UNITED STATES
DEPARTMENT OF AGRICULTURE
RURAL DEVELOPMENT
RURAL UTILITIES SERVICE

ELECTRIC PROGRAMS

SUMMARY OF ITEMS OF ENGINEERING INTEREST
December 2012

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ENGINEERING

Emerging Use of Fiber Reinforced Polymer Poles on Transmission Lines

In the recent years, some increasing attention has been given to the use of Fiber Reinforced Polymer (FRP) poles as transmission line structures. Currently, RUS reviews FRP poles, sometimes referred to as fiberglass poles, on a case-by-case basis. FRP poles are mostly used in distribution instances, with some hesitation for use in transmission line design.

Some of the prominent benefits of FRP poles are that they are lightweight, providing for easier transport, and are non-conductive, thus giving the structure a high BIL. The fiber material is strong, yet flexible. Because of this, the poles are typically not tapered due to deflection issues. FRP poles are designed to use the same standard hardware as wood poles, except lag screws. Additionally, since the poles are hollow, copper ground wires may be installed on the inside of the pole to prevent theft. FRP poles generally require low maintenance; however, in order to preserve the life of the poles, the poles must accommodate a rigorous UV protection system.

Supposedly, concerns arise over the lack of vast usage. With increased attention about these poles also arise questions of their effectiveness if design calls for larger classes and longer lengths. While there are articles regarding design of FRP poles for transmission designs, there remains to be no official standard. As of now, there are not many manufacturers who produce transmission FRP poles. However, manufacturers are in the development stages for their poles to accommodate transmission designs. As the curiosity and demand for FRP poles increases, RUS anticipates standards in the near future.

If you would like more information or have any questions, please contact Gabrielle Stokes, Electrical Engineer, Transmission Branch at (202) 720-1924 or gabrielle.stokes@wdc.usda.gov.

Fiber Reinforced Polymer (FRP) Poles and Steel Distribution Poles

The United States Department of Agriculture (USDA) Rural Utilities Service (RUS) Electric Programs has been contacted concerning the use of Fiber Reinforced Polymer (FRP) and steel distribution poles. RUS has documents titled "Guidelines for RUS Approval to Use Fiber Reinforced Polymer (FRP) poles" and "Guidelines and Approval for the Use of Steel Distribution Poles" on the engineering page of their website http://www.rurdev.usda.gov/UEP_Engineering_Community.html

The guidelines provide engineering considerations that borrowers should be aware of. If an electric cooperative wishes to use fiber reinforced polymer poles or steel distribution poles, they should adequately address in writing the items mentioned in the guidelines and submit a request to the Engineering Branch of appropriate regional office (Southern Regional Division or Northern Regional Division).

If you would like more information or have any questions, please contact Donald Junta, Branch Chief, Distribution Branch at (202) 720-3720, or Donald.Junta@wdc.usda.gov.

Selecting the Best Current and Voltage Transformers

Selecting current transformers (CT's) and voltage transformers (VT's) for your metering applications should not be based solely on the lowest price or on their good output capability and accuracy. You should also double check your purchase specifications for CT's and VT's operational performances and your installation practices for these devices. It does not matter how good the output capability and accuracy of a CT or VT is when it comes off the production line as operational performance can be ruined by inappropriate application and poor installation practices.

In selecting your CT and VT, the lowest price may not be the best value. Selecting the next higher burden (load) capability than is required may result in higher cost, but the improved accuracy will most likely result in additional metering revenue and will pay back the additional cost within a short time.

IEEE/ANSI Standard C57.13, Table 9, "Standard Burdens for Current Transformers with 5 A Secondary," lists CT burdens in units of ohms but the table also lists CT burdens in units of equivalent volt-amperes (VA) and power factor. Where use of a VT will be such that the burden margin is low; it is best to calculate the VT's secondary burden using both VA and power factor. Keep in mind that the connecting leads are often the major burdens (load) for the CT secondary. As a rule of thumb, think of an ohm as equal to 1000 feet of No.10 AWG copper wire. For example: a total of 1800-feet of No. 10 AWG wire leads attached to a CT secondary would fully load a 1.8 ohm rated CT. 100-foot long connecting leads on each terminal would cause a CT rated at a 0.2 ohms burden to be at its maximum.

Users are encouraged to know the standards and how to select CT's and VT's for both standard and non-standard applications.

If you would like more information or have any questions, please contact Theodore V. Pejman, Electrical Engineer, Transmission Branch, via E-mail at ted.pejman@wdc.usda.gov.

OPERATIONS and MAINTENANCE

Reducing Copper Theft

IOUs, the wireless industry, and RUS cooperatives across the country are suffering huge losses to copper thieves.

The copper scrap prices are at all time high ($4.50-$5.00 per pound) an increase of almost 60 percent since 2007. Stealing copper wire and other metal equipment by the thieves from utilities' power lines and substations are on the rise.

Thieves not only stealing from electric coop companies but they are also stealing from cooperative members in form of stilling their assets. Utilities are not the only target for thieves. Copper thieves have stolen from communication towers, home owner's air conditioning unites, rooftop HVAC system on commercial properties, vacant homes, farm irrigation equipment, even from churches. Thieves have taken heating copper pipes from an old warehouse in Baltimore, Maryland where some hand-written records kept that goes back to 1700's. These kinds of documents require a precise temperature and humidity to survive.

Insurance companies have experienced an increase in number of claims by home owners to replace their air conditioning unites because thieves have been stripped them off of their copper wiring. Insurance companies often have to pay far more than just a few hundred dollars to replace the copper wiring. They pay thousands to repair damaged walls and water damages if pipes are taken from a water heater or AC condenser unit.

Law enforcement statistics indicate that the theft of copper and other precious metals are directly related to methamphetamine addition. Some state law makers are introducing bills that attempt to curb the theft of these metals in their state. This legislative proposal may include some provisions like make selling stolen copper a felony offense, take picture of the scraps, outlaw buying copper with cash and similar measures. Utilities also report 30 to 50 deaths or injuries associated with copper theft every year.

There are some measures are taken by utilities to prevent copper theft. Some are:

1. Make your copper harder to steal and less valuable to thieves.
2. Have your manufacture stamp the words "STOLEN DO NOT RECYCLE" on your copper wires.
3. Use of available copper clad steel is reliable alternative to the use of solid and stranded copper.
4. Secure metal pull boxes with security fasteners that the thieves cannot break open.
5. Use copper that are manufactured with traceable technology. This new tech wires carry codes that are stored in a data base system that are tie back to owner's data based and they are also accessible by the recyclers, law enforcement and other utilities in the area.

If you would like more information or have any questions, please e-mail Theodore V. Pejman, Electrical Engineer, Transmission Branch, at ted.pejman@wdc.usda.gov

Energy Efficiency and Renewable Energy

The Importance of SEER and EER in Utility Air Conditioning Demand Side Management Programs

By, Mark Faulkenberry, Manager Marketing & Communications and Kalun Kelley, Commercial and Industrial Marketing Manager. Both with Western Farmers Electric Cooperative

The Seasonal Energy Efficiency Ratio (SEER) has been the federal efficiency metric for residential air conditioners since the late 1980s. On January 23, 2006 new federal standards increased the minimum (SEER) requirement for central air conditioning equipment from 10 to 13. These revised standards required air conditioning equipment manufacturers to build their new units to the higher SEER rating level and also created a marketing race to develop units that exceed the minimum standards. Because the Federal standard is based on SEER many utilities have also based their efficiency program incentives on SEER. Manufacturers have responded by focusing their efforts on building units that have high SEER ratings. Unfortunately, this has resulted in overlooking the Energy Efficiency Ratio (EER) which provides a more accurate measure of the peak demand impacts of cooling equipment.

Seasonal Energy Efficiency Rating (SEER) based utility demand side management incentive efforts including loans and rebates provided for residential central air conditioners and heat pumps to encourage improved cooling efficiency may directly hurt utility load factor by reducing kWh sales without a corresponding reduction in peak demand. This is because SEER provides a reasonable measure of seasonal energy efficiency but it does not reflect efficiency (and related peak demand) on peak load days driven by above average temperatures. In fact, it is not uncommon that air conditioning units with the highest SEER ratings have lower efficiency (and higher peak demand) at high outdoor temperature than units with lower SEER values. If a utility's goal is to reduce air conditioning kWh consumption without regard to peak demand, SEER is a useful tool. However if the utility's goal is to reduce peak demand from air conditioning loads, the utility planner must look at the Energy Efficiency Ratio (EER) of air conditioning units at the expected summer peak weather (outdoor air temperature) condition.
It is also important to note that When ARI certifies the SEER rating of an air conditioner; it does so for specific indoor and outdoor unit combinations, which are designated as "matched assemblies." If some combination other than the ones ARI has tested is installed, the SEER rating will not be known.

Introduction to SEER, EER, and COP

SEER (Seasonal Energy Efficiency Ratio)

SEER was developed to provide a proxy for the expected average efficiency of an air conditioner or heat pump throughout an average cooling season in the U.S. It is a calculated value that uses the estimated Btus that will be provided for cooling over the year divided by the estimated watt-hours that will be used to provide this cooling (Btus/watt-hours). The formula for this calculation is based on measurements of a unit's performance at several different operating conditions/temperatures in a testing lab. The resulting data points are then used to calculate the SEER rating using an established Department of Energy (DOE) protocol. This calculation protocol was developed to represent the expected total cooling energy delivered by the unit during an average cooling season and the total electric energy that would be consumed to deliver the cooling over the course of the season. Because it is a calculated value based on a few measurement points, SEER does not measure peak load efficiency and it cannot be used to predict a unit's peak demand requirements on the hottest days of the year. It can only be used to estimate the unit's annual cost of operation against other units with different SEER ratings.

EER (Energy Efficiency Ratio)

The Energy Efficiency Ratio was developed to indicate the cooling performance of an air conditioner or heat pump at a single, fully loaded operating point (outdoor air temperature). EER is calculated by dividing the cooling output of a unit in Btus over the course of one hour (Btu/hour) by the peak electric energy (watt) used to deliver the cooling ((Btu/hour)/watt). Consequently, EER represents the peak cooling capacity divided by the electric power input during steady state continuous operation. EER is typically measured and reported at standard test conditions of 95°F outdoor and 80°F indoor dry bulb temperatures using the Air Conditioning and Refrigeration Institute's (ARI) test procedures. It is important to note that the published EER data does not represent the peak demand conditions on an individual utility's system. Many utilities have peak conditions above 95 degrees and many consumers keep their homes well below 80 degrees. Consequently, industry EER ratings are good for comparing the relative peak performance of different cooling equipment but the EER rating of a unit at the expected indoor and outdoor air temperatures must be used to calculate the true expected peak demand of the unit on the utility's peak load condition. It is possible to estimate the actual peak demand of a unit using published EER values. For every 1°F change in outdoor temperature above 95°F the EER drops by approximately 0.1 (an outside temperature of 105°F would drop the published EER of a unit by 1.0 point below the listed EER value). An accurate EER can only be developed by testing a unit at the expected indoor and outdoor air temperatures.

SEER and utility rebate programs

SEER based utility program incentives including loans and rebates for central air conditioners and heat pumps can directly hurt a utility's financial position by inadvertently ignoring peak demand impacts. Because air conditioning is often the biggest component of a utility's summer peak, it is important for utilities to consider the peak demand impacts of its demand side management programs. If peak capacity is not an issue for the utility, SEER is a good measure for efficiency programs. If demand reduction is important to the utility, using SEER can result in utility program investments that do not provide peak load reductions because SEER provides a reasonable measure of seasonal energy efficiency but does not reflect peak demand when load is driven by above average temperatures. In fact, it is not uncommon that the units with high SEER ratings have lower efficiency at high outdoor temperature than units with lower SEER values. Efficiency programs promote SEER because it is the basis of the Federal efficiency standard and the rating data is readily available. These efficiency efforts were not developed to focus on the peak load issues that are becoming a critical issue for utility resource planners.

EER and Utility rebate Programs

If demand reduction is an important consideration for a utility's Demand Side program, the utility must specify the equipment EER it requires at its peak load/outdoor air temperature condition to be eligible for loans, rebates, or other program incentives. Manufacturers of air source equipment are often reluctant to provide this information. While Manufacturers are not required to certify the EER values of their equipment, most do publish their standard EER values in their central air conditioner and heat pump catalogs. Fortunately, the California Energy Commission also publishes a directory that lists both the SEER and EER for many, but not all, air source cooling equipment.

EER and Ground Source Heat Pumps

Ground source heat pumps (GHPS), also called geothermal heat pumps or GeoExchange systems, are a unique heating, cooling and water heating technology that use the steady state ground temperature for their operation. These systems combine the compressor and energy distribution components associated with air source heat pumps with a ground loop that dissipates the heat removed from a building into the earth (where it can later be used for winter heating). Their cooling efficiency is measured in EER at an established entering water temperature. Because the ground is always cooler than the surrounding air during peak air conditioning loads, GSHPs will always provide a higher EER and lower peak demand per unit of cooling energy delivered vs. air source equipment. This is one of the reasons GHPS are the most energy efficient, environmentally clean, and cost-effective space conditioning systems available, according to ENERGY STAR (a U.S. Department of Energy and Environmental Protection Agency initiative). The heat captured from air conditioning using a GSHP can also be transferred into the domestic hot water system, further increasing the EER of the system.

Western Farmers Electric Cooperative as a Case Study

The Western Farmers Electric Cooperative (WF) has been operating for nearly 70 years as a generation and transmission cooperative that provides essential electric service to 19 member cooperatives in Oklahoma, 4 cooperatives in New Mexico and the Altus Air Force Base. WF supplies the electrical needs of more than two-thirds of the geographical region of Oklahoma, part of New Mexico, as well as small portions of Texas and Kansas.

By the end of 2012, over 15 percent of WF's total annual electricity production will come from power purchase agreements with wind farm generators in Oklahoma. WF also has five natural gas and coal generating facilities with a total power capacity of more than 1,700 MW including some purchased hydropower. WF owns and maintains more than 3,600 miles of transmission line to more than 265 substations.

To balance its supply portfolio, WF established an aggressive goal of avoiding the construction of 30 MW of new generating capacity by 2017, through peak demand savings. The G&T staff was provided a$1,000,000 annual budget to meet this goal. While this budget is large by any measure, the 30 MW of new generation is expected to cost $1,850/kW, or $55,500,000. This value does not include interest costs, O&M costs associated with the generation, and the capital costs of the related transmission and distribution needed to serve the additional load. Because WF does not operate under mandates to meet reduced kWh "conservation" requirements, its efforts are focused on reducing peak capacity requirements and improve their overall system load factor and efficiency.

WF's management was clear in establishing that they wanted a reasonable ROI that would take into account the net difference between reduced energy sales, capacity reduction and the value of numerous other factors including carbon offset, long term interest expense, and consumer and member cooperative value calculations.

Given these directions, WF established a rebate program for both air source and ground source equipment. They looked at program development like sighting in a rifle. They would load it … start shooting … and zero in as they went. Their initial rebate effort relied on EER for ground source and SEER for air source. However it didn't take them long after evaluating the results of their 2010 program to understand that they had to drastically modify their program if they hoped to achieve their peak reduction goal. Their original savings projections per ton of equipment installed are shown below:

Original results projections	ASHP	GSHP
Projected kW reduction per ton rebated	0.33 kW	0.66 kW
2010 results kW reduction/ton rebated	0.16 kW	0.65 kW

Their 2010 program results analysis also revealed the following:

- Approximately 80% of rebates where on Air Source equipment and 20% were on Ground Source
- 92% of rebates where on replacements (equipment failure) and new construction
- 8% of rebates were on planned retrofits (pre-failure)

- The original rebate program had an extremely long ROI on Air Source rebates compared to a relatively short ROI on Ground Source rebates. In several cases the ROI on air source installations exceeded the expected life expectancy of the air source equipment
- In many cases the new (rebated) air source equipment had decreased energy sales without reducing peak capacity requirements

As WF probed to understand why their air source demand reductions fell so short of the expected results in 2010, it became apparent that the negative result was due to the difference between the equipment's actual **Energy Efficiency Ratio (**EER) on peak load days when compared to the published **Seasonal Energy Efficiency Ratio (**SEER). What really opened their eyes was that the EER on even the higher SEER systems was horrible compared to those on Ground Source systems, which met their expected EER on peak load days. The WF analysis, based on a sample of measured data, showed that the high SEER rated equipment had a poor EER during the record breaking heat of the 2010 Oklahoma summer when temperatures were over 100 degrees for days on end and hit 110 degrees in the middle of August. This got them to adjusting their program design rifle scope!

