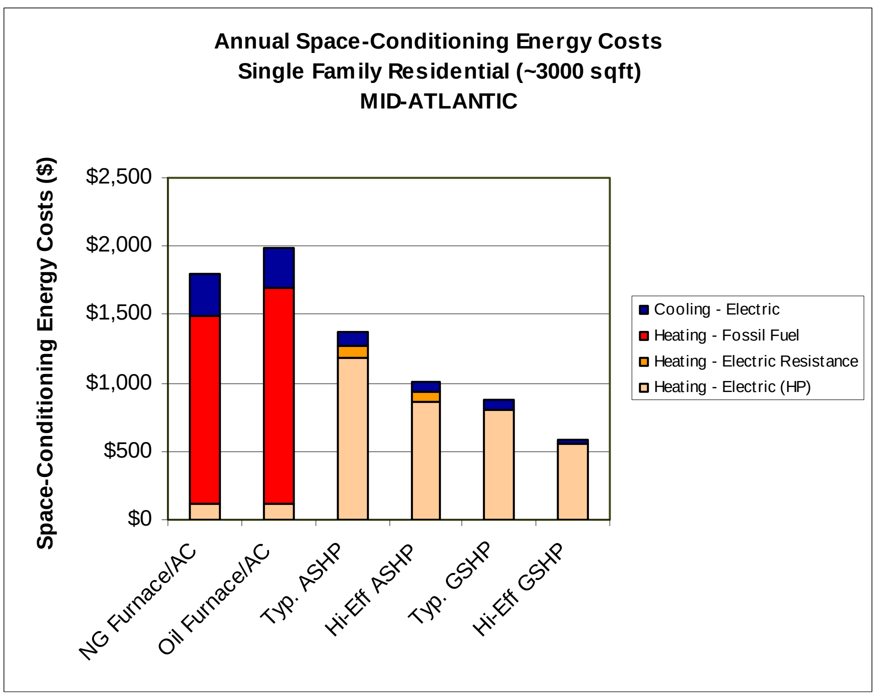


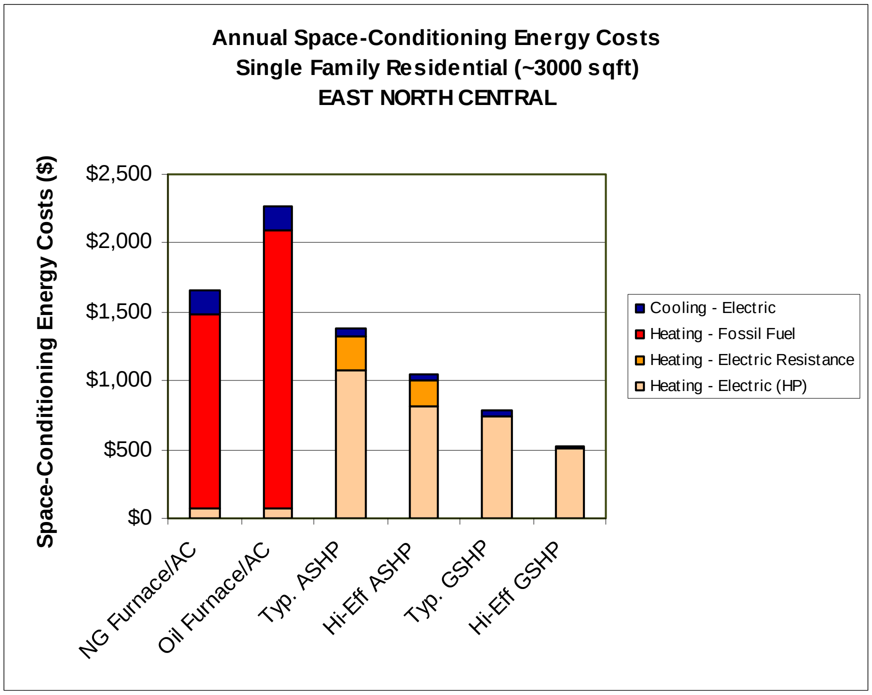
Figure F-4: Commercial Electricity Price Projections by Census Region

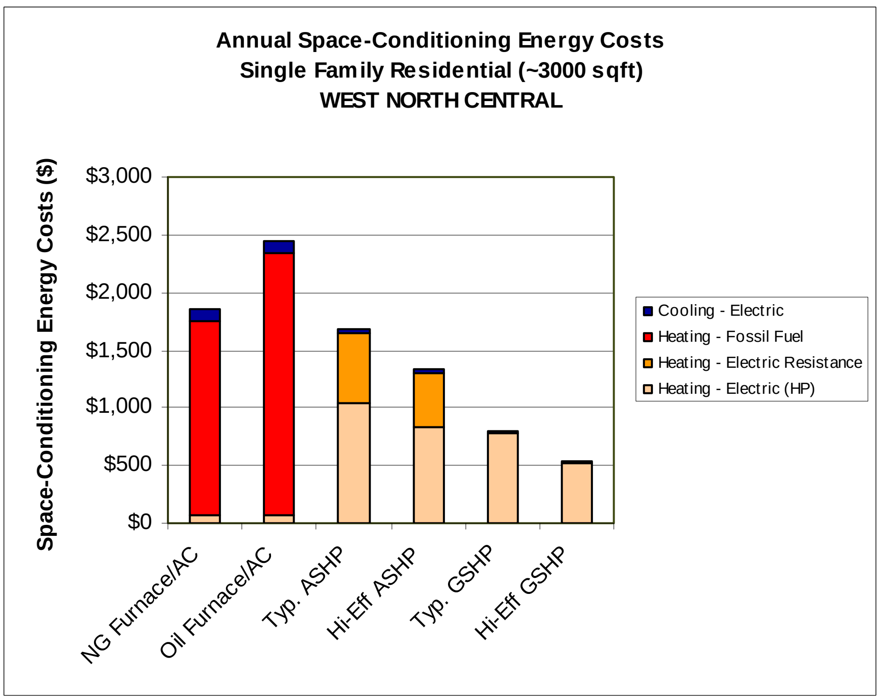

Electricity Price Projections by Census Region - Residential
(2006 Dollars)
Electricity Price (cents per kWh)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
2005
2010
2015
2020
2025
2030
Year
Middle Atlantic
East North Central
West North Central
South Atlantic
East South Central
West South Central
Mountain
Pacific
New England

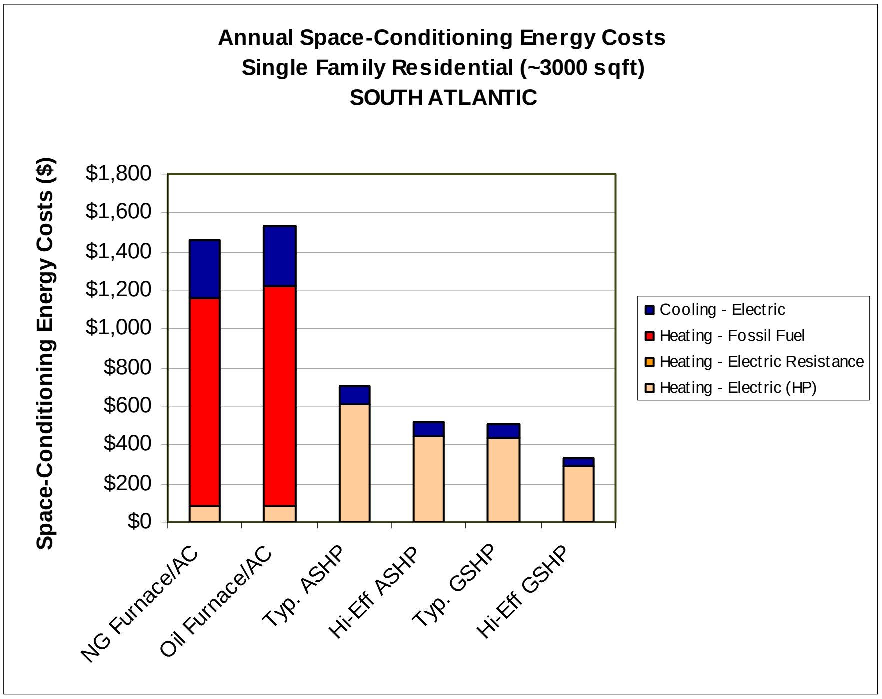
Appendix G: Residential Annual Energy Costs