For 2012 (and beyond) WF thought about completely eliminating their Air Source rebates due to the low peak contribution obtained from this type of cooling equipment, but opted instead to abandon SEER as a program rebate metric and to increase the EER requirement of rebate eligible air source equipment. While they would have preferred to have this EER based on 100 + degree (f) outside air to reflect peak load conditions, the inability to find this data forced them to continue to look at EER at 95 degrees. They will reevaluate this decision based on 2012 unit performance under the new EER requirement. WF also came to the conclusion that if were to achieve their 30 MW peak demand reduction goal, they would have to focus on flipping the 80/20 Air Source to Ground Source installation ratio experienced in 2010 to 80% Ground Source. Their 2013 demand reduction Business plan will also focus on addressing the following hurdles that must be covered to achieve that ratio flip mentioned above.

1. Ground Source System Retrofit Costs
2. Commercial and Residential Member Education
3. Addressing Urgency Issues (time needed to address system failures)
4. Changing the Target Market for Ground Source by Making it a Common Retrofit Opportunity

In conclusion, Western Farmers Electric Cooperative has learned a few things over the last couple of years regarding HVAC efficiency ratings (SEER vs. EER). Based on the wisdom acquired through the first two years of the program, they plan to continue to provide rebates and other member incentives for their Energy Efficiency Rebate Program (EERP) going into 2012 for all Distribution Cooperatives (Co-ops) in Oklahoma and New Mexico. This program was designed to promote efficient use of energy with the long-term goal of reducing approximately 30 megawatts (MW) of future capacity. A few changes have been made for 2012, including a focus on peak day cooling equipment performance based on EER, an increased focus on increasing peak equipment performance awareness, and improved ways to educate their member Co-op's consumers and promote energy efficiency. Their initial focus, centered on heating, ventilation and air-conditioning (HVAC) equipment with rebates being offered for the installation of both Ground Source Heat Pumps (GSHP) and Air Source Heat Pumps (ASHP) that meet specified efficiency ratings will continue. They also want to continue the support for education and incentive opportunities for the installation of proven technologies, such as the Ground Source Heat Pumps, that also provide "Green" environmental benefits. Continuing this effort will help improve the heating and air conditioning energy efficiency of their Residential and Small Commercial rate classes, while reducing peak demand costs. They will also work closely with each of their member Co-op's to gather the data needed to justify and modify the program as it moves forward so that it will benefit the entire WFEC family.

References for Additional Information

Numerous on-line resources are available that provide information on EER, SEER, and peak load performance. The Oak Ridge National Laboratory has released a report that documents the significant peak demand savings that could be obtained in the U.S. through the use of ground source heat pumps vs. traditional cooling technology.

ESource has also produced a series of papers on EER vs. SEER

If you would like additional information or have any questions, please contact ……………..

Administrative and Other

2013 RUS Engineering Seminar

RUS is planning to present the 2013 RUS Engineering Seminar, Monday, February 18, 2013, in New Orleans, in conjunction with the NRECA TechAdvantage. This one day, pre-conference event will have presentations covering an update of RUS activities, rebuilt transformers, transformer efficiency standards, Energy Efficiency, National Electric Safety Code revisions, smart grid at the distribution level, treated wood products, Seasonal Energy Efficiency Ratio(SEER) and copper theft.

For information on how to register for this event, visit www.techadvantage.org. For more information on this seminar contact Bob Lash, Branch Chief, Transmission Branch at
(202)720-2301 or bob.lash@wdc.usda.gov.

Revision of RUS Timber Specifications

A Federal Register notice dated June 24, 2011 announced the revision of the three RUS bulletins that cover the manufacture and inspection of timber products. These bulletins are:
Bulletin 1728F-700- RUS Specification for Wood Poles, Stubs and anchor Logs Bulletin 1728H-701-RUS Specification for Wood Crossarms (Solid and Laminated), Transmission timbers and Pole Keys Bulletin 1728H-702- RUS Specification for Quality Control and Inspection of Timber Products.

The major changes to these bulletins are:

1. All references cited in these bulletins are updated to the latest edition.
2. The definition “pole broker” is added to the list of definitions to include as many organizations as possible to provide borrowers a source from which they might purchase wood products.
3. Allow borrowers six months to notify treating plants about poles not meeting the required preservative retention.
4. In accordance with agency policy on insurance requirements for contractors working for borrowers, the specification is revised to require manufacturers and inspection agencies to maintain certain limits of liability and errors and omission insurance.
5. All poles are required to be sterilized during the conditioning or treating cycle. This sterilization should further reduce the number of poles with pre-treatment decay.
6. Brand independent inspection agency’s identification on the face of the pole.
7. The agency revises the qualifications for inspectors and quality control personnel. The requirement returns to the qualifications from the 1987 edition of the specifications.
8. Provisions are added to further clarify that wood products, producers and inspection agencies maintain the greatest degree of separation and eliminate any appearance of conflict of interest.
9. Eliminated the requirement of borrowers to send an annual notice to RUS.
10. Allow the use of butt treated poles in moderate decay zones.

These bulletins can be printed from the RUS website. If you would like more information or have any questions, please contact Bob Lash, Branch Chief, Transmission Branch at
(202)720-2301 or bob.lash@wdc.usda.gov.

Use of Old Numbering System in 12.47/7.2 kV Overhead Distribution Specification

The use of the old numbering system from the previous version of the 12.47/7.2 kV overhead distribution specification (Rural Utilities Service (RUS) Bulletin 50-3) is still permitted. RUS Bulletin 50-3 has been replaced by RUS Bulletin 1728F-804. RUS Bulletin 1728F-804 specifically states on page 1 and 2 in item (b) of the "General" section that the use of the old numbers from RUS Bulletin 50-3 is permitted. Additionally RUS Bulletin 1728F-804 has an Exhibit 3 in the back of the bulletin that is a table that showing equivalent old and new bulletin numbers.

In the new RUS Bulletin 1728F-804 a total of 167 assemblies and 8 guide drawings were reused from the old bulletin. Borrowers should refer to the assemblies and drawings in the new RUS Bulletin 1728F-804 when performing construction in the field as some of the reused assemblies and drawings have slight changes to them from the old bulletin.

If you would like more information or have any questions, please contact Donald Junta, Branch Chief, Distribution Branch at (202) 720-3720, or Donald.Junta@wdc.usda.gov.

Primary Cable Specification Revisions

RUS in conjunction with the Office of the Federal Register determined that Bulletin 50–70 (U–1), ''REA Specification for 15 kV and 25 kV Primary Underground Power Cable,'' would be codified. The material will now appear in 7 CFR 1728.204.

Rescinding Bulletin 50–70 (U–1) and codifying the material in its entirety provides greater convenience for RUS borrowers when searching for specifications and standards requirements. Additionally, the specifications and standards that appeared in the old RUS Bulletin 50–70 (U–1) will be incorporated by reference in 1728.97 and will update the specifications for 15kV and 25kV underground power cable, and provide RUS borrowers with specifications for 35 kV underground power cable for use in 25 kV primary systems.

These specifications cover single-phase and multi-phase primary underground power cable which RUS electric borrowers use to construct their rural underground electric distribution systems. These changes provide standard requirements for 15kV and 25 kV single-phase and multi-phase primary underground power cable with cross-linked polyethylene with tree retardant or ethylene propylene rubber insulation, concentric neutral, and insulating outer jacket and updates the specifications for 15kV and 25 kV primary underground cable while adding specifications for 35 kV primary underground power cable.

The following changes and updates are as follows:

1. Water blocking sealant would be required in all stranded conductor cables.
2. The plain cross-linked polyethylene (XLP) would be removed and be replaced by tree-retardant cross-linked polyethylene (TR–XLPE) as an acceptable insulation material.
3. Nominal insulation thickness on 25 kV cable would be reduced from 345 mils to 260 mils.
4. An optional semi-conducting jacketing material would be added to the specification for cables of all three specified voltages. Cables with semiconducting jackets may be used by RUS borrowers in areas with soil resistivity greater than 25 ohm-meter, in lieu of using cables with an insulating jacket to help improve the effectiveness of system grounding in locations of high soil resistivity.

If you would like more information or have any questions, please contact Trung Hiu, Electrical Engineer, Distribution Branch at (202) 720-1877 or email at trung.hiu@rus.usda.gov.

SPCC Plan Template for Tier I Qualified Facilities Now Available from EPA

As you know, NRECA pushed very hard to have EPA streamline the requirements for Spill Prevention, Control and Countermeasure (SPCC) plans as they apply to small facilities like substations. We worked with other small business representatives through the SBA to help EPA develop a template that companies could use to satisfy the SPCC requirements. As we announced in earlier memos, EPA issued final amendments to the SPCC regulations in the Federal Register at **73 F.R. 74307 (December 5, 2008)** that addressed "Tier I Qualified Facilities". The amendments included a template that those facilities could use instead of having to draw up an individual plan. The final amendments did not become effective, however, until January 14, 2010. While these regulations are now finally effective, the template was only available by making paper copies of the forms contained in the 12/5/2008 Federal Register publication.

In response to requests from NRECA and other groups, EPA has now made the SPCC plan template available in a form that can be filled out electronically and they have just posted it on their webpage at http://www.epa.gov/emergencies/content/spcc/tier1temp.htm.

This should make it much easier for small co-operatives to avail themselves of the streamlined SPCC requirements. If you have questions about the SPCC program, please contact Mike Eskandary, Electrical Engineer at mike.eskandary@wdc.usda.gov or (202) 720-9098; or contact Jim Stine at james.stine@nreca.coop or (703) 907-5739.

APPENDIX

ORNL/TM-2010/122

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Assessment of National Benefits from Retrofitting Existing Single-Family Homes with Ground Source Heat Pump Systems

Final Report

June 2010

Prepared by

Xiaobing Liu

Energy and Transportation Science Division

Sponsored by
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UT-BATTELLE

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DOCUMENT AVAILABILITY

Reports produced after January 1, 1996, are generally available free via the U.S. Department of Energy (DOE) Information Bridge.

Web site http://www.osti.gov/bridge

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Energy and Transportation Science Division

Assessment of National Benefits from Retrofitting Existing Single-Family Homes with Ground Source Heat Pump Systems

Final Report

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UT-BATTELLE, LLC
For the
U.S. DEPARTMENT OF ENERGY
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Contents

List of Acronyms and Abbreviations

AC	Air conditioning
AFUE	Annual fuel utilization efficiency
ASHP	Air-source heat pump
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
BEDB	DOE-EIA Buildings Energy Data Book
BHEX	Borehole heat exchanger
COP	Coefficient of performance
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOE-BT	U.S. Department of Energy Building Technologies Program
EER	Energy efficiency ratio
EF	Energy factor
EIA	DOE Energy Information Administration
GHG	Greenhouse gas
GHP	Geothermal heat pump
IECC	International Energy Conservation Code
LPG	Liquified petroleum gas
NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
ORNL	Oak Ridge National Laboratory
RECS	Residential Energy Consumption Survey
SC	Space cooling
SFH	Single-family home
SH	Space heating
UESC	Utility energy services contract
WH	Water heating
ZEH	Zero-energy home

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Abstract

This report first briefly reviews geothermal heat pump (GHP) technology and the current status of the GHP industry in the United States. Then it assesses the potential national benefits, in terms of energy savings, reduced summer peak electrical demand, consumer energy cost savings, and reduced CO_2 emissions from retrofitting the space heating, space cooling, and water heating systems in existing U.S. single-family homes with state-of-the-art GHP systems. The investment for retrofitting typical U.S. single-family homes with state-of-the-art GHP systems is also analyzed using the metrics of net present value and levelized cost.

Executive Summary

The geothermal heat pump (GHP) is a proven technology capable of significantly reducing energy use and summer peak electrical demand in buildings. However, there are only about 600,000 GHP units installed in the United States (Rybach 2005). Given the 111.1 million households in the United States, even if all the 600,000 GHP units were installed in residential buildings, they would account for only slightly more than 0.5% of the entire U.S. housing stock. The barriers preventing rapid growth of GHP applications have been identified as high first cost to consumers, lack of knowledge and/or trust in GHP system benefits, limited design and installation infrastructure for GHP systems, and lack of new technologies and techniques (Hughes 2008).

This report assesses the potential national benefits of retrofitting U.S. single-family homes with state-of-the-art GHP systems at various penetration rates. The benefits considered include energy savings, reduced summer electrical peak demand, consumer utility bill savings, and reduced CO_2 emissions. The assessment relied heavily on energy consumption and other data obtained from the Residential Energy Consumption Survey (RECS) conducted by DOE's Energy Information Administration (EIA). It also considered relative differences in energy consumption between a state-of-the-art GHP system and existing residential space-heating, space-cooling, and water-heating (SH-SC-WH) systems, which were determined with a well-established energy analysis program for residential SH-SC-WH systems. The impacts of various climate and geological conditions, as well as efficiency and market share of existing residential SH-SC-WH systems, have been taken into account in the assessment.

The analysis shows that replacing all SH-SC-WH systems in existing U.S. single-family homes with properly designed, installed, and operated state-of-the-art GHP systems would yield the following benefits annually:

- Savings of **4.2 quadrillion (quad) Btu in primary energy**, a **45.1%** reduction in primary energy consumption associated with SH-SC-WH in existing U.S. single-family homes
- Reduction of **271.9 million metric tons in** CO_2 **emissions**, a **45.3%** reduction in CO_2 emissions associated with SH-SC-WH in existing U.S. single-family homes
- Savings of $**52.2 billion in energy expenditures**, a **48.2%** reduction in energy costs for SH-SC-WH in these homes
- Reduction of **202.1 gigawatt in summer peak electrical demand**, a **55.2%** reduction in summer peak electrical demand for space cooling in existing U.S. single-family homes

Though it may not be feasible to realize the above maximum benefits, the benefits of GHP retrofits are also significant even at lower market penetration rates, as shown in the following table.

Table E-1. Potential benefits of retrofitting existing U.S. single-family homes with state-of-the-art GHP systems at various market penetration rates.

Market Penetration Rate of GHP Retrofit	20%	40%	60%	80%	100%
Primary Energy Savings [Quad BTU]	0.8	1.7	2.5	3.3	**4.2**
Percentage Savings	9.0%	18.0%	27.1%	36.1%	**45.1%**
CO2 Emissions Reduction [MM ton]	54.3	108.7	163.0	217.3	**271.7**
Percentage Savings	9.1%	18.1%	27.2%	36.2%	**45.3%**
Summer Peak Electrical Demand Reduction [GW]	40.4	80.8	121.3	161.7	**202.1**
Percentage Savings	11.0%	22.1%	33.1%	44.2%	**55.2%**
Energy Expenditures Savings [Billion $]	10.4	20.9	31.3	41.7	**52.2**
Percentage Savings	9.6%	19.3%	28.9%	38.5%	**48.1%**

The investment for retrofitting typical U.S. single-family homes with state-of-the-art GHP systems is evaluated using the metrics of net present value and levelized cost. It was determined that state-of-the-art GHP systems will yield a positive net present value (NPV) over a 20-year period at current market prices for installed systems, and without any financial incentives, when the discount rate is lower than 8%. The levelized-cost analysis shows that saving energy with the GHP retrofit is cheaper than generating and delivering electricity to residences when the discount rate is lower than 8%. The currently enacted federal tax credits for 30% of the installed cost of a GHP system (valid through 2016) were not considered in this analysis. Had they been, investments in state-of-the-art GHP systems would be beneficial even at higher discount rates. Other factors not considered in this analysis include the residual value of the ground loop heat exchanger (ground loops outlive the building and several generations of heat pumps), and financial values from reduced CO_2 emissions and summer peak electrical demand.

1. Introduction

Buildings present one of the best opportunities for cost-effectively reducing energy consumption and limiting CO_2 emissions. The long-term goal of the U.S. Department of Energy's Building Technologies Program (DOE–BTP) is to maximize the cost-effective energy efficiency in buildings. DOE-BTP's vision for achieving the goal involves, among other things, reducing the energy used by residential energy service equipment (equipment providing space heating and cooling and water heating) by 50% compared with today's best common practice.

The geothermal heat pump (GHP) is a proven technology capable of significantly reducing energy use and peak electrical demand in buildings and could play an important role in reaching the goal. According to the latest Residential Energy Consumption Survey (RECS) by the U.S. Energy Information Administration (EIA), 71.8% of the 111.1 million U.S. households (the Census Bureau's statistical estimate of the number of occupied housing units in 2005) live in single-family homes, most of which have space conditioning and/or water heating (DOE-EIA 2009). These 79.8 million single-family homes are excellent candidates for GHP retrofits because

- an average of about 73% of the delivered energy consumed in single-family homes is used for space conditioning and water heating — about 43% for space heating alone (DOE-EIA 2009);
- most of the conventional space conditioning and water heating equipment used in existing single-family homes is approaching the end of its expected service life and needs to be replaced; and
- most U.S. single-family homes have front and/or back yards, which usually have more than enough space for installing vertical or horizontal ground heat exchangers for GHP systems.

However, there are only about 600,000 GHP units installed in the United States (Rybach 2005). Given the 111.1 million households in the United States, even if all 600,000 GHP units were installed in residential buildings, they would account for only slightly more than 0.5% of the entire U.S. housing stock. Obviously, there is huge potential for the growth of GHP installations in residential buildings.

A study recently conducted by Oak Ridge National Laboratory (Hughes 2008) concludes from a survey of U.S. GHP industry experts that high first costs to consumers, lack of knowledge and/or trust in GHP system benefits, limited design and installation infrastructures for GHP systems, and lack of new technologies and techniques are the most significant barriers to the wide application of GHP. The study recommends a series of actions to overcome these barriers. One of the two highest-priority actions is to conduct an independent assessment of the national benefits (energy, demand, cost, CO_2 emissions, jobs) achievable from implementing a maximum deployment strategy for GHP systems, including comparisons with other supply- and demand-side options in terms of when benefits could be achieved, national investment required, and probability of success.

This report gives a brief overview of GHP technology and the current status of the GHP industry in the United States (section 2), and assesses the “technical potential” for total energy savings, reduced summer electrical peak demand, consumer utility bill savings, and reduced CO_2 emissions from retrofitting SH-SC-WH systems in existing U.S. single-family homes with state-of-the-art GHP systems. The study methodology is described in section 3. An analysis of the economics of GHP retrofits is presented in section 4.

2. Overview of GHP Technology and GHP Industry in the United States

This section of the report presents the basics of GHP technology and an overview of the current status of the GHP industry in the United States. Key barriers preventing rapid growth of the GHP industry in the United States identified by a recent survey of GHP industry experts are summarized. Hughes (2008) provides a more detailed and comprehensive overview of GHP technology and the GHP industry.

2.1 Basics of GHP Technology

GHP is a relatively new technology for space conditioning and water heating. The biggest difference between GHP and conventional space conditioning and water heating systems is that instead of rejecting heat from buildings to the ambient air (in cooling mode) and extracting heat from fossil fuel combustion, electricity, or the ambient air (in space heating and/or water heating modes), a GHP rejects heat to (in cooling mode) or extracts heat from (in space heating and/or water heating modes) various ground resources, including the earth, surface water, recycled gray water, sewage treatment plant effluent, storm water retention basins, harvested rainwater, and water from subsurface aquifers — either alone or in combination with conventional heat addition/rejection devices in a hybrid configuration.

Since the ground resources usually have a more favorable temperature than the ambient air for the heating/cooling operation of the vapor-compression refrigeration cycle, GHP systems can operate with much higher energy efficiency than conventional air-source heat pumps, especially for heating operation in cold climates. GHP systems harvest the free and renewable energy (solar, geothermal, and heat removed from the built environment) stored in various ground resources to provide space heating and/or water heating, which is a reverse of the vapor-compression cycle widely used in air conditioning and refrigeration. GHPs thus significantly reduce energy consumption and greenhouse gas (GHG) emissions compared with conventional equipment, such as furnaces and boilers using natural gas, oil, or electricity.

A study by the U.S. Environmental Protection Agency (EPA) comparing the major heating, ventilating, and air-conditioning (HVAC) options for residential applications determined that GHP was the most energy-efficient and environmentally benign option (EPA 1993). The Nobel-Prize-winning Intergovernmental Panel on Climate Change specifically identified GHP as a solution that is “economically feasible under certain circumstances” in continental and cold climates (IPCC 2007a, see Table 6.1) and cited cases in which total electricity use decreased by a third (IPCC 2007a, p. 404) and heating energy use decreased by 50 to 60%. The potential of GHP to reduce nonrenewable energy use was also highlighted in a 2007 United Nations Environmental Programme report (UNEP 2007). A 2008 American Physical Society report (2008) referred to GHP systems (pp. 56 and 73) as being among the options that could help the U.S. building sector achieve the goal of using no more primary energy in 2030 than in 2008, rather than increasing energy use by 30% by 2030 as currently projected. Enhanced use of ground energy sources and heat sinks at the building or community level is highlighted as a promising option in the 2008 report designed to establish the federal R&D agenda for buildings issued by the Executive Office of the President's National Science and Technology Council (2008).

A GHP system is made up of three major components: a water-source heat pump (WSHP) unit operable over an extended range of entering-fluid temperatures (referred to as the GHP unit hereafter); a ground heat exchanger designed for available ground resources; and a circulation system to deliver cold or warm air or water to the built environment and circulate the liquid heat transfer medium (water or aqueous anti-freeze solution) through the GHP unit and the ground heat exchanger.

Small packaged or split water-to-air heat pump units are most popularly used in the GHP systems in the United States. An alternative configuration that may be more economical in some situations is a small or large water-to-water heat pump unit. Rather than directly delivering cold or hot air to spaces as the water-to-air heat pump does, a water-to-water heat pump delivers chilled or hot water to various types of zone terminals. Today's GHP systems move 3 to 5 times more energy between the building and the ground sources than they consume in doing so. If there were sufficient motivation, the GHP industry could increase this multiplier effect to 6 – 8 by integrating the most advanced commercially available components and technologies into their heat pumps, such as variable-speed compressors, variable-refrigerant-flow systems, and special refrigerants.

Figure 1 illustrates a number of options for the ground heat exchanger. The vast majority of GHP systems in the United States are installed with closed-loop heat exchangers using high-density polyethylene (HDPE) pipe buried in the earth in either a vertical or horizontal configuration. The closed-loop technology permits GHPs to be applied effectively almost anywhere. The HDPE piping technology has been perfected by the natural gas industry for collecting underground natural gas in production fields and distributing it to customers.

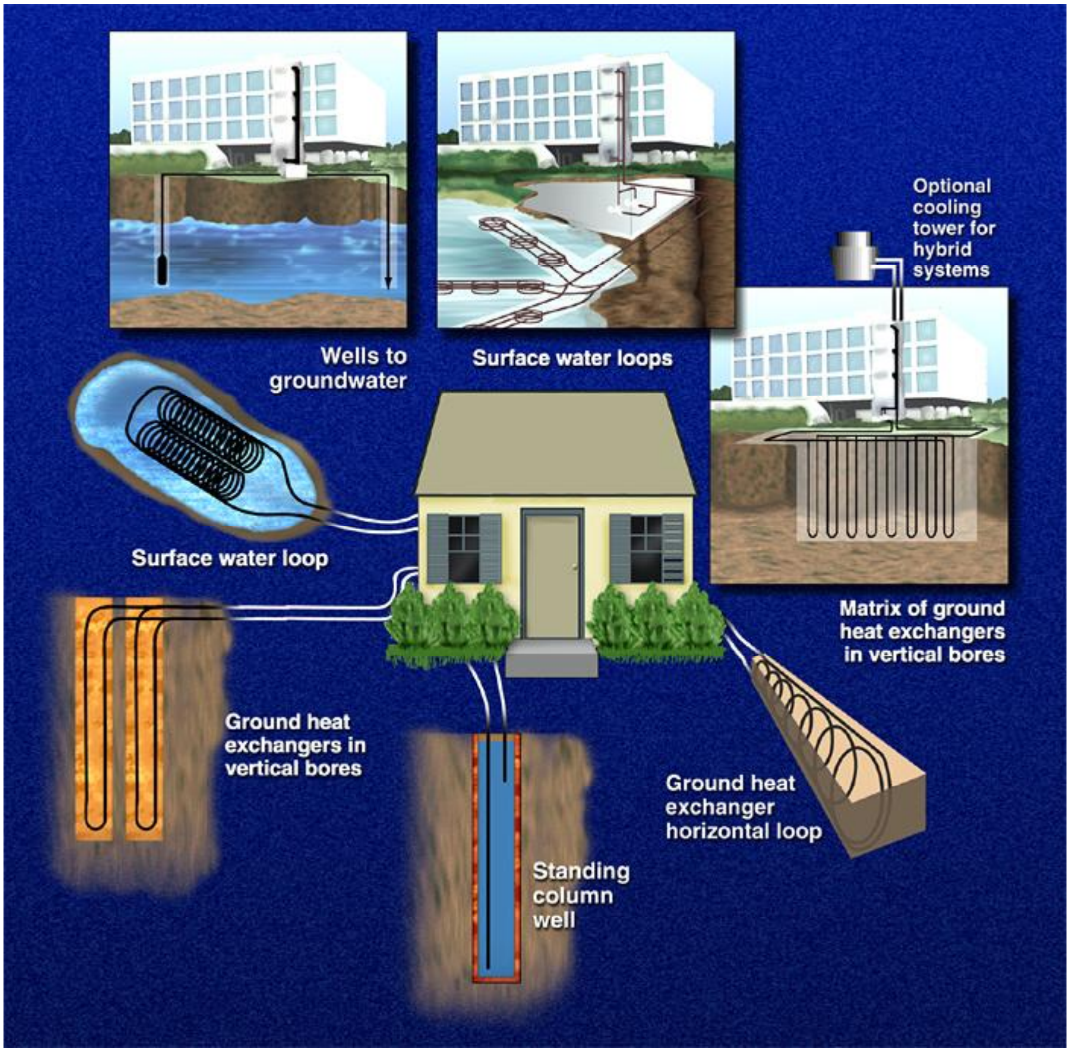

Fig. 1 Typical options for ground heat exchanger used in GHP systems.

The ground heat exchanger can be designed at the scale of a community or a single building and can serve new construction or retrofits of existing communities or buildings. In many areas, it may be possible to serve the modest heating, cooling, ventilation, water heating, and refrigeration loads of highly efficient new homes and commercial buildings with efficient heat pumps coupled to ground loops placed in construction excavations, without any extra digging or drilling whatsoever.

GHP technology is not the same technology as geothermal power production, in which the extreme heat of subsurface geological processes is used to produce steam and ultimately to generate electricity. Nor is it the same as the direct use of geothermal heat, in which moderate-temperature geothermal sources such as hot springs are used directly to heat greenhouses, aquaculture ponds, and other agricultural facilities. Whereas geothermal power production and direct use of geothermal heat can be economical at only a limited number of locations in the United States, GHP systems can be used almost anywhere. GHP systems use the only renewable energy resource that is available at every building's point of use, on-demand, that cannot be depleted (assuming proper design), and are potentially affordable in all 50 states.

Technologies aiming at cost reduction and performance improvement of GHP systems are being pursued in the United States and even more aggressively in some European and Asian countries. Topics being researched include the following.

- Integrated GHP units serving multiple purposes including heating, cooling, water heating, and dehumidification
- Design tools and models for ground heat exchangers installed in the excavations and/or foundations needed to construct buildings
- Design tools for surface-water heat pump systems
- Design guidelines and tools for hybrid GHPs
- Single-well groundwater supply and return systems
- Compact horizontal loops reloaded via heat exchange with exhaust air
- Devices to test borehole heat exchanger installation quality
- New-generation technology for in-situ ground thermal property testing

2.2 Current Status of GHP Industry in the United States

The U.S. GHP industry was started in the early 1970s by entrepreneurs including contractors and manufacturers. Currently, it is made up of manufacturers of water-source heat pumps (WSHPs), HDPE piping and fittings, circulating pumps, and specialty components, as well as a design infrastructure, an installation infrastructure, and various trade allies, most notably electric utilities.

A small group of manufacturers — including ClimateMaster (a unit of LSB Industries), Florida Heat Pump (a unit of Bosch), WaterFurnace International, Inc., and Trane (a unit of Ingersoll Rand) — are believed to produce most GHP units, supplemented by McQuay International (a unit of Daikin), Mammoth, and several regional manufacturers. Most of these manufacturers produce WSHP units not only for the GHP market but also for water loop heat pump (WLHP) systems, which use more conventional cooling towers and boilers in place of ground heat exchangers. Other major brands such as Carrier participate in the WLHP and GHP markets by sourcing WSHP units from other manufacturers.

In addition to serving GHP applications, HDPE pipe is used in oil production fields and for natural gas collection and distribution, sewerage collection, potable water distribution, landfill gas collection, industrial applications, and irrigation. The manufacturing base is large and well established. It is believed that Performance Pipe (a unit of Chevron–Philips), ISCO Industries, and Centennial Plastics are the largest suppliers of HDPE to the GHP market.

Circulating pumps, propylene glycol antifreeze, plate heat exchangers, fluid coolers, and many other products used in GHP systems are already mass-produced to serve markets much larger than the GHP market.

The specialty products unique to the GHP market—such as flow centers, flush carts, purge pumps, pump stations, headers, vaults, hose kits, thermally enhanced grouts, specialty installation equipment, and surface water immersion heat exchangers—are generally made by relatively small regional firms.

Although there are a significant number of competent and experienced designers of residential and commercial GHP systems, especially those with vertical-bore ground heat exchangers, the number is still a small percentage of HVAC design engineers. Similarly, experienced and competitive installation infrastructures for ground heat exchangers are in short supply and exist only in portions of some states.

During the 30-year history of the U.S. GHP industry, many modest but successful GHP programs sponsored by the electric utilities have boosted the GHP industry in some localities. The contribution of GHP systems in reducing summer peak electrical demand and improving the load factor of the electricity supply is the main reason for electric utility support of the GHP industry. Until the 1990s, GHP technology got attention from policymakers in Washington, D.C., and two notable federal GHP programs — the National Earth Comfort Program and the Federal Energy Management Program GHP technology-specific program (Hughes and Pratsch 2002) — were initiated to demonstrate GHP technology, mobilize the GHP market, and provide financial and technical support for implementing GHP systems. These utility and federal GHP programs were successful in increasing public awareness of GHP technology and increasing GHP unit shipments, as well as collecting hard data proving the benefits of GHP systems in terms of reducing maintenance and energy costs.

Though the United States was the world leader in GHP technology and still has the largest installed base of GHP systems — approximately 600,000 units in 2005 (Rybach 2005) — the GHP market share in the United States is much smaller than in some European counties. A 2005 review of the global market status of GHP systems estimated that Sweden, Denmark, Switzerland, and some other countries ranked higher on a per capita basis (Rybach 2005) than the United States. Owing to supportive government policies, the GHP market is growing rapidly in Asia, especially in China and South Korea. It is believed that the European and Asian markets have currently exceeded U.S. markets in annual shipments of GHP units.

Although the GHP industry in the United States remains small, it is better positioned for rapid growth than at any time during the past 30 years in many respects. Federal and state governments in the United States are giving strong incentives to support the development and application of energy efficiency and renewable energy technologies, among which GHP has been given high priority. Tax credits for home and business owners investing in GHP systems were enacted in October 2008 through 2016. Since 2007, rural electric cooperatives have been able to obtain loans from the U.S. Department of Agriculture Rural Utilities Service with terms of up to 35 years, at the cost of government funds, to provide the outside-the-building portion of GHP systems to customers in exchange for a tariff on the utility bill. The tariff would be more than offset by the GHP system’s energy cost savings. In December 2007 Congress directed the General Services Administration (GSA) to establish a program to accelerate the use of more cost-effective energy-saving technologies and practices in GSA facilities, starting with lighting and GHPs. A growing number of states offer tax credits or other incentives for GHP systems (listed on the

Database of State Incentives for Renewable Energy [DSIRE] Web site). In October 2009, DOE awarded a total of $63 million in American Recovery and Reinvestment Act funds to support the sustainable growth of the U.S. GHP industry though actions in three areas:

1. Demonstrating innovative business and financing strategies and/or technical approaches designed to overcome barriers to commercialization of GHPs
2. Gathering data, conducting analysis, and developing tools to assist consumers in determining project feasibility and achieving lowest-life-cycle-cost GHP applications
3. Creating a national certification standard for the GHP industry to increase consumer confidence in the technology, reduce the potential for improperly installed systems, and ensure product quality and performance

GHP units have been improved significantly in energy efficiency, noise level, and lifespan. Most GHP unit manufacturers have well-established supply chains and paths to market. There also have been improvements in the design and energy analysis of GHP systems, including (1) a design tool sponsored by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRASE) for hybrid GHP systems (Hackel 2009) and (2) the integration of improved representations of vertical bore ground heat exchangers and GHP systems in eQUEST, a DOE-2–based building energy analysis program that is credible but also relatively easy to use (Liu 2008).