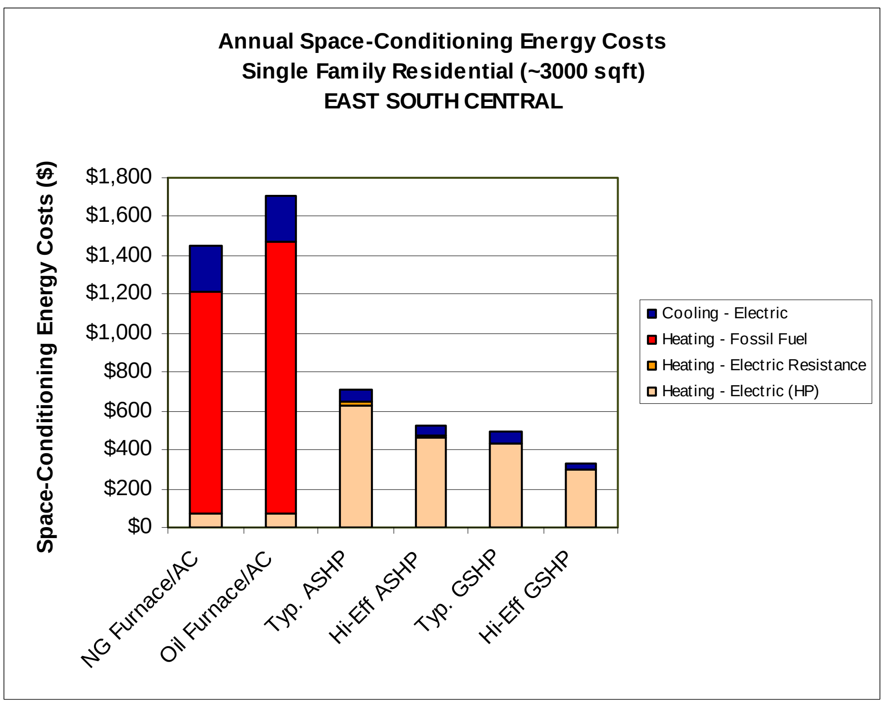



Annual Space-Conditioning Energy Costs
Single Family Residential (~3000 sqft)
EAST NORTH CENTRAL
Space-Conditioning Energy Costs ($)
$2,500
$2,000
$1,500
$1,000
$500
$0
NG Furnace/AC
Oil Furnace/AC
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling - Electric
Heating - Fossil Fuel
Heating - Electric Resistance
Heating - Electric (HP)

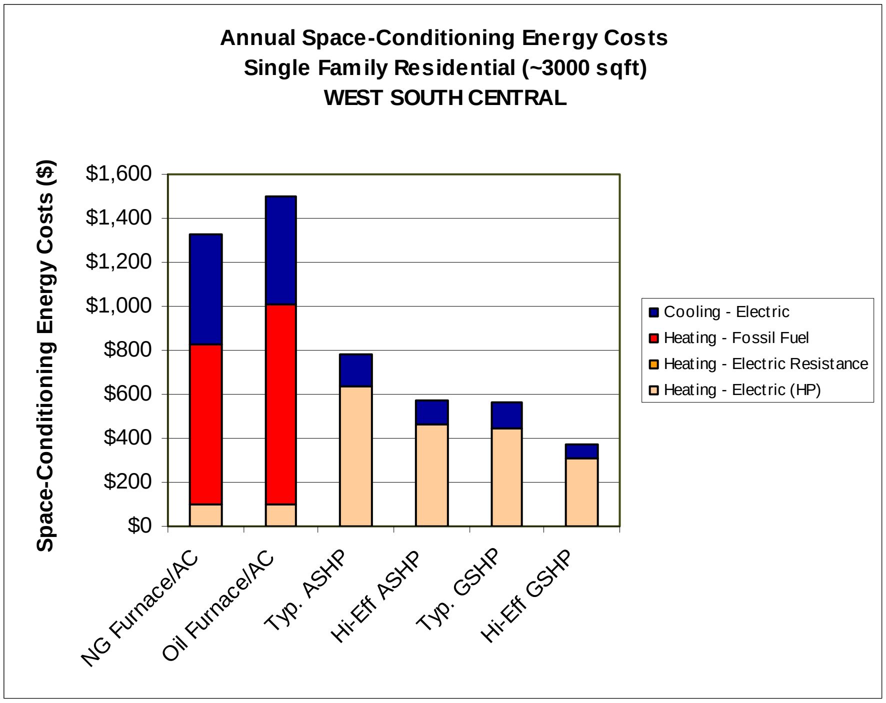

Annual Space-Conditioning Energy Costs
Single Family Residential (~3000 sqft)
WEST NORTH CENTRAL
Space-Conditioning Energy Costs ($)
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
NG Furnace/AC
Oil Furnace/AC
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling - Electric
Heating - Fossil Fuel
Heating - Electric Resistance
Heating - Electric (HP)