The diverse segments of the GHP industry are better able to work with each other as a cohesive whole than ever before. The installed base of systems is much larger today and can serve to inform best practices. The most important trade allies of the GHP industry, electric utilities, are better able now to focus on peak load reduction and improved load factor, two key GHP system benefits, than they were in 1993 when utility restructuring was looming.

The infrastructure of support organizations is also much stronger now than it was in 1993. The International Ground Source Heat Pump Association (IGSHPA), which represents all segments of the industry, has matured. It provides the nation’s only major conferences and exhibitions totally focused on GHP technology, and it has developed respected training for drillers and installers. The Geothermal Heat Pump Consortium has been reconstituted as an advocacy and government relations organization sponsored by the GHP industry. ASHRAE Technical Committee TC 6.8, Geothermal Energy Utilization, has made great strides in developing the technical foundation for sound design of commercial GHP systems. The National Ground Water Association (NGWA) is more engaged than ever. National laboratory and university expertise persists, even though there have never been reliable funding sources to sustain GHP programs at these institutions.

2.3 Key Barriers Preventing Rapid Growth of the GHP industry in the United States

ORNL recently conducted an informal survey of a group of GHP industry experts to identify the barriers to rapid growth of the U.S. GHP industry (Hughes 2008). The survey identified the following barriers in order of priority (1 being the most important):

Tier 1
1. High first cost of GHP systems to consumers

Tier 2
2. Lack of consumer knowledge of and/or trust in GHP system benefits
3. Lack of policymaker and regulator knowledge of and/or trust in GHP system benefits
4. Limitations in GHP design and business planning infrastructure
5. Limitations in GHP installation infrastructure

Tier 3
6. Lack of new technologies and techniques to improve GHP system cost/performance

The multiple tiers are included to indicate that barriers 2–5 had essentially the same level of support among survey participants, whereas barrier 1 was perceived as being of greater importance and barrier 6 of lesser importance than 2 through 5. A bit of a surprise was that most of these barriers are the same as those identified in surveys conducted decades ago. As early as 1994, the National Earth Comfort Program (GHPC 1994) had identified first cost, confidence or trust in the technology, and design and installation infrastructure as the primary barriers to the growth of the GHP industry.

How high is the first cost of GHP systems to consumers? The Department of Defense — perhaps the largest single customer for GHP retrofit projects — reports that in 2006 dollars, housing and commercial retrofits cost $4,600 and $7,000 per ton respectively, and simple paybacks in the two regions with the most installed capacity averaged 8.6 to 12 years (DoD 2007). Retrofits in the private sector would likely be similar in cost and payback. New construction has the potential to be more economical because part of the first cost is offset by the avoided cost of the displaced conventional system, but simple paybacks exceeding 5 years are still common. First cost and long payback periods clearly limit GHP system acceptance in many markets. Currently in commercial markets, GHPs are primarily limited to institutional customers (e.g., federal, state, and local governments; K-12 schools) that take the life-cycle view. In residential markets, GHPs are limited to a small subset of newly constructed homes that the builder plans to occupy and thus wants to equip with the best available system, and to home retrofits in which the owner plans to occupy the premises long enough to justify the investment. In all of these cases, the building owner must have the financial wherewithal to use his/her own credit to finance the system.

What contributes to the high first cost of GHP systems? The ground heat exchanger (especially the vertical bore system, the one most often used) is the major reason for the high first cost. The cost of the ground heat exchanger usually makes up more than half the total cost of a GHP system. The GHP unit also contributes to the high first cost — currently 50–100% more expensive at retail than air-source heat pump units of comparable capacity and component quality. Several other interacting factors, which are directly or indirectly related to the tier 2 and 3 barriers listed above, also contribute to the high first cost. Figure 2 illustrates the factors that affect the first cost of GHP systems and their relationships to the identified barriers.

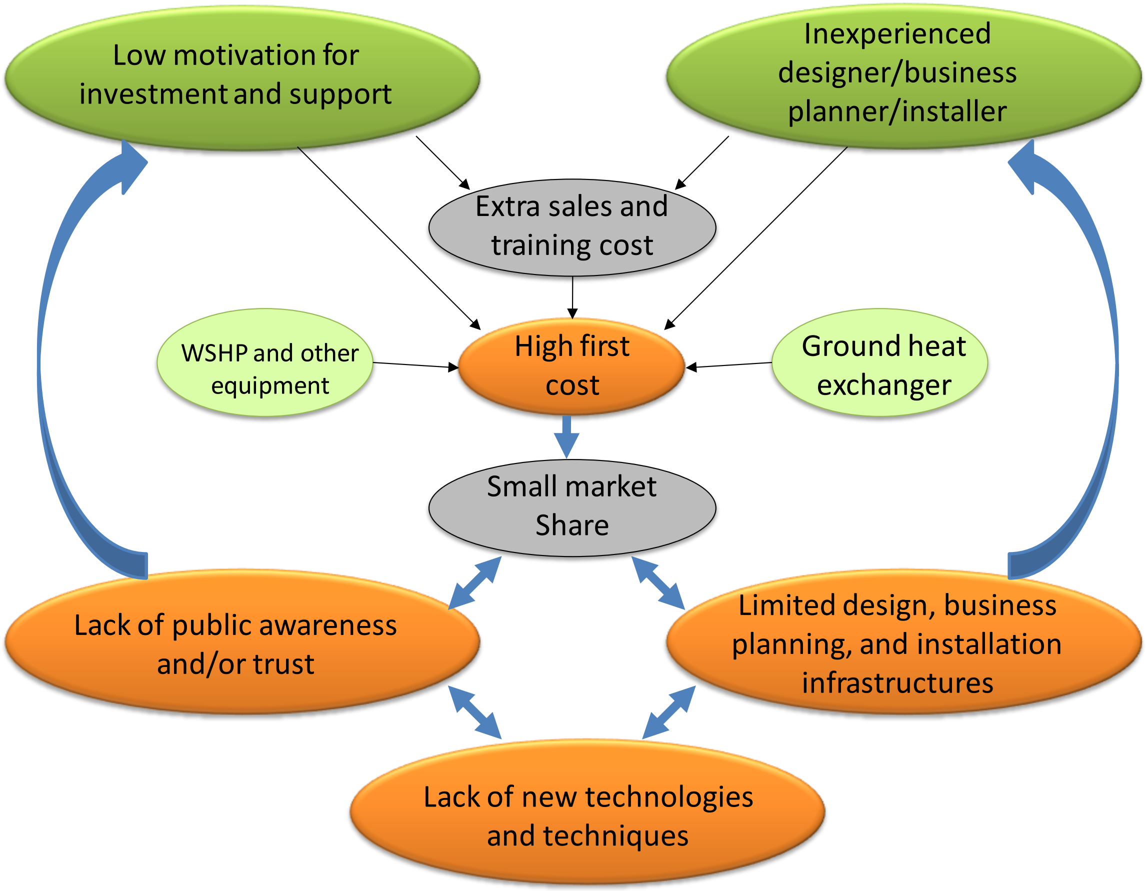

Fig. 2. Factors that affect the first cost of GHP systems and their relationships.

As shown in Figure 2, all the barriers result in a small market share for GHP systems in the United States. In turn, the small market share perpetuates the barriers because the GHP technology is almost invisible to the general public and thus unattractive to design, business planning, and installation professionals. The lack of public awareness and trust directly leads to low motivation to invest in and support the GHP industry. The limited design, business planning, and installation infrastructure implies that many HVAC professionals are not experienced with GHP applications. As a result, research and development (R&D) for GHP technology has been limited, and few new technologies and techniques have been developed. Without a substantial contribution from R&D, neither significant cost reduction and performance enhancement nor significant improvements in public awareness/trust and design/installation infrastructure are likely.

Given the large proportion of unmotivated consumers and inexperienced design/installation professionals, the GHP supply chain (original equipment manufacturers, distributors, dealers) must educate them and even provide extra technical assistance for the design and installation of GHP systems. These extra selling and training costs are included in the prices of GHP products. That partially explains why GHP units are currently 50–100% more expensive at retail than air-source heat pump units of comparable capacity and component quality. Of course, the relatively small shipment volume and the low motivation for investment and support (i.e., R&D to reduce cost and improve performance) also contribute to the relatively high cost of GHP units.

Inexperienced designers tend to oversize GHP systems and/or add excessive backup capacity to provide a larger safety margin, but doing so unnecessarily increases their cost. Lack of experience and competition in ground heat exchanger installation is another reason for the high first cost of GHP systems. Typically, the cost of installing a ground heat exchanger for a project can be 100–400% higher when an experienced and competitive installation infrastructure is not available.

Figure 2 shows that the GHP industry is trapped in a cycle of high first cost leading to small market leading to high first cost. To escape this cycle, the high first cost of GHP systems to consumers must be reduced to a level more competitive with other technologies.

3. Assessment of National Benefits from GHP Retrofit

The benefits achievable from retrofitting existing single-family homes with GHP systems depend on many factors, including the characteristics of the building itself (construction, orientation, insulation level, air tightness, etc.), energy efficiency and fuel type of existing SH-SC-WH systems (e.g. natural gas, heating oil, propane/liquefied propane gas, and electricity), occupants' lifestyle, and many other location-sensitive parameters, such as:

- climate conditions,
- cost of fuels used by the existing SH-SC-WH systems,
- primary energy (e.g. coal, natural gas, nuclear, and various types of renewable energy) consumption and CO_2 emissions associated with generating electricity and delivering it to building sites, which depends on the energy mix for electricity generation at a particular location, and
- primary energy consumption and CO_2 emissions associated with harvesting and delivering fossil fuels to building sites.

To accurately predict the magnitude of the national potential of benefits from retrofitting U.S. single-family homes with GHP systems, all of these factors need to be properly accounted for.

3.1 Energy Use of Typical SH-SC-WH Systems in Existing Single-Family Homes

EIA (Energy Information Agency) keeps track of the annual delivered energy[1] consumption of the entire U.S. residential sector through national area-probability-sample surveys[2], and the results are published regularly by DOE in the Buildings Energy Data

[1] Energy delivered to building without adjustment for energy consumed for producing and delivering the energy.

[2] The survey collected data from 4,382 households sampled at random using a complex, multistage, area-probability design to represent 111.1 million U.S. households, the Census Bureau's statistical estimate for all occupied housing units in 2005. Data were obtained from residential energy suppliers for each unit in the sample to produce the Consumption & Expenditures data.

Book. Data for SH-SC-WH system types and associated annual energy use for existing U.S. single-family homes have been extracted from the Public Use Microdata Files of the latest residential energy consumption survey (RECS 2005). Table 1 summarizes the SH-SC-WH systems that are most popularly used in existing U.S. single-family homes and their energy efficiencies (EIA 1978-1997, DOE BTP 2005). The number of single-family homes that use a particular SH/SC/WH system in each U.S. census region and corresponding annual consumption of delivered energy are presented in Table 2.

Table 1. Typical SH-SC-WH systems used in U.S. single-family homes.

Energy Services	Existing Systems/Equipments	Rated Efficiencies
Space Heating	Air source heat pump (ASHP)	3.2 COP (i)
	Electric heater	100 EF (ii)
	Natural gas fired furnace/boiler	80 AFUE (iii)
	Propane/LPG fired furnace/boiler	80 AFUE
	Heating oil fired furnace/boiler	80 AFUE
Space Cooling	Central air conditioner (CAC) / ASHP	10 SEER (iv)
	Room air conditioner (RAC)	7.7 SEER
	Combination of CAC and RAC	7.7 – 10 SEER
Water Heating	Electric heater	88 EF
	Natural gas heater	58 EF
	Propane/LPG heater	58 EF
	Heating oil heater	58 EF

i. COP stands for Coefficient of Performance, which is the ratio of heating energy provided to the space to the electric energy consumed when operating at standard conditions. The COP of the air source heat pump listed in the table is measured at standard, mild weather (47°F) rating conditions.

ii. EF stands for Energy Factor, which indicates a water heater's overall energy efficiency based on the amount of hot water produced per unit of fuel consumed over a typical day.

iii. AFUE stands for Annual Fuel Utilization Efficiency, which is the ratio of the annual amount of heat actually delivered to the amount of fuel supplied to the furnace.

iv. SEER stands for Seasonal Energy Efficiency Ratio, which is the average annual cooling efficiency of an air-conditioning or heat pump system determined with a standard methodology and assuming typical weather.

Table 2. Number of single-family homes with SH/SC/WH in each census region and corresponding annual consumption of delivered energy (based on data from RECS Public Use Microdata Files).

Census Region	SH/SC/WH System Types	Number of Existing Single-Family Homes	Percentage of Existing Single-Family Homes in a Region that Use Various Systems for SH/SC/WH	Delivered Energy Consumed for SH/SC/WH by Existing Single-family Homes in each Census Region (from RECS 2005)	Percentage of Delivered Energy Consumption in a Region by Single-Family Homes with Various Systems for SH/SC/WH
		Millions	-	Billion Btu	-
Northeast	**Space Heating**	**13.0**	**100%**	**1,036,111.4**	**100%**
	Electric Heat Pump	0.18	1.4%	1,869.5	0.2%
	Electric Heater	0.70	5.4%	15,518.5	1.5%
	Natural gas	7.19	55.5%	545,290.1	52.6%
	Propane/LPG	0.36	2.8%	26,577.9	2.6%
	Fuel Oil	4.54	35.0%	446,855.4	43.1%
	Space Cooling	**11.1**	**100%**	**55,800.7**	**100%**
	Central air conditioner	4.95	44.4%	35,651.9	63.9%
	Room air conditioner	6.10	54.8%	18,571.6	33.3%
	Both central and room AC	0.10	0.9%	1,577.1	2.8%
	Water Heating	**13.3**	**100%**	**322,149.1**	**100%**
	Electric	2.93	22.0%	27,361.2	8.5%
	Natural gas	7.08	53.1%	187,572.4	58.2%
	Propane/LPG	0.52	3.9%	17,533.8	5.4%
	Fuel Oil	2.80	21.0%	89,681.8	27.8%
	Regional Sub-Total	37.4		1,414,061.2	
Midwest	**Space Heating**	**19.4**	**100%**	**1,220,359.0**	**100%**
	Electric Heat Pump	0.69	3.6%	9,528.2	0.8%
	Electric Heater	1.38	7.1%	38,577.5	3.2%
	Natural gas	14.91	76.9%	1,007,014.8	82.5%
	Propane/LPG	1.71	8.8%	110,737.9	9.1%
	Fuel Oil	0.69	3.6%	54,500.6	4.5%
	Space Cooling	**18.6**	**100%**	**125,209.6**	**100%**
	Central air conditioner	14.64	78.6%	111,213.5	88.8%
	Room air conditioner	3.62	19.4%	11,851.6	9.5%
	Both central and room AC	0.36	1.9%	2,144.4	1.7%
	Water Heating	**23.0**	**109%**	**450,429.6**	**100%**
	Electric	5.56	24.2%	60,561.6	13.4%
	Natural gas	13.60	59.3%	348,376.4	77.3%
	Propane/LPG	0.99	4.3%	40,391.1	9.0%
	Fuel Oil	2.80	21.0%	1,100.5	0.2%
	Regional Sub-Total	61.0		1,795,998.2	
South	**Space Heating**	**28.0**	**100%**	**692,639.8**	**100%**
	Electric Heat Pump	6.04	21.6%	39,701.8	5.7%
	Electric Heater	8.02	28.6%	105,666.7	15.3%
	Natural gas	11.58	41.3%	416,522.4	60.1%
	Propane/LPG	1.92	6.9%	91,162.6	13.2%
	Fuel Oil	0.45	1.6%	39,586.2	5.7%
	Space Cooling	**28.0**	**100%**	**443,245.8**	**100%**
	Central air conditioner	22.71	81.0%	388,678.9	87.7%
	Room air conditioner	4.64	16.5%	39,477.2	8.9%
	Both central and room AC	0.70	2.5%	15,089.7	3.4%
	Water Heating	**31.9**	**112%**	**521,217.2**	**100%**
	Electric	16.67	52.3%	166,429.5	31.9%
	Natural gas	11.53	36.2%	314,584.5	60.4%
	Propane/LPG	0.86	2.7%	35,951.7	6.9%
	Fuel Oil	2.80	21.0%	4,251.5	0.8%
	Regional Sub-Total	87.9		1,657,102.8	
West	**Space Heating**	**15.6**	**100%**	**473,587.2**	**100%**
	Electric Heat Pump	0.79	5.1%	5,269.7	1.1%
	Electric Heater	2.72	17.4%	31,853.3	6.7%
	Natural gas	11.26	72.0%	378,182.1	79.9%
	Propane/LPG	0.66	4.2%	35,628.5	7.5%
	Fuel Oil	0.21	1.3%	22,653.6	4.8%
	Space Cooling	**9.5**	**100%**	**78,108.0**	**100%**
	Central air conditioner	7.74	81.7%	73,231.3	93.8%
	Room air conditioner	1.49	15.8%	3,433.9	4.4%
	Both central and room AC	0.24	2.5%	1,442.8	1.8%
	Water Heating	**19.5**	**107%**	**409,343.8**	**100%**
	Electric	3.41	17.5%	39,301.4	9.6%
	Natural gas	12.56	64.5%	338,378.5	82.7%
	Propane/LPG	0.72	3.7%	30,576.5	7.5%
	Fuel Oil	2.80	21.0%	1,087.4	0.3%
	Regional Sub-Total	44.6		961,039.0	
Total				**5.8 Quad Btu**	

3.2 State-of-the-Art GHP System

The state-of-the-art GHP system presented in this study consists of a packaged water-to-air GHP unit with a two-stage scroll compressor and variable-speed electronically commutated motor (ECM) fan, a properly sized and highly energy efficient loop fluid circulator, and a properly designed and installed vertical borehole ground heat exchanger. The nominal cooling efficiency of the two-stage GHP unit is EER[3] 18.2 at full capacity and EER 27 at 76% of full capacity. The nominal heating efficiency of the two-stage GHP unit is COP 4 at full capacity and COP 4.5 at 76% of full capacity[4].