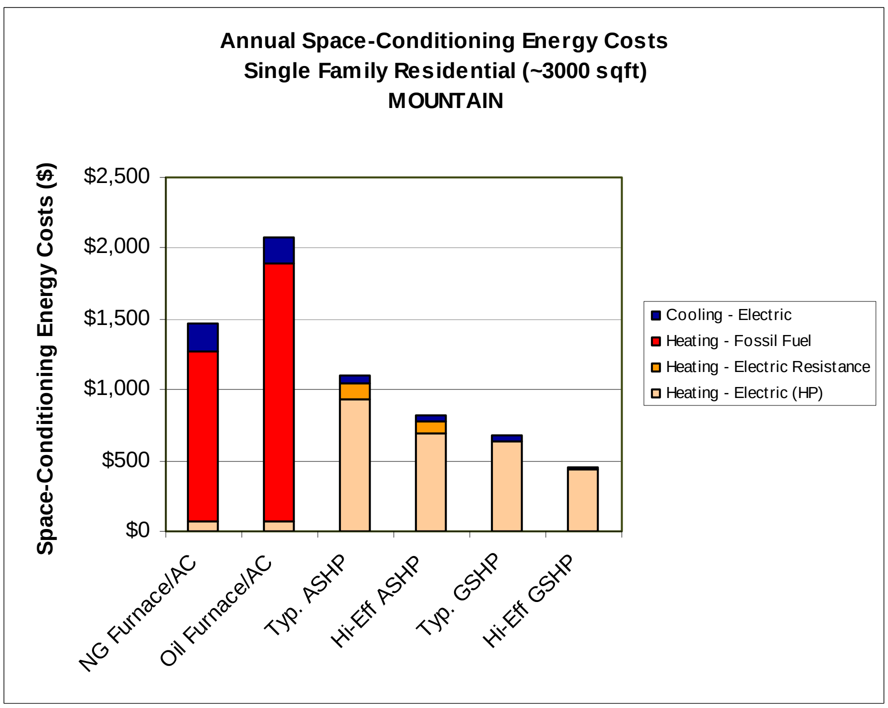


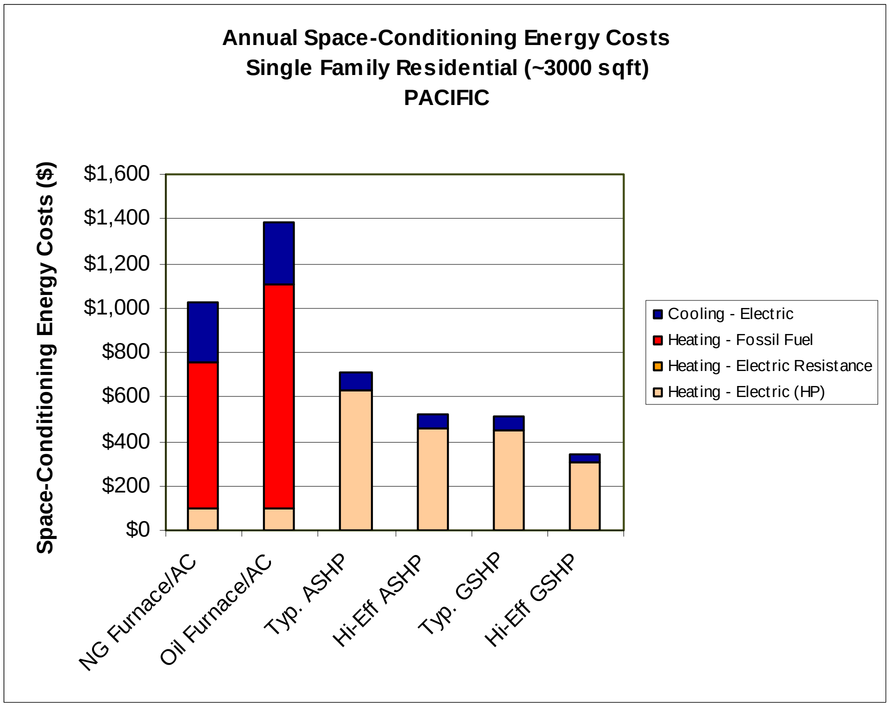
Annual Space-Conditioning Energy Costs
Single Family Residential (~3000 sqft)
SOUTH ATLANTIC
Space-Conditioning Energy Costs ($)
$1,800
$1,600
$1,400
$1,200
$1,000
$800
$600
$400
$200
$0
NG Furnace/AC
Oil Furnace/AC
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling - Electric
Heating - Fossil Fuel
Heating - Electric Resistance
Heating - Electric (HP)



Annual Space-Conditioning Energy Costs
Single Family Residential (~3000 sqft)
EAST SOUTH CENTRAL
Space-Conditioning Energy Costs ($)
$1,800
$1,600
$1,400
$1,200
$1,000
$800
$600
$400
$200
$0
NG Furnace/AC
Oil Furnace/AC
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling - Electric
Heating - Fossil Fuel
Heating - Electric Resistance
Heating - Electric (HP)