The ground heat exchanger is sized to maintain the fluid temperature from the ground loop [the entering fluid temperature (EFT) to the GHP unit] within the range of 30°F - 95°F for given building loads, ground thermal properties, and the undisturbed ground temperature.

The state-of-the-art GHP system can contribute to water heating through use of a desuperheater. Desuperheaters apply the waste heat produced whenever the GHP runs for space cooling to the water heater (usually an electric storage-type water heater). In this study, the efficiency of the electric water heater is assumed to be EF 88.

3.3 Reference Building

Given the vast number and wide variation of homes in the United States, it is not practical to model each of the existing single-family homes. On the other hand, the relative difference in annual energy consumption between the state-of-the-art GHP system and existing SH-SC-WH systems for providing the same energy service depends more on the characteristics of the compared systems, weather, and geological conditions than the building itself. Therefore, one reference building representing typical U.S. single-family homes (including internal loads from lighting, appliances, cooking, and occupants) is used in this study to calculate the relative difference in annual energy consumption between the state-of-the-art GHP system and existing SH-SC-WH systems. The description of this reference building is provided in Appendix A.

3.4 Calculation Tool

The annual delivered energy consumption of the state-of-the-art GHP system and typical existing SH-SC-WH systems was calculated with GeoDesigner, a well-established energy analysis program developed by ClimateMaster, Inc.

GeoDesigner uses the ASHRAE bin analysis method to calculate the energy consumption of GHP and other residential SH-SC-WH systems. Compared with more sophisticated hourly energy simulation programs, bin analysis is less accurate in estimating the impacts of weather elements (i.e., solar, wind, precipitation, etc.) and the heat gain from activities inside the building (i.e., lighting, cooking, showering, etc.) on the building heating/cooling loads. Bin analysis also limits the capability for more detailed analysis of electrical demand of the building and more accurate calculation of ground heat exchanger temperatures.

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

[4] The COP and EER are measured at AHRI/ISO/ASHRAE/ANSI 13256-1 rating conditions: for cooling at full capacity, EFT is 77°F; for heating at full capacity, EFT is 32°F.

However, while there are some discrepancies in the predicted total energy consumption of particular SH-SC-WH systems, the relative difference in energy consumption between the state-of-the-art GHP system and the existing SH-SC-WH systems predicted by GeoDesigner and the more sophisticated programs are fairly close.

Since, as described below, it is the relative difference in annual energy consumption between different SH-SC-WH systems that is needed for this study, and considering the advantages of GeoDesigner, including user-friendly interfaces and reports, robust and fast calculations, and capability for performing energy analysis for a wide range of residential SH-SC-WH systems, GeoDesigner was selected for this study. The more detailed description of the algorithms, capabilities, and limitations of GeoDesigner are given in Appendix B.

3.5 Calculation Procedure for Energy Savings and CO_2 Emissions Reduction

The efficiencies of air source heat pumps and air conditioners are affected by the outdoor ambient temperature, and the efficiency of a GHP system is influenced by the fluid temperature from the ground heat exchanger, which is determined by the building heating and cooling loads, the size of the ground heat exchanger, and geological conditions (i.e., the ground thermal properties) where the system is installed. Therefore, to obtain an estimate of the regional average of the relative difference in annual energy consumption between the GHP system and existing SH-SC-WH systems, different weather and geological conditions within the region were accounted for in this study. As a simplification, it is assumed that the weather and undisturbed ground temperatures are identical across a climate zone within a census region. Ground thermal properties values that are very common in the United States are used for all the climate zones (representing the typical thermal properties of granite, limestone, and sandstone with 1.4 Btu/hr-ft-F thermal conductivity and 0.04 ft^2/hr thermal diffusivity). We first calculated the delivered energy consumed annually by each of the typical existing SH-SC-WH systems and the state-of-the-art GHP system for providing the same SH-SC-WH service, in each climate zone within a particular census region. Then we used the population associated with each climate zone as a weighting factor to calculate the regional average of annual delivered energy consumption for each of the compared systems. Finally we computed the regional relative difference in annual delivered energy consumption between the state-of-the-art GHP system and each of the existing SH-SC-WH systems.

The procedure and formulas used for estimating the annual national potential savings in delivered energy from retrofitting U.S. single-family homes with GHP systems is described in the following.

<u>Step 1:</u>

Calculate the peak heating and cooling loads of the reference building at various locations that represent major climate zones with each of the four U.S. census regions.

<u>Step 2:</u>

Calculate the annual delivered energy consumption of each compared SH-SC-WH system with GeoDesigner based on the peak heating and cooling loads determined in Step 1 and the associated weather and geological conditions.

Step 3:

Calculate the regional average of annual delivered energy consumption of a particular SH-SC-WH system serving the reference building with Equation 1.

$$Avg\_Sys\_DE(j,k) = \frac{\sum_{i=1}^{n} Sys\_DE(i,j,k) \cdot CZ(i,k)}{\sum_{i=1}^{n} CZ(i,k)} \quad \text{(Eq. 1)}$$

where

$Avg\_Sys\_DE(j,k)$ is the average annual delivered energy consumption of SH-SC-WH system *j* in census region *k*;

$Sys\_DE(i,j,k)$ is the annual delivered energy consumption of SH-SC-WH system *j* in climate zone *i* of census region *k*;

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

n is the number of major climate zones in census region *k*.

Step 4:

Calculate the regional average relative differences in annual delivered energy consumption between the state-of-the-art GHP system and each of the typical existing SH-SC-WH systems with Equation 2.

$$RD\_DE(j,k) = \frac{Avg\_Sys\_DE(j,k) - Sys\_DE\_GHP(k)}{Avg\_Sys\_DE(j,k)} \quad \text{(Eq. 2)}$$

where

$RD\_DE(j,k)$ is the regional average relative difference in annual delivered energy consumption between the state-of-the-art GHP system and SH-SC-WH system *j* in census region *k*; and

$Sys\_DE\_GHP(k)$ is the average annual energy consumption of the state-of-the-art GHP system in census region *k*.

Step 5:

Calculate the annual savings in delivered energy from GHP retrofits in a particular region with Equation 3.

$$Reg\_DE(k) = \sum_{j=1}^{m} SFHS\_DE(j,k) \cdot Penetration \cdot RD\_DE(j,k) \qquad \text{(Eq. 3)}$$

where

$Reg\_DE(k)$ is the annual savings in delivered energy in census region *k*;

$SFHS\_DE(j,k)$ is the annual delivered energy consumed by existing SH-SC-WH system *j* in census region *k*;

$Penetration$ is the assumed fraction of existing U.S. single-family homes captured by GHP retrofits; and

m is the number of existing SH-SC-WH systems used in U.S. single-family homes.

Step 6:

Calculate the national potential savings in delivered energy from retrofitting existing U.S. single-family homes with the state-of-the-art GHP system with Equation 4.

$$National\_DE = \sum_{k=1}^{4} Reg\_DE(k) \qquad \text{(Eq. 4)}$$

Following this procedure, the national potential of savings/reductions in energy expenditure, primary energy consumption, and CO_2 emissions were also estimated. In these calculations, the annual delivered energy consumption of each compared SH-SC-WH system was replaced with the associated energy expenditure, primary energy consumption, or CO_2 emissions using corresponding regional utility rates, conversion factors between delivered and primary energy, and emissions factors of various fuels used by the compared SH-SC-WH systems.

3.6 Calculation Procedure for Summer Peak Electrical Demand Reduction

Since there is no documented data available for regional or national summer peak electrical demand of residential buildings, the potential reduction in peak demand from GHP retrofits is estimated from the bin analysis data generated by GeoDesigner.

In general, the summer peak electrical demand of single-family homes is coincident with the peak electrical demand for space cooling. Therefore, the reduction in summer peak electrical demand is determined in this study as the reduction of electrical demand for space cooling at its peak. The calculation is expressed in Equation 5.

$$PEDFSC = \frac{kWh\_MaxTemp}{Hr\_MaxTemp \times Fraction\_HP} \qquad \text{(Eq. 5)}$$

Where

$PEDFSC$ is the peak electrical demand for space cooling, kW;

$kWh\_MaxTemp$ is the electrical energy consumed for space cooling when outdoor ambient temperature is within the highest temperature bin of a particular location, kWh;

$Hr\_MaxTemp$ is the number of hours when outdoor ambient temperature is within the highest temperature bin of a particular location, hour; and

$Fraction\_HP$ is the percentage of $Hr\_MaxTemp$ when the heat pump runs.

The above calculated peak electrical demand for cooling is further normalized by dividing it with the coincident peak cooling load (expressed in tons) of the reference building at the particular location, in kW/ton.

The regional average summer peak electrical demand for space cooling for the state-of-the-art GHP system and typical existing SC systems are determined by applying the population weighting factor of each climate zone to the normalized electrical demands calculated for each climate zone within a particular census region. The regional total summer peak electrical demand for space cooling is the product of three variables:

- the average normalized summer peak electrical demand for space cooling per household in a census region (kW/ton);
- the average cooling tonnage per household in a census region (ton); and
- the total number of households in a census region that use space cooling.

3.7 Selected Locations for Energy Analysis

The 2004 International Energy Conservation Code (IECC) Climate Zones for the U.S. are used in this study. These climate zones were developed based on analysis of the 4775 National Oceanic and Atmospheric Administration (NOAA) weather sites and statistical analysis of regional information, and are used in ASHRAE standards 90.1 and 90.2, the ASHRAE Advanced Energy Design Guide Series, and DOE's Building America program. Figure 3 shows the 2004 IECC Energy Code Climate Zones, which are assigned using county boundaries.

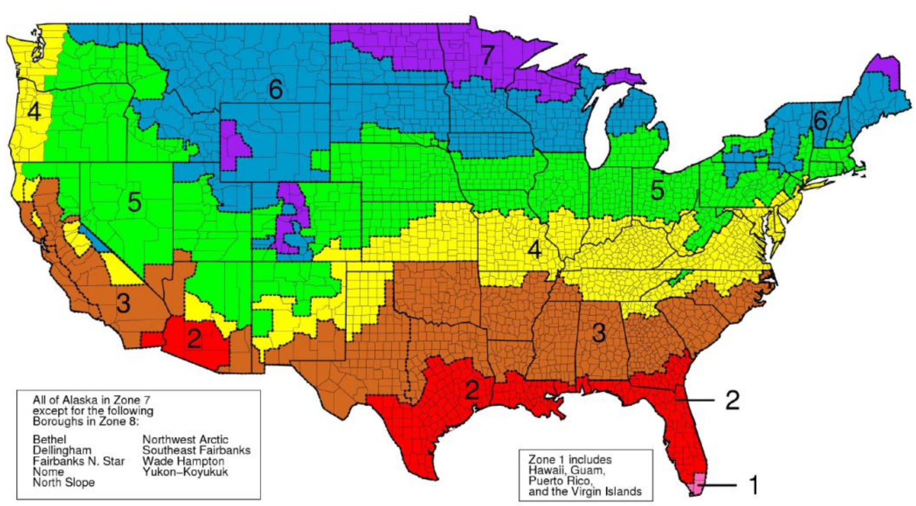

Fig. 3. 2004 IECC Climate Zones of the United States.

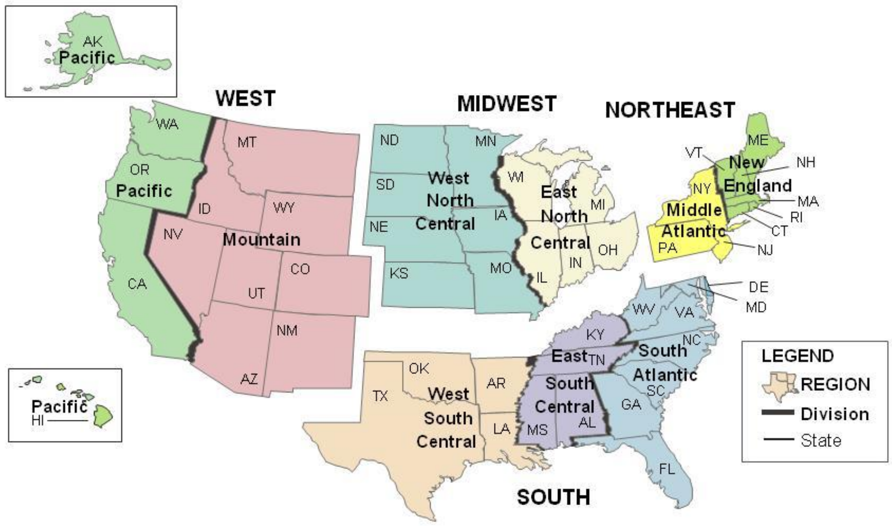

Fig. 4. U.S. Census Regions and Divisions.

Comparing the U.S. census regions map in Figure 4 with the climate zones in Figure 3 shows that each census region covers multiple climate zones. Table 3 lists the percentages of population in each climate zone in each census region. Where the percentage of the population in a climate zone is very low (less than 5% of the total population in the census region), that climate zone is omitted from the calculations. One location (a city) was selected to represent each of the 14 climate zones included in this study.

Table 3. Percentage of population in each climate zone within each of the U.S. Census Regions.

Climate Zones	U.S. Census Regions			
	Northeast	Midwest	South	West
1A	-	-	4.0%	1.9%
1B	-	-	-	-
2A	-	-	**29.2%**	-
2B	-	-	0.4%	**7.4%**
3A	-	-	**35.1%**	-
3B	-	-	1.8%	**44.7%**
3C	-	-	-	**11.5%**
4A	**40.1%**	**18.8%**	**28.2%**	-
4B	-	-	0.5%	2.6%
4C	-	-	-	**11.8%**
5A	**51.5%**	**60.2%**	0.9%	-
5B	-	-	-	**16.4%**
5C	-	-	-	-
6A	**8.3%**	**18.4%**	-	-
6B	-	-	-	3.5%
7A	0.1%	2.5%	-	-
7B	-	-	-	0.3%
8A	-	-	-	-
8B	-	-	-	-

The peak heating and cooling loads for the reference building at each of the 14 locations were calculated using eQUEST, a DOE-2–based building energy analysis program, and the results are listed in Table 4. These peak heating and cooling loads, along with other user-specified parameters (i.e., location/bin-weather data, SH-SC-WH system type and efficiency, number of occupants, hot water temperature, etc.), are used by GeoDesigner to calculate the annual delivered energy consumption of various SH-SC-WH systems serving the building.

Table 4. Peak heating and cooling loads for the reference building in 14 representative locations (cities).