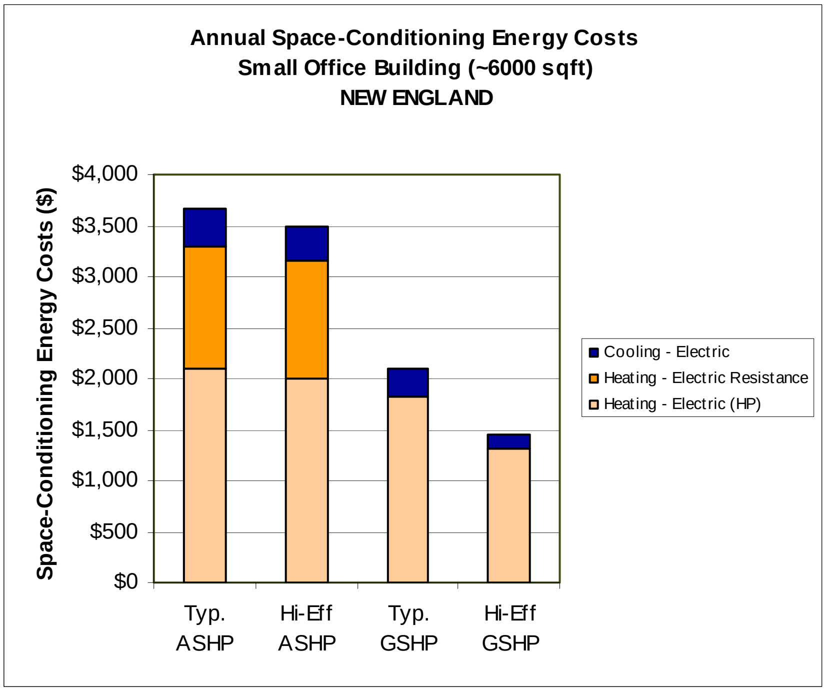

Annual Space-Conditioning Energy Costs
Single Family Residential (~3000 sqft)
WEST SOUTH CENTRAL
Space-Conditioning Energy Costs ($)
$1,600
$1,400
$1,200
$1,000
$800
$600
$400
$200
$0
NG Furnace/AC
Oil Furnace/AC
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling - Electric
Heating - Fossil Fuel
Heating - Electric Resistance
Heating - Electric (HP)

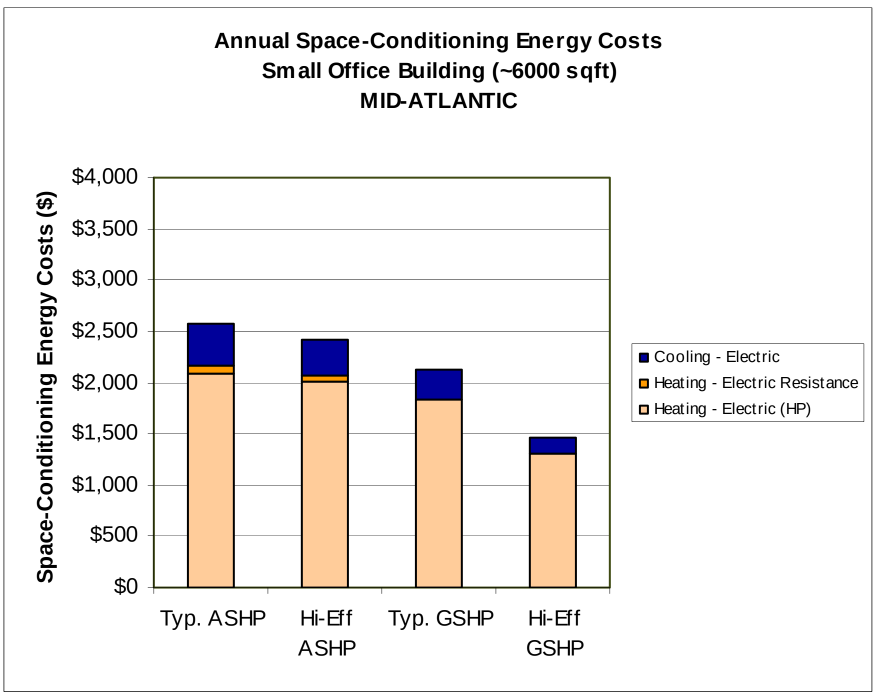

Annual Space-Conditioning Energy Costs
Single Family Residential (~3000 sqft)
MOUNTAIN
Space-Conditioning Energy Costs ($)
$2,500
$2,000
$1,500
$1,000
$500
$0
NG Furnace/AC
Oil Furnace/AC
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling - Electric
Heating - Fossil Fuel
Heating - Electric Resistance
Heating - Electric (HP)

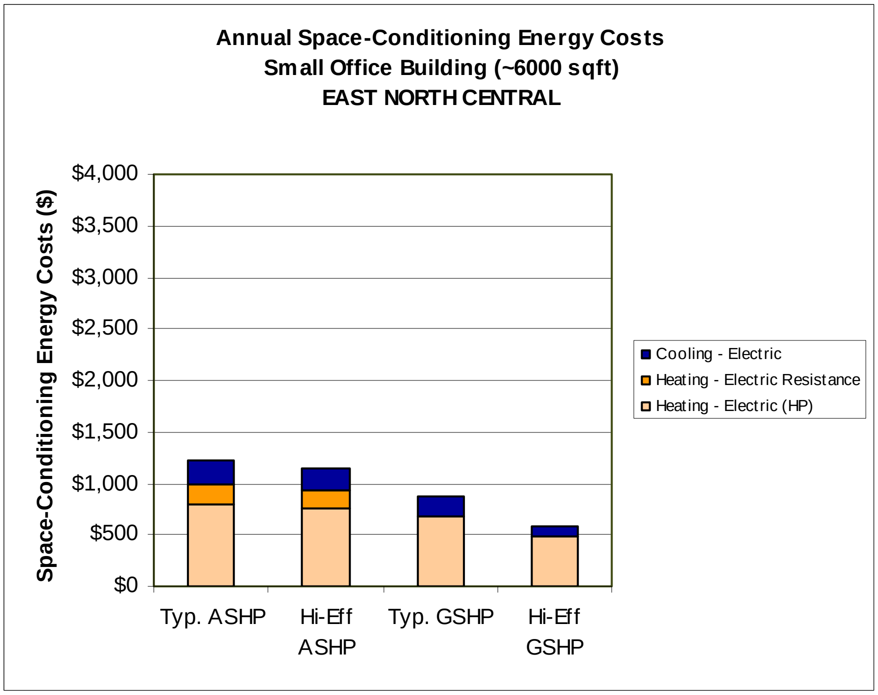


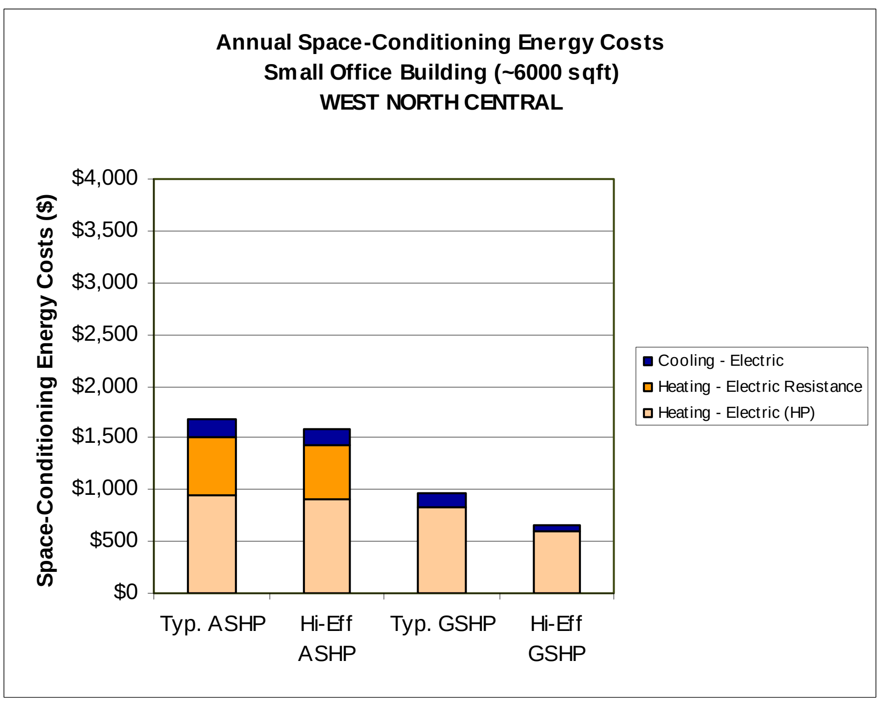
Annual Space-Conditioning Energy Costs
Single Family Residential (~3000 sqft)
PACIFIC
Space-Conditioning Energy Costs ($)
$1,600
$1,400
$1,200
$1,000
$800
$600
$400
$200
$0
NG Furnace/AC
Oil Furnace/AC
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling - Electric
Heating - Fossil Fuel
Heating - Electric Resistance
Heating - Electric (HP)

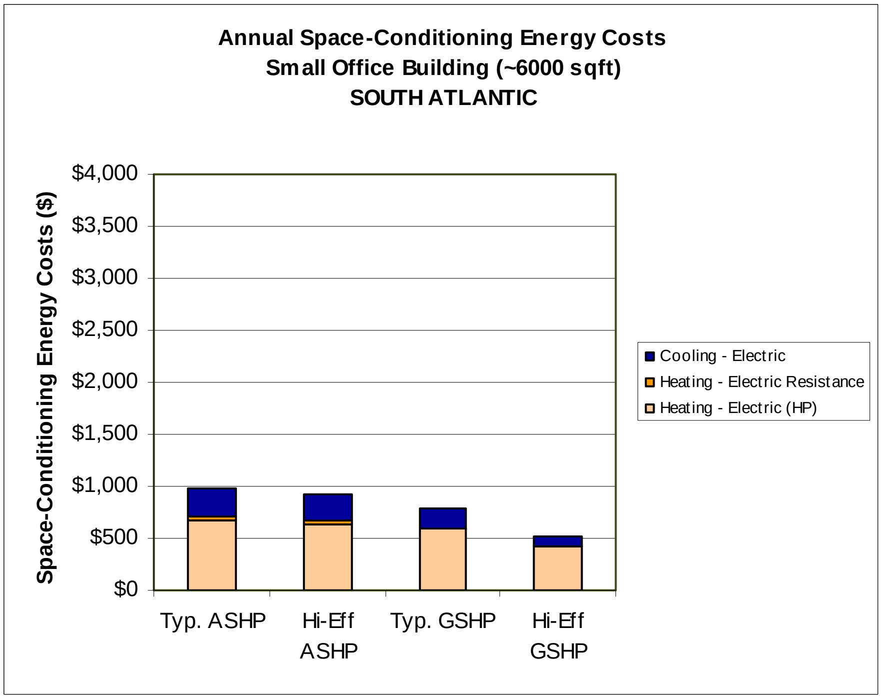
Appendix H: Commercial Annual Energy Costs