Census Region	Climate Zone	City	State	Peak Heating Load	Peak Cooling Load (Tot)	Peak Cooling Load (Sen)
				Btu/Hr	Btu/Hr	Btu/Hr
NorthEast	4A	Philadelphia	PA	29,204	20,650	15,116
NorthEast	5A	Boston	MA	32,695	15,307	11,358
NorthEast	6A	Bangor	ME	44,309	18,761	14,165
MidWest	4A	Kansas City	MO	33,772	25,286	18,358
MidWest	5A	Chicago	IL	40,490	20,092	14,627
MidWest	6A	Minneapolis	MN	45,452	18,191	13,570
South	2A	Houston	TX	22,004	25,113	18,458
South	3A	Atlanta	GA	26,436	23,884	18,152
South	4A	Nashville	TN	35,860	24,489	18,489
West	2B	Phoenix	AZ	14,191	26,598	25,215
West	3B	Sacramento	CA	15,890	19,388	17,120
West	3C	San Francisco	CA	14,734	13,589	12,828
West	4C	Portland	OR	25,756	15,076	12,860
West	5B	Denver	CO	40,817	15,118	15,118

3.8 Estimated Benefits

The potential benefits from retrofitting U.S. single-family homes with the state-of-the-art GHP system were estimated using the procedures described in previous sections. The estimated national potential for each of the four major benefits of GHP retrofits — energy savings, reductions in CO_2 emissions, avoided summer peak electrical demand, and energy expenditure savings — all at various market penetration rates, are presented in the following sections. The energy consumption, CO_2 emissions, summer peak electrical demand, and energy expenditures of each of the compared SH/SC/WH systems at each of the 14 representative locations, as well as the population-weighted average for each census region, are listed in Appendix C.

3.8.1 Energy Savings

The estimated regional and national potential savings in delivered energy are presented in Table 5. Columns 3 and 4 summarize the regional average of the delivered energy consumed by the state-of-the-art GHP system and the existing SH-SC-WH systems, respectively, for providing the same energy services to the reference building. As described previously, these regional averages have taken into account the impacts of typical weather, geological conditions, and population distribution within the region. Column 5 lists the regional average of savings in delivered energy from retrofitting the existing SH-SC-WH systems with the state-of-the-art GHP system. Column 6 expresses the savings as a percentage of the delivered energy consumed by the existing SH-SC-WH systems. Column 7 provides the regional total of delivered energy consumed for SH-SC-WH at single-family homes, which is obtained from Public Use Microdata Files of the latest residential energy consumption survey (RECS 2005). Columns 8 through 12 present the estimated regional potential in savings of delivered energy at various market penetration rates.

Table 5. National savings of delivered energy from GHP retrofits for existing U.S. single-family homes

Census Region	SH-SC-WH System Types	Regional Average Delivered Energy Cons. by Existing SH-SC-WH System in Reference Building	Regional Average Delivered Energy Cons. by GHP System in Reference Building	Regional Average Savings of Delivered Energy in Reference Building	Percentage Savings of Delivered Energy from GHP Retrofit	Regional Delivered Energy Cons. for SH-SC-WH in All Single-Family Homes (RECS 2005)	Estimated Regional Potential in Savings of Delivered Energy: 20% Market Penetration Rate for GHP Retrofit	40% Market Penetration Rate for GHP Retrofit	60% Market Penetration Rate for GHP Retrofit	80% Market Penetration Rate for GHP Retrofit	100% Market Penetration Rate for GHP Retrofit
		Million Btu	Million Btu	Million Btu	%	Trillion Btu	Trillion Btu	Trillion Btu	Trillion Btu	Trillion Btu	Trillion Btu
Northeast	**Space Heating**					**1,036.1**	**170.9**	**341.8**	**512.6**	**683.5**	**854.4**
	Electric Heat Pump	41.5	14.4	27.1	65.3%	1.9	0.2	0.5	0.7	1.0	1.2
	Electric Heater	56.5	14.4	42.1	74.5%	15.5	2.3	4.6	6.9	9.3	11.6
	Natural gas	78.4	14.4	64.0	81.7%	545.3	89.1	178.1	267.2	356.3	445.3
	Propane/LPG	76.3	14.4	61.9	81.2%	26.6	4.3	8.6	12.9	17.3	21.6
	Fuel Oil	89.0	14.4	74.7	83.9%	446.9	74.9	149.9	224.8	299.8	374.7
	Space Cooling					**55.8**	**8.5**	**16.9**	**25.4**	**33.8**	**42.3**
	Central air conditioner	5.8	1.5	4.3	73.7%	35.7	5.3	10.5	15.8	21.0	26.3
	Room air conditioner	7.5	1.5	6.0	79.7%	18.6	3.0	5.9	8.9	11.8	14.8
	Both central and room AC	6.6	1.5	5.1	77.1%	1.6	0.2	0.5	0.7	1.0	1.2
	Water Heating					**322.1**	**37.4**	**74.8**	**112.1**	**149.5**	**186.9**
	Electric	16.7	10.4	6.3	37.8%	27.4	2.1	4.1	6.2	8.3	10.3
	Natural gas	26.0	10.4	15.7	60.2%	187.6	22.6	45.2	67.8	90.4	113.0
	Propane/LPG	25.3	10.4	15.0	59.1%	17.5	2.1	4.1	6.2	8.3	10.4
	Fuel Oil	25.5	10.4	15.1	59.4%	89.7	10.7	21.3	32.0	42.6	53.3
	Regional Total SH-SC-WH					**1,414.1**	**216.7**	**433.4**	**650.2**	**866.9**	**1,083.6**
Midwest	**Space Heating**					**1,220.4**	**195.8**	**391.6**	**587.4**	**783.2**	**979.0**
	Electric Heat Pump	56.6	18.2	38.5	67.9%	9.5	1.3	2.6	3.9	5.2	6.5
	Electric Heater	67.1	18.2	48.9	72.9%	38.6	5.6	11.3	16.9	22.5	28.1
	Natural gas	93.2	18.2	75.0	80.5%	1,007.0	162.1	324.3	486.4	648.5	810.7
	Propane/LPG	90.6	18.2	72.5	80.0%	110.7	17.7	35.4	53.1	70.8	88.5
	Fuel Oil	105.8	18.2	87.6	82.8%	54.5	9.0	18.1	27.1	36.1	45.1
	Space Cooling					**125.2**	**17.2**	**34.5**	**51.7**	**69.0**	**86.2**
	Central air conditioner	8.3	2.6	5.6	68.1%	111.2	15.1	30.3	45.4	60.6	75.7
	Room air conditioner	10.7	2.6	8.1	75.4%	11.9	1.8	3.6	5.4	7.2	8.9
	Both central and room AC	9.5	2.6	6.9	72.2%	2.1	0.3	0.6	0.9	1.2	1.5
	Water Heating					**450.4**	**53.0**	**106.0**	**159.1**	**212.1**	**265.1**
	Electric	18.6	11.1	7.5	40.4%	60.6	4.9	9.8	14.7	19.6	24.4
	Natural gas	29.1	11.1	18.0	61.8%	348.4	43.1	86.2	129.3	172.4	215.5
	Propane/LPG	28.3	11.1	17.2	60.7%	40.4	4.9	9.8	14.7	19.6	24.5
	Fuel Oil	28.5	11.1	17.4	61.0%	1.1	0.1	0.3	0.4	0.5	0.7
	Regional Total SH-SC-WH					**1,796.0**	**266.1**	**532.1**	**798.2**	**1,064.2**	**1,330.3**
South	**Space Heating**					**692.6**	**112.7**	**225.4**	**338.0**	**450.7**	**563.4**
	Electric Heat Pump	20.5	7.8	12.8	62.2%	39.7	4.9	9.9	14.8	19.7	24.7
	Electric Heater	33.8	7.8	26.1	77.1%	105.7	16.3	32.6	48.9	65.1	81.4
	Natural gas	47.0	7.8	39.3	83.5%	416.5	69.6	139.1	208.7	278.2	347.8
	Propane/LPG	45.8	7.8	38.0	83.0%	91.2	15.1	30.3	45.4	60.6	75.7
	Fuel Oil	53.4	7.8	45.7	85.5%	39.6	6.8	13.5	20.3	27.1	33.8
	Space Cooling					**443.2**	**54.9**	**109.8**	**164.8**	**219.7**	**274.6**
	Central air conditioner	14.7	5.7	9.0	61.0%	388.7	47.4	94.8	142.2	189.6	237.0
	Room air conditioner	19.1	5.7	13.4	70.0%	39.5	5.5	11.0	16.6	22.1	27.6
	Both central and room AC	16.9	5.7	11.2	66.0%	15.1	2.0	4.0	6.0	8.0	10.0
	Water Heating					**521.2**	**57.5**	**114.9**	**172.4**	**229.8**	**287.3**
	Electric	15.6	9.3	6.4	40.7%	166.4	13.5	27.1	40.6	54.1	67.7
	Natural gas	24.4	9.3	15.1	62.0%	314.6	39.0	78.0	117.1	156.1	195.1
	Propane/LPG	23.7	9.3	14.5	60.9%	36.0	4.4	8.8	13.1	17.5	21.9
	Fuel Oil	23.9	9.3	14.6	61.2%	4.3	0.5	1.0	1.6	2.1	2.6
	Regional Total SH-SC-WH					**1,657.1**	**225.1**	**450.1**	**675.2**	**900.2**	**1,125.3**
West	**Space Heating**					**473.6**	**77.5**	**155.0**	**232.5**	**310.0**	**387.5**
	Electric Heat Pump	20.7	8.2	12.5	60.2%	5.3	0.6	1.3	1.9	2.5	3.2
	Electric Heater	34.0	8.2	25.7	75.7%	31.9	4.8	9.6	14.5	19.3	24.1
	Natural gas	47.0	8.2	38.8	82.5%	378.2	62.4	124.7	187.1	249.5	311.8
	Propane/LPG	45.8	8.2	37.5	82.0%	35.6	5.8	11.7	17.5	23.4	29.2
	Fuel Oil	53.4	8.2	45.1	84.5%	22.7	3.8	7.7	11.5	15.3	19.2
	Space Cooling					**78.1**	**9.6**	**19.2**	**28.7**	**38.3**	**47.9**
	Central air conditioner	8.1	3.2	4.9	60.8%	73.2	8.9	17.8	26.7	35.6	44.5
	Room air conditioner	10.6	3.2	7.4	69.8%	3.4	0.5	1.0	1.4	1.9	2.4
	Both central and room AC	9.3	3.2	6.2	65.9%	1.4	0.2	0.4	0.6	0.8	1.0
	Water Heating					**409.3**	**45.1**	**90.2**	**135.3**	**180.4**	**225.5**
	Electric	16.0	10.7	5.4	33.6%	39.3	2.6	5.3	7.9	10.6	13.2
	Natural gas	25.1	10.7	14.4	57.5%	338.4	38.9	77.8	116.7	155.6	194.5
	Propane/LPG	24.4	10.7	13.7	56.2%	30.6	3.4	6.9	10.3	13.8	17.2
	Fuel Oil	24.5	10.7	13.9	56.6%	1.1	0.1	0.2	0.4	0.5	0.6
	Regional Total SH-SC-WH					**961.0**	**132.2**	**264.4**	**396.5**	**528.7**	**660.9**
National Total of Delivered Energy Savings [Quad Btu]							**0.8**	**1.7**	**2.5**	**3.4**	**4.2**
Percentage Savings							**14.4%**	**28.8%**	**43.2%**	**57.7%**	**72.1%**

As shown in Table 5, while the annual consumption of delivered energy for a particular SH/SC/WH system varied significantly among the census regions, the relative differences between the state-of-the-art GHP system and the existing SH/SC/WH systems were not very sensitive to the census region. Compared with SH/SC/WH systems typically used in existing single-family homes, the state-of-the-art GHP system consumed 60% – 86% less delivered energy for space heating, 60% – 80% less delivered energy for space cooling, and 34% - 62% less delivered energy for water heating. If all SH/SC/WH systems in existing U.S. single-family homes are replaced with state-of-the art GHP systems, it is estimated that 4.2 Quad Btu of delivered energy will be saved each year, which equals 72.1% of all delivered energy currently consumed for SH-SC-WH in U.S. single-family homes. However, if only 20% of U.S. single-family homes are retrofitted with the state-of-the-art GHP system, the savings of delivered energy is about 0.8 Quad Btu, which is a 14.4% reduction from current consumption levels.

By converting the delivered energy consumption data (both the calculated delivered energy consumption for SH-SC-WH in the reference building and the documented delivered energy consumption for all existing U.S. single-family homes) to the associated primary energy consumption with the conversion factors listed in Table 6, the national potential of savings in annual primary energy consumption is estimated, as shown in Table 7. The primary energy conversion factors for electricity and fossil fuels were adopted from a recent report from National Renewable Energy Laboratory (NREL 2007). While the primary energy conversion factors for other fossil fuels are independent of the location where the delivered energy is consumed, the primary energy conversion factor for electricity depends on the energy portfolio for electricity generation for the particular location, and these portfolios will likely include more renewable/green energy in the future. However, since the primary energy conversion factors for electricity at each census region were not available when this study was conducted, the 2005 national average of the primary energy conversion factor for electricity was used.

Table 6. Source energy factors for fuel or electricity delivered to buildings.

Fuel	Conversion Factor
Natural Gas	1.092
Propane	1.151
Heating Oil	1.158
Electricity	3.365

As shown at the bottom of Table 7, a total of 3.8 Quad Btu of primary energy, which corresponds to 41.1% of primary energy currently consumed for SH-SC-WH in existing U.S. single-family homes, could be saved each year by retrofitting all existing U.S. single-family homes with state-of-the-art GHP systems. The savings of primary energy is linearly correlated to the market penetration rate of GHP retrofits.

Since the primary energy conversion factor for electricity is larger than that for fossil fuels, the savings in primary energy for space heating and water heating is lower than the savings in delivered energy. The primary energy consumption for water heating actually increased when existing water heaters fired with fossil fuels were replaced with electric water heaters assisted with GHP unit desuperheaters. If by policy the existing water heaters fired with fossil fuels were not replaced with desuperheater-assisted electric water heaters, the maximum savings of primary energy from GHP retrofits rises from 3.8 Quad Btu to **4.2 Quad Btu**, which is **45.1%** of primary energy currently consumed for SH-SC-WH in existing U.S. single-family homes.