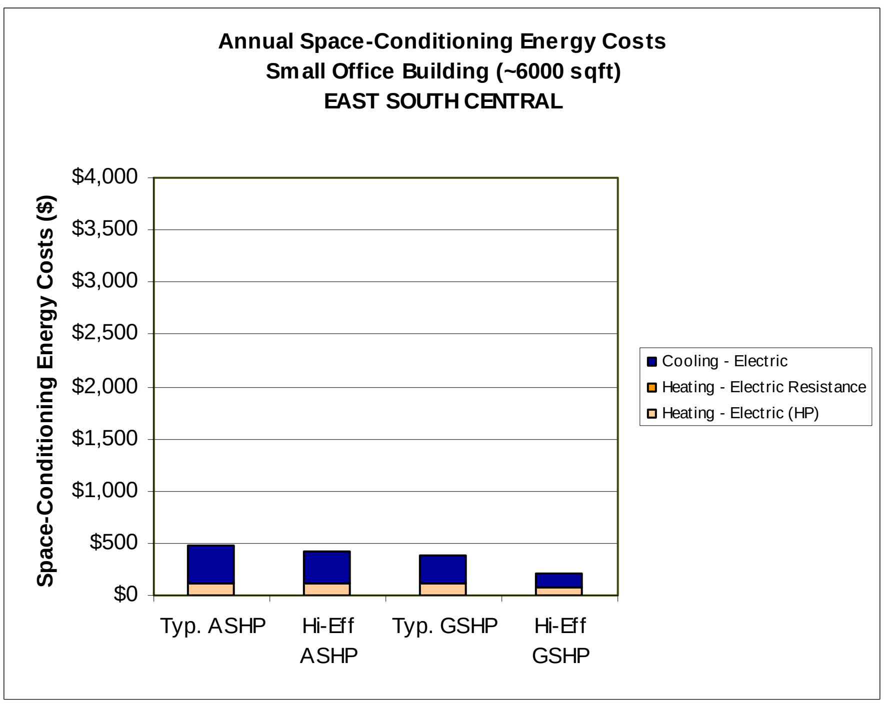


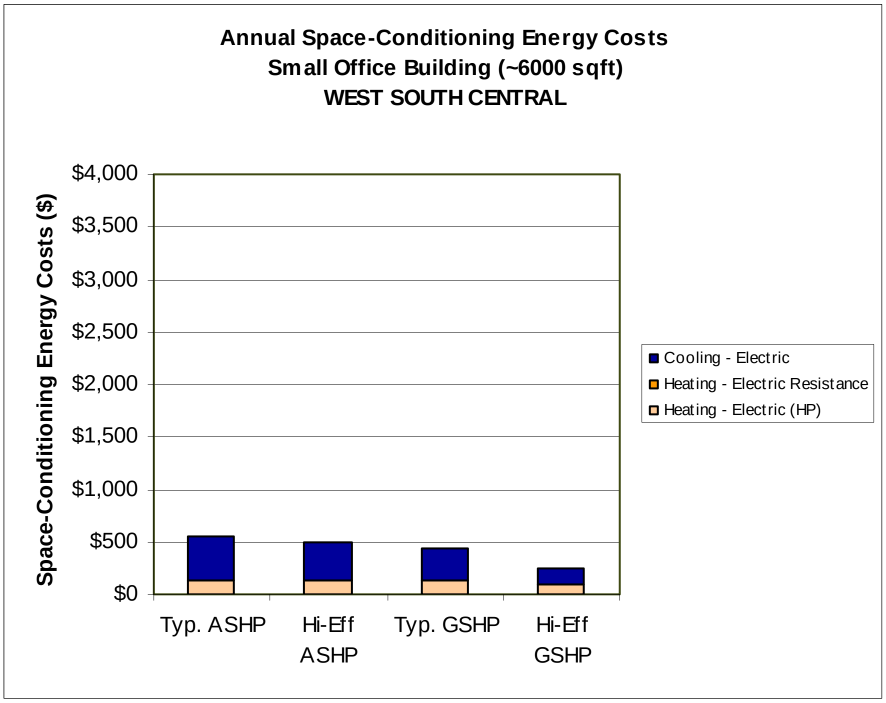


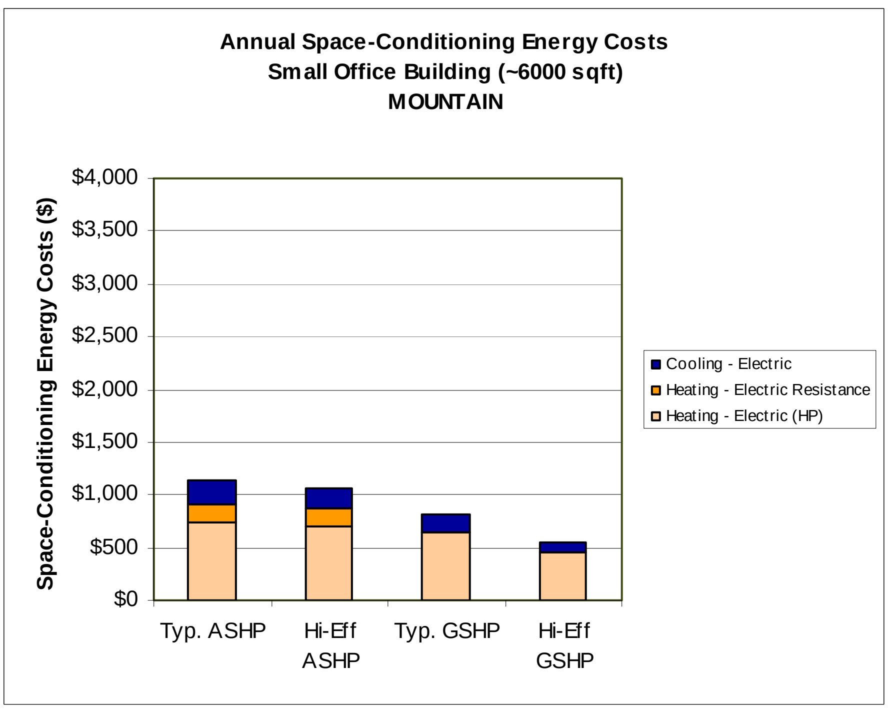

Annual Space-Conditioning Energy Costs
Small Office Building (~6000 sqft)
EAST NORTH CENTRAL
Space-Conditioning Energy Costs ($)
$4,000
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling - Electric
Heating - Electric Resistance
Heating - Electric (HP)

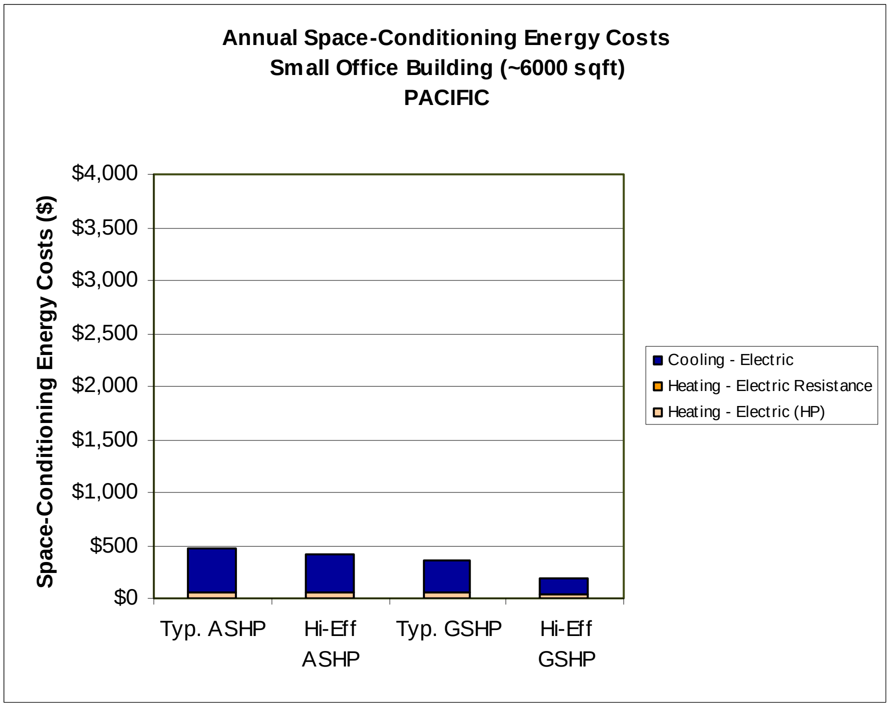

Annual Space-Conditioning Energy Costs
Small Office Building (~6000 sqft)
WEST NORTH CENTRAL
Space-Conditioning Energy Costs ($)
$4,000
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling - Electric
Heating - Electric Resistance
Heating - Electric (HP)


Annual Space-Conditioning Energy Costs
Small Office Building (~6000 sqft)
SOUTH ATLANTIC
Space-Conditioning Energy Costs ($)
$4,000
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling - Electric
Heating - Electric Resistance
Heating - Electric (HP)


Annual Space-Conditioning Energy Costs
Small Office Building (~6000 sqft)
EAST SOUTH CENTRAL
Space-Conditioning Energy Costs ($)
$4,000
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling - Electric
Heating - Electric Resistance
Heating - Electric (HP)


Annual Space-Conditioning Energy Costs
Small Office Building (~6000 sqft)
WEST SOUTH CENTRAL
Space-Conditioning Energy Costs ($)
$4,000
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling - Electric
Heating - Electric Resistance
Heating - Electric (HP)


Annual Space-Conditioning Energy Costs
Small Office Building (~6000 sqft)
MOUNTAIN
Space-Conditioning Energy Costs ($)
$4,000
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling - Electric
Heating - Electric Resistance
Heating - Electric (HP)


Annual Space-Conditioning Energy Costs
Small Office Building (~6000 sqft)
PACIFIC
Space-Conditioning Energy Costs ($)
$4,000
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Typ. ASHP
Hi-Eff ASHP
Typ. GSHP
Hi-Eff GSHP
Cooling - Electric
Heating - Electric Resistance
Heating - Electric (HP)