Table 7. National savings of primary energy from GHP retrofits for existing U.S. single-family homes

Census Region	SH-SC-WH System Types	Regional Average Primary Energy Cons. by Existing SH-SC-WH System in Reference Building	Regional Average Primary Energy Cons. by GHP System in Reference Building	Regional Average Savings of Primary Energy Cons. in Reference Building	Percentage Savings of Primary Energy Cons. from GHP Retrofit	Regional Primary Energy Cons. for SH-SC-WH in All Single-Family Homes (RECS 2005)	Estimated Regional Potential in Savings of Primary Energy Cons.				
							20% Market Penetration Rate for GHP Retrofit	40% Market Penetration Rate for GHP Retrofit	60% Market Penetration Rate for GHP Retrofit	80% Market Penetration Rate for GHP Retrofit	100% Market Penetration Rate for GHP Retrofit
		Million Btu	Million Btu	Million Btu	%	Trillion Btu	Trillion Btu	Trillion Btu	Trillion Btu	Trillion Btu	Trillion Btu
Northeast	**Space Heating**					**1,202.0**	**122.7**	**245.5**	**368.2**	**491.0**	**613.7**
	Electric Heat Pump	139.5	48.4	91.2	65.3%	6.3	0.8	1.6	2.5	3.3	4.1
	Electric Heater	190.0	48.4	141.6	74.5%	52.2	7.8	15.6	23.4	31.1	38.9
	Natural gas	88.4	48.4	40.0	45.3%	595.5	53.9	107.8	161.8	215.7	269.6
	Propane/LPG	91.5	48.4	43.1	47.2%	30.6	2.9	5.8	8.7	11.5	14.4
	Fuel Oil	108.4	48.4	60.1	55.4%	517.5	57.3	114.7	172.0	229.3	286.7
	Space Cooling					**187.8**	**28.5**	**56.9**	**85.4**	**113.8**	**142.3**
	Central air conditioner	19.5	5.1	14.3	73.7%	120.0	17.7	35.4	53.0	70.7	88.4
	Room air conditioner	25.3	5.1	20.1	79.7%	62.5	10.0	19.9	29.9	39.9	49.8
	Both central and room AC	22.4	5.1	17.2	77.1%	5.3	0.8	1.6	2.5	3.3	4.1
	Water Heating					**420.9**	**(7.9)**	**(15.8)**	**(23.7)**	**(31.6)**	**(39.5)**
	Electric	56.1	34.9	21.2	37.8%	92.1	7.0	13.9	20.9	27.9	34.8
	Natural gas	27.9	34.9	-7.0	-25.0%	204.8	(10.2)	(20.5)	(30.7)	(41.0)	(51.2)
	Propane/LPG	28.9	34.9	-5.9	-20.5%	20.2	(0.8)	(1.7)	(2.5)	(3.3)	(4.1)
	Fuel Oil	29.5	34.9	-5.4	-18.3%	103.9	(3.8)	(7.6)	(11.4)	(15.2)	(19.0)
	Regional Total SH-SC-WH					**1,810.7**	**143.3**	**286.6**	**429.9**	**573.2**	**716.5**
Midwest	**Space Heating**					**1,452.1**	**132.9**	**265.9**	**398.8**	**531.7**	**664.7**
	Electric Heat Pump	190.6	61.1	129.5	67.9%	32.1	4.4	8.7	13.1	17.4	21.8
	Electric Heater	225.8	61.1	164.7	72.9%	129.8	18.9	37.9	56.8	75.7	94.7
	Natural gas	105.0	61.1	43.8	41.8%	1,099.7	91.9	183.7	275.6	367.4	459.3
	Propane/LPG	108.7	61.1	47.6	43.8%	127.5	11.2	22.3	33.5	44.6	55.8
	Fuel Oil	128.8	61.1	67.6	52.5%	63.1	6.6	13.3	19.9	26.5	33.2
	Space Cooling					**421.3**	**58.0**	**116.0**	**174.0**	**232.1**	**290.1**
	Central air conditioner	27.8	8.9	18.9	68.1%	374.2	51.0	101.9	152.9	203.8	254.8
	Room air conditioner	36.1	8.9	27.2	75.4%	39.9	6.0	12.0	18.0	24.1	30.1
	Both central and room AC	31.9	8.9	23.1	72.2%	7.2	1.0	2.1	3.1	4.2	5.2
	Water Heating					**632.0**	**(0.2)**	**(0.3)**	**(0.5)**	**(0.7)**	**(0.9)**
	Electric	62.7	37.4	25.3	40.4%	203.8	16.4	32.9	49.3	65.8	82.2
	Natural gas	31.2	37.4	-6.2	-19.9%	380.4	(15.1)	(30.3)	(45.4)	(60.6)	(75.7)
	Propane/LPG	32.3	37.4	-5.0	-15.5%	46.5	(1.4)	(2.9)	(4.3)	(5.8)	(7.2)
	Fuel Oil	32.9	37.4	-4.4	-13.5%	1.3	(0.0)	(0.1)	(0.1)	(0.1)	(0.2)
	Regional Total SH-SC-WH					**2,505.4**	**190.8**	**381.6**	**572.3**	**763.1**	**953.9**
South	**Space Heating**					**1,094.8**	**134.2**	**268.3**	**402.5**	**536.7**	**670.8**
	Electric Heat Pump	69.1	26.1	42.9	62.2%	133.6	16.6	33.2	49.8	66.4	83.1
	Electric Heater	113.9	26.1	87.7	77.1%	355.6	54.8	109.6	164.4	219.2	274.0
	Natural gas	53.1	26.1	27.0	50.8%	454.8	46.2	92.5	138.7	185.0	231.2
	Propane/LPG	55.0	26.1	28.9	52.5%	104.9	11.0	22.0	33.1	44.1	55.1
	Fuel Oil	65.2	26.1	39.1	59.9%	45.8	5.5	11.0	16.5	22.0	27.5
	Space Cooling					**1,491.5**	**184.8**	**369.6**	**554.4**	**739.2**	**924.0**
	Central air conditioner	49.6	19.3	30.2	61.0%	1,307.9	159.5	319.0	478.5	638.0	797.6
	Room air conditioner	64.4	19.3	45.0	70.0%	132.8	18.6	37.2	55.8	74.3	92.9
	Both central and room AC	57.0	19.3	37.6	66.0%	50.8	6.7	13.4	20.1	26.8	33.5
	Water Heating					**949.9**	**30.9**	**61.8**	**92.6**	**123.5**	**154.4**
	Electric	52.6	31.2	21.4	40.7%	560.0	45.5	91.1	136.6	182.1	227.7
	Natural gas	26.1	31.2	-5.1	-19.3%	343.5	(13.3)	(26.6)	(39.9)	(53.2)	(66.4)
	Propane/LPG	27.1	31.2	-4.1	-15.0%	41.4	(1.2)	(2.5)	(3.7)	(5.0)	(6.2)
	Fuel Oil	27.6	31.2	-3.6	-12.9%	4.9	(0.1)	(0.3)	(0.4)	(0.5)	(0.6)
	Regional Total SH-SC-WH					**3,536.2**	**349.8**	**699.7**	**1,049.5**	**1,399.4**	**1,749.2**
West	**Space Heating**					**605.1**	**64.5**	**128.9**	**193.4**	**257.9**	**322.3**
	Electric Heat Pump	69.8	27.8	42.0	60.2%	17.7	2.1	4.3	6.4	8.5	10.7
	Electric Heater	114.3	27.8	86.6	75.7%	107.2	16.2	32.5	48.7	64.9	81.2
	Natural gas	52.7	27.8	24.9	47.3%	413.0	39.1	78.2	117.2	156.3	195.4
	Propane/LPG	54.6	27.8	26.8	49.1%	41.0	4.0	8.1	12.1	16.1	20.1
	Fuel Oil	64.6	27.8	36.8	57.0%	26.2	3.0	6.0	9.0	12.0	15.0
	Space Cooling					**262.8**	**32.2**	**64.5**	**96.7**	**128.9**	**161.2**
	Central air conditioner	27.4	10.7	16.7	60.8%	246.4	30.0	60.0	89.9	119.9	149.9
	Room air conditioner	35.5	10.7	24.8	69.8%	11.6	1.6	3.2	4.8	6.5	8.1
	Both central and room AC	31.5	10.7	20.7	65.9%	4.9	0.6	1.3	1.9	2.6	3.2
	Water Heating					**538.2**	**(18.1)**	**(36.1)**	**(54.2)**	**(72.3)**	**(90.4)**
	Electric	54.0	35.9	18.1	33.6%	132.2	8.9	17.8	26.6	35.5	44.4
	Natural gas	26.8	35.9	-9.0	-33.6%	369.5	(24.9)	(49.7)	(74.6)	(99.4)	(124.3)
	Propane/LPG	27.9	35.9	-8.0	-28.8%	35.2	(2.0)	(4.0)	(6.1)	(8.1)	(10.1)
	Fuel Oil	28.4	35.9	-7.5	-26.4%	1.3	(0.1)	(0.1)	(0.2)	(0.3)	(0.3)
	Regional Total SH-SC-WH					**1,406.2**	**78.6**	**157.3**	**235.9**	**314.5**	**393.1**
National Total of Primary Energy Savings [Quad Btu]							**0.8**	**1.5**	**2.3**	**3.1**	**3.8**
Percentage Savings							**8.2%**	**16.5%**	**24.7%**	**32.9%**	**41.2%**

3.8.2 Reductions in CO_2 Emissions

By converting the delivered energy consumption data (both the calculated delivered energy consumption for SH-SC-WH in the reference building and the documented delivered energy consumption for all existing U.S. single-family homes) to the associated CO_2 emissions with the conversion factors listed in Table 8, the national potential reductions in annual CO_2 emissions was determined (Table 9). The emissions factors for electricity and fossil fuels (which account for emissions from both on-site combustion and pre-combustion activities including extracting and delivering the fossil fuels to the point of use) were adopted from a recent report by the National Renewable Energy Laboratory (NREL 2007).

Table 8. Emissions factors for fuels and electricity.

Fuel	CO2 equivalent Emmission Factor	
Natural Gas	150.80	lb per Mcf
Propane	16.06	lb per gallon
Heating Oil	26.90	lb per gallon
Electricity	1.67	lb per kWh

As shown at the bottom of Table 9, 244.6 million metric tons of CO_2 emissions, which accounts for 40.8% of all the CO_2 emissions associated with SH-SC-WH in existing U.S. single-family homes, could be saved each year by GHP retrofits at the 100% market penetration rate.

As with primary energy, the CO_2 emissions associated with water heating increased when existing water heaters fired by fossil fuels were replaced with desuperheater-assisted electric water heaters. If by policy these water heaters were not replaced with desuperheater-assisted electric water heaters, the maximum reduction of CO_2 emissions from GHP retrofits would rise from 244.8 to **271.9 million metric tons**, which is **45.3%** of all CO_2 emissions associated with SH-SC-WH in existing U.S. single-family homes.

Table 9. National total of reduced CO2 emissions from GHP retrofit for existing U.S. single-family homes

Census Region	SH-SC-WH System Types	Regional Average CO2 Emission by Existing SH-SC-WH System in Reference Building	Regional Average CO2 Emission by GHP System in Reference Building	Regional Average Reduction of CO2 Emission in Reference Building	Percentage Reduction of CO2 Emission from GHP Retrofit	Regional CO2 Emission for SH-SC-WH in All Single-Family Homes (RECS 2005)	Estimated Regional Potential in Reduction of CO2 Emission: 20% Market Penetration Rate for GHP Retrofit	40% Market Penetration Rate for GHP Retrofit	60% Market Penetration Rate for GHP Retrofit	80% Market Penetration Rate for GHP Retrofit	100% Market Penetration Rate for GHP Retrofit
		Lb	Lb	Lb	%	Million Lb	Million Lb	Million Lb	Million Lb	Million Lb	Million Lb
Northeast	**Space Heating**					**179,480.4**	**18,961.6**	**37,923.3**	**56,884.9**	**75,846.5**	**94,808.2**
	Electric Heat Pump	20,287.6	7,031.2	13,256.3	65.3%	914.8	119.5	239.1	358.6	478.2	597.7
	Electric Heater	27,621.8	7,031.2	20,590.6	74.5%	7,593.3	1,132.1	2,264.1	3,396.2	4,528.3	5,660.4
	Natural gas	12,138.6	7,031.2	5,107.4	42.1%	79,834.7	6,718.1	13,436.3	20,154.4	26,872.6	33,590.7
	Propane/LPG	13,978.7	7,031.2	6,947.5	49.7%	4,659.8	463.2	926.4	1,389.6	1,852.8	2,316.0
	Fuel Oil	17,971.3	7,031.2	10,940.0	60.9%	86,477.8	10,528.7	21,057.4	31,586.0	42,114.7	52,643.4
	Space Cooling					**27,303.6**	**4,138.2**	**8,276.4**	**12,414.5**	**16,552.7**	**20,690.9**
	Central air conditioner	2,829.2	745.0	2,084.3	73.7%	17,444.7	2,570.2	5,140.5	7,710.7	10,281.0	12,851.2
	Room air conditioner	3,674.3	745.0	2,929.4	79.7%	9,087.2	1,449.0	2,897.9	4,346.9	5,795.8	7,244.8
	Both central and room AC	3,251.8	745.0	2,506.8	77.1%	771.7	119.0	238.0	356.9	475.9	594.9
	Water Heating					**61,279.9**	**(978.6)**	**(1,957.2)**	**(2,935.8)**	**(3,914.4)**	**(4,893.0)**
	Electric	8,153.8	5,070.0	3,083.8	37.8%	13,388.0	1,012.7	2,025.3	3,038.0	4,050.7	5,063.4
	Natural gas	3,813.4	5,070.0	(1,256.7)	-33.0%	27,462.1	(1,810.0)	(3,620.0)	(5,430.0)	(7,240.0)	(9,050.0)
	Propane/LPG	4,438.2	5,070.0	(631.9)	-14.2%	3,074.2	(87.5)	(175.1)	(262.6)	(350.1)	(437.7)
	Fuel Oil	4,936.7	5,070.0	(133.3)	-2.7%	17,355.7	(93.7)	(187.5)	(281.2)	(374.9)	(468.7)
	Regional Total SH-SC-WH					**268,063.8**	**22,121.2**	**44,242.4**	**66,363.6**	**88,484.8**	**110,606.0**
Midwest	**Space Heating**					**200,935.8**	**17,731.8**	**35,463.7**	**53,195.5**	**70,927.4**	**88,659.2**
	Electric Heat Pump	27,711.8	8,887.5	18,824.3	67.9%	4,662.2	633.4	1,266.8	1,900.2	2,533.6	3,167.0
	Electric Heater	32,836.8	8,887.5	23,949.3	72.9%	18,876.2	2,753.4	5,506.9	8,260.3	11,013.8	13,767.2
	Natural gas	14,416.8	8,887.5	5,529.3	38.4%	147,434.8	11,309.2	22,618.3	33,927.5	45,236.6	56,545.8
	Propane/LPG	16,604.4	8,887.5	7,716.9	46.5%	19,415.4	1,804.7	3,609.3	5,414.0	7,218.6	9,023.3
	Fuel Oil	21,346.6	8,887.5	12,459.1	58.4%	10,547.2	1,231.2	2,462.4	3,693.6	4,924.8	6,156.0
	Space Cooling					**61,265.7**	**8,435.8**	**16,871.6**	**25,307.5**	**33,743.3**	**42,179.1**
	Central air conditioner	4,040.4	1,289.7	2,750.7	68.1%	54,417.4	7,409.5	14,819.0	22,228.5	29,638.0	37,047.5
	Room air conditioner	5,247.3	1,289.7	3,957.6	75.4%	5,799.1	874.7	1,749.5	2,624.2	3,499.0	4,373.7
	Both central and room AC	4,643.8	1,289.7	3,354.2	72.2%	1,049.3	151.6	303.2	454.7	606.3	757.9
	Water Heating					**87,932.8**	**(549.9)**	**(1,099.9)**	**(1,649.8)**	**(2,199.8)**	**(2,749.7)**
	Electric	9,112.5	5,434.7	3,677.8	40.4%	29,633.1	2,392.0	4,784.0	7,176.0	9,568.0	11,959.9
	Natural gas	4,261.9	5,434.7	(1,172.8)	-27.5%	51,005.0	(2,807.1)	(5,614.2)	(8,421.3)	(11,228.4)	(14,035.5)
	Propane/LPG	4,960.2	5,434.7	(474.5)	-9.6%	7,081.7	(135.5)	(271.0)	(406.5)	(541.9)	(677.4)
	Fuel Oil	5,517.4	5,434.7	82.7	1.5%	213.0	0.6	1.3	1.9	2.6	3.2
	Regional Total SH-SC-WH					**350,134.4**	**25,617.7**	**51,235.4**	**76,853.1**	**102,470.9**	**128,088.6**
South	**Space Heating**					**155,756.0**	**18,978.0**	**37,956.0**	**56,934.0**	**75,912.0**	**94,890.0**
	Electric Heat Pump	10,043.7	3,799.3	6,244.4	62.2%	19,426.3	2,415.6	4,831.1	7,246.7	9,662.3	12,077.8
	Electric Heater	16,557.1	3,799.3	12,757.8	77.1%	51,703.3	7,967.8	15,935.7	23,903.5	31,871.4	39,839.2
	Natural gas	7,301.0	3,799.3	3,501.7	48.0%	60,982.1	5,849.7	11,699.3	17,549.0	23,398.6	29,248.3
	Propane/LPG	8,404.0	3,799.3	4,604.7	54.8%	15,983.3	1,751.5	3,503.0	5,254.5	7,006.1	8,757.6
	Fuel Oil	10,804.6	3,799.3	7,005.3	64.8%	7,660.9	993.4	1,986.8	2,980.2	3,973.7	4,967.1
	Space Cooling					**216,882.6**	**26,872.3**	**53,744.5**	**80,616.8**	**107,489.1**	**134,361.3**
	Central air conditioner	7,209.4	2,813.2	4,396.2	61.0%	190,182.8	23,194.4	46,388.8	69,583.2	92,777.6	115,972.0
	Room air conditioner	9,362.9	2,813.2	6,549.7	70.0%	19,316.4	2,702.5	5,405.0	8,107.6	10,810.1	13,512.6
	Both central and room AC	8,286.1	2,813.2	5,473.0	66.0%	7,383.5	975.4	1,950.7	2,926.1	3,901.4	4,876.8
	Water Heating					**134,618.6**	**4,030.2**	**8,060.3**	**12,090.5**	**16,120.7**	**20,150.9**
	Electric	7,644.4	4,536.8	3,107.6	40.7%	81,434.9	6,621.0	13,242.0	19,863.0	26,484.0	33,105.0
	Natural gas	3,574.5	4,536.8	(962.3)	-26.9%	46,057.6	(2,479.9)	(4,959.8)	(7,439.7)	(9,919.6)	(12,399.5)
	Propane/LPG	4,160.1	4,536.8	(376.6)	-9.1%	6,303.3	(114.1)	(228.3)	(342.4)	(456.5)	(570.7)
	Fuel Oil	4,627.4	4,536.8	90.7	2.0%	822.8	3.2	6.4	9.7	12.9	16.1
	Regional Total SH-SC-WH					**507,257.2**	**49,880.4**	**99,760.9**	**149,641.3**	**199,521.7**	**249,402.2**
West	**Space Heating**					**84,164.0**	**8,756.5**	**17,512.9**	**26,269.4**	**35,025.8**	**43,782.3**
	Electric Heat Pump	10,148.6	4,036.4	6,112.2	60.2%	2,578.5	310.6	621.2	931.8	1,242.4	1,553.0
	Electric Heater	16,624.4	4,036.4	12,588.0	75.7%	15,586.0	2,360.3	4,720.7	7,081.0	9,441.4	11,801.7
	Natural gas	7,233.1	4,036.4	3,196.7	44.2%	55,368.8	4,894.1	9,788.2	14,682.2	19,576.3	24,470.4
	Propane/LPG	8,340.6	4,036.4	4,304.2	51.6%	6,246.7	644.7	1,289.4	1,934.2	2,578.9	3,223.6
	Fuel Oil	10,721.8	4,036.4	6,685.4	62.4%	4,384.0	546.7	1,093.4	1,640.2	2,186.9	2,733.6
	Space Cooling					**38,218.7**	**4,687.0**	**9,374.0**	**14,060.9**	**18,747.9**	**23,434.9**
	Central air conditioner	3,980.4	1,559.2	2,421.2	60.8%	35,832.5	4,359.2	8,718.4	13,077.7	17,436.9	21,796.1
	Room air conditioner	5,169.3	1,559.2	3,610.1	69.8%	1,680.2	234.7	469.4	704.1	938.8	1,173.4
	Both central and room AC	4,574.8	1,559.2	3,015.6	65.9%	706.0	93.1	186.1	279.2	372.3	465.4
	Water Heating					**74,343.0**	**(3,123.7)**	**(6,247.5)**	**(9,371.2)**	**(12,495.0)**	**(15,618.7)**
	Electric	7,848.4	5,214.7	2,633.8	33.6%	19,230.4	1,290.7	2,581.3	3,872.0	5,162.7	6,453.3
	Natural gas	3,669.2	5,214.7	(1,545.4)	-42.1%	49,541.2	(4,173.2)	(8,346.4)	(12,519.7)	(16,692.9)	(20,866.1)
	Propane/LPG	4,270.4	5,214.7	(944.2)	-22.1%	5,360.9	(237.1)	(474.1)	(711.2)	(948.3)	(1,185.4)
	Fuel Oil	4,750.1	5,214.7	(464.5)	-9.8%	210.4	(4.1)	(8.2)	(12.3)	(16.5)	(20.6)
	Regional Total SH-SC-WH					**196,725.7**	**10,319.7**	**20,639.4**	**30,959.1**	**41,278.8**	**51,598.5**
National Total of CO2 Emission Reduction [Million Metric Ton]							**49.0**	**97.9**	**146.9**	**195.8**	**244.8**
Percentage Savings							**8.2%**	**16.3%**	**24.5%**	**32.7%**	**40.8%**

3.8.3 Reductions in Summer Peak Electrical Demand

The national total reduction in summer peak electrical demand was calculated following the procedure described in section 3.6, and the results are listed in Table 10. As shown at the bottom of Table 10, **202 GW** of **summer peak electrical demand** could be avoided if the state-of-the-art GHP retrofits were deployed to all U.S. single-family homes. According to EIA (2008), the total U.S. net summer electric generating capacity as of December 31, 2008, was 1,010 GW. The 202-GW peak demand reduction from GHP retrofits could reduce the total required summer electric generating capacity in the United States by about 20%.

Table 10 National total of reduced summer peak electrical demand from GHP retrofit for existing US single-family homes

Census Region	SH-SC-WH System Types	Number of Single-Family Homes that Have Space Cooling	Percentage of Various Equipments Used for Space Cooling	Regional Average of Installed Space Cooling Capacity for the Reference Building	Normalized Peak Electrical Deamd for Space Cooling of Existing SC Systems	Normalized Peak Electrical Deamd for Space Cooling of the GHP System	Reduction in Normalized Peak Electrical Deamd for Space Cooling from the GHP Retrofit	Percentage Reduction of Peak Electrical Deamd for Space Cooling from GHP Retrofit	Estimated Regional Peak Electrical Demand for Space Cooling by Existing Systems	Estimated Regional Potential in Reduction of Peak Electrical Deamd for Space Cooling				
										20% Market Penetration Rate for GHP Retrofit	40% Market Penetration Rate for GHP Retrofit	60% Market Penetration Rate for GHP Retrofit	80% Market Penetration Rate for GHP Retrofit	100% Market Penetration Rate for GHP Retrofit
		(millions)		Ton	kW/ton	kW/ton	kW/ton	%	GW	GW	GW	GW	GW	GW
Northeast	**Space Cooling**	**11.1**	**100%**	**2.0**	**2.7**	**1.0**	**1.8**	**64.9%**	**60.7**	**7.9**	**15.8**	**23.6**	**31.5**	**39.4**
	Central air conditioner	4.95	44.4%		2.3	1.0	1.4	59.0%						
	Room air conditioner	6.10	54.8%		3.0	1.0	2.1	68.5%						
	Both central and room AC	0.10	0.9%		2.7	1.0	1.7	64.4%						
Midwest	**Space Cooling**	**18.6**	**100%**	**2.5**	**2.0**	**0.9**	**1.2**	**56.5%**	**95.3**	**10.8**	**21.5**	**32.3**	**43.0**	**53.8**
	Central air conditioner	14.64	78.6%		1.9	0.9	1.0	53.8%						
	Room air conditioner	3.62	19.4%		2.5	0.9	1.6	64.5%						
	Both central and room AC	0.36	1.9%		2.2	0.9	1.3	59.8%						
South	**Space Cooling**	**28.0**	**100%**	**3.0**	**2.0**	**1.0**	**1.0**	**52.2%**	**168.8**	**17.6**	**35.2**	**52.8**	**70.5**	**88.1**
	Central air conditioner	22.71	81.0%		1.9	1.0	0.9	49.6%						
	Room air conditioner	4.64	16.5%		2.5	1.0	1.5	61.2%						
	Both central and room AC	0.70	2.5%		2.2	1.0	1.2	56.2%						
West	**Space Cooling**	**9.5**	**100%**	**2.0**	**2.2**	**1.1**	**1.1**	**50.4%**	**41.4**	**4.2**	**8.3**	**12.5**	**16.7**	**20.8**
	Central air conditioner	7.74	81.7%		2.1	1.1	1.0	47.8%						
	Room air conditioner	1.49	15.8%		2.7	1.1	1.6	59.9%						
	Both central and room AC	0.24	2.5%		2.4	1.1	1.3	54.6%						
National Total Reduction of Peak Electrical Deamd for Space Cooling [GW]										**40.4**	**80.8**	**121.3**	**161.7**	**202.1**
Percentage Savings										**11.0%**	**22.1%**	**33.1%**	**44.2%**	**55.2%**

3.8.4 Savings in Consumer Energy Expenditures

By converting the delivered energy consumption data (both the calculated delivered energy consumption for SH-SC-WH in the reference building and the documented delivered energy consumption for all existing U.S. single-family homes) to the associated energy expenditures with the regional average utility rates for fuels and electricity listed in Table 11, the national potential savings in annual energy expenditures for SH-SC-WH was determined and is shown in Table 12. The regional average utility rates for fuels and electricity were obtained from the EIA Short-Term Energy Outlook (EIA STEO 2010).

Table 11. Utility rates for fuels and electricity in each Census Region.

Census Region	Gas $/Mcf		Oil $/gallon_O		Propane $/gallon_P		Electric $/MWh	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Northeast	14.92	17.20	2.918	2.835	2.653	2.66	154.655	164.314
Midwest	10.93	13.54	2.826	2.796	1.909	1.84	97.984	105.770
South	14.67	18.77	2.866	2.734	2.429	2.33	105.899	110.320
West	10.31	11.30	2.978	2.968	2.354	2.23	109.361	118.881

As shown at the bottom of Table 12, $53.4 billion of consumer energy expenditures, which accounts for 49.3% of all the energy expenditures associated with SH-SC-WH in existing U.S. single-family homes, could be saved each year by GHP retrofits at the 100% market penetration rate.

Unlike primary energy and CO_2 emissions, energy expenditures associated with water heating were reduced when existing water heaters were replaced with desuperheater-assisted electric water heaters, except for replacement of natural gas water heaters in the Northeast and West census regions. If the existing water heaters fired with fossil fuels were not replaced with desuperheater-assisted electric water heaters, the maximum savings of consumer energy expenditures from GHP retrofits would be reduced from 53.4 to **52.2 billion U.S. dollars**, which is **48.2%** of all the consumer energy expenditures for SH-SC-WH in existing U.S. single-family homes.

Table 12. National total of reduced energy expenditures from GHP retrofits for existing U.S. single-family homes.

Census Region	SH-SC-WH System Types	Regional Average Energy Expenditure by Existing SH-SC-WH System in Reference Building	Regional Average Energy Expenditure by GHP System in Reference Building	Regional Average Savings of Energy Expenditure in Reference Building	Percentage Savings of Energy Expenditure from GHP Retrofit	Regional Energy Expenditure for SH-SC-WH in All Single-Family Homes (RECS 2005)	Estimated Regional Potential in Savings of Energy Expenditure				
							20% Market Penetration Rate for GHP Retrofit	40% Market Penetration Rate for GHP Retrofit	60% Market Penetration Rate for GHP Retrofit	80% Market Penetration Rate for GHP Retrofit	100% Market Penetration Rate for GHP Retrofit
		$	$	$	%	Million $	Million $	Million $	Million $	Million $	Million $
Northeast	**Space Heating**					**18,834.3**	**2,186.7**	**4,373.3**	**6,560.0**	**8,746.6**	**10,933.3**
	Electric Heat Pump	1878.8	651.1	1227.6	65.3%	84.7	11.1	22.1	33.2	44.3	55.4
	Electric Heater	2558.0	651.1	1906.8	74.5%	703.2	104.8	209.7	314.5	419.4	524.2
	Natural gas	1194.7	651.1	543.5	45.5%	7,896.5	718.5	1,437.0	2,155.5	2,874.1	3,592.6
	Propane/LPG	2240.7	651.1	1589.5	70.9%	769.8	109.2	218.4	327.7	436.9	546.1
	Fuel Oil	1929.8	651.1	1278.7	66.3%	9,380.0	1,243.0	2,486.0	3,729.0	4,972.1	6,215.1
	Space Cooling					**2,686.4**	**407.2**	**814.3**	**1,221.5**	**1,628.7**	**2,035.8**
	Central air conditioner	278.4	73.3	205.1	73.7%	1,716.4	252.9	505.8	758.7	1,011.6	1,264.5
	Room air conditioner	361.5	73.3	288.2	79.7%	894.1	142.6	285.1	427.7	570.3	712.8
	Both central and room AC	319.9	73.3	246.6	77.1%	75.9	11.7	23.4	35.1	46.8	58.5
	Water Heating					**6,566.7**	**49.4**	**98.9**	**148.3**	**197.7**	**247.2**
	Electric	778.7	484.2	294.5	37.8%	1,278.5	96.7	193.4	290.1	386.8	483.5
	Natural gas	406.0	484.2	-78.2	-19.3%	2,923.9	(112.6)	(225.2)	(337.8)	(450.4)	(563.0)
	Propane/LPG	733.9	484.2	249.7	34.0%	508.3	34.6	69.2	103.8	138.4	173.0
	Fuel Oil	527.9	484.2	43.7	8.3%	1,855.9	30.7	61.5	92.2	122.9	153.7
	Regional Total SH-SC-WH					**28,087.4**	**2,643.3**	**5,286.5**	**7,929.8**	**10,573.0**	**13,216.3**
Midwest	**Space Heating**					**15,482.7**	**1,757.3**	**3,514.5**	**5,271.8**	**7,029.0**	**8,786.3**
	Electric Heat Pump	1625.9	521.5	1104.5	67.9%	273.5	37.2	74.3	111.5	148.7	185.8
	Electric Heater	1926.6	521.5	1405.2	72.9%	1,107.5	161.6	323.1	484.7	646.2	807.8
	Natural gas	1029.5	521.5	508.1	49.3%	10,685.3	1,054.6	2,109.3	3,163.9	4,218.5	5,273.1
	Propane/LPG	1907.0	521.5	1385.6	72.7%	2,308.1	335.4	670.8	1,006.2	1,341.6	1,677.0
	Fuel Oil	2175.9	521.5	1654.5	76.0%	1,108.2	168.5	337.0	505.6	674.1	842.6
	Space Cooling					**3,880.3**	**534.3**	**1,068.6**	**1,602.9**	**2,137.1**	**2,671.4**
	Central air conditioner	255.9	81.7	174.2	68.1%	3,446.5	469.3	938.6	1,407.8	1,877.1	2,346.4
	Room air conditioner	332.3	81.7	250.7	75.4%	367.3	55.4	110.8	166.2	221.6	277.0
	Both central and room AC	294.1	81.7	212.4	72.2%	66.5	9.6	19.2	28.8	38.4	48.0
	Water Heating					**6,794.4**	**252.5**	**505.0**	**757.4**	**1,009.9**	**1,262.4**
	Electric	555.9	331.5	224.4	40.4%	1,807.7	145.9	291.8	437.8	583.7	729.6
	Natural gas	345.7	331.5	14.2	4.1%	4,137.7	34.0	68.0	102.0	136.0	170.0
	Propane/LPG	579.1	331.5	247.5	42.7%	826.7	70.7	141.4	212.0	282.7	353.4
	Fuel Oil	576.6	331.5	245.0	42.5%	22.3	1.9	3.8	5.7	7.6	9.5
	Regional Total SH-SC-WH					**26,157.4**	**2,544.0**	**5,088.0**	**7,632.1**	**10,176.1**	**12,720.1**
South	**Space Heating**					**13,674.6**	**1,946.4**	**3,892.8**	**5,839.2**	**7,785.5**	**9,731.9**
	Electric Heat Pump	636.9	240.9	396.0	62.2%	1,231.9	153.2	306.4	459.5	612.7	765.9
	Electric Heater	1049.9	240.9	809.0	77.1%	3,278.6	505.3	1,010.5	1,515.8	2,021.0	2,526.3
	Natural gas	690.0	240.9	449.1	65.1%	5,930.6	772.0	1,544.0	2,315.9	3,087.9	3,859.9
	Propane/LPG	1218.9	240.9	978.0	80.2%	2,417.1	387.9	775.8	1,163.6	1,551.5	1,939.4
	Fuel Oil	1118.1	240.9	877.2	78.5%	816.3	128.1	256.2	384.3	512.3	640.4
	Space Cooling					**14,327.3**	**1,775.2**	**3,550.4**	**5,325.6**	**7,100.7**	**8,875.9**
	Central air conditioner	476.3	185.8	290.4	61.0%	12,563.5	1,532.2	3,064.5	4,596.7	6,128.9	7,661.1
	Room air conditioner	618.5	185.8	432.7	70.0%	1,276.0	178.5	357.1	535.6	714.1	892.6
	Both central and room AC	547.4	185.8	361.5	66.0%	487.8	64.4	128.9	193.3	257.7	322.2
	Water Heating					**11,396.0**	**797.2**	**1,594.3**	**2,391.5**	**3,188.6**	**3,985.8**
	Electric	494.9	293.7	201.2	40.7%	5,271.8	428.6	857.2	1,285.9	1,714.5	2,143.1
	Natural gas	396.2	293.7	102.5	25.9%	5,105.4	264.2	528.4	792.6	1,056.9	1,321.1
	Propane/LPG	615.9	293.7	322.2	52.3%	933.2	97.6	195.3	292.9	390.5	488.2
	Fuel Oil	481.7	293.7	188.0	39.0%	85.6	6.7	13.4	20.1	26.7	33.4
	Regional Total SH-SC-WH					**39,397.9**	**4,518.7**	**9,037.4**	**13,556.2**	**18,074.9**	**22,593.6**
West	**Space Heating**					**6,375.0**	**743.1**	**1,486.1**	**2,229.2**	**2,972.3**	**3,715.3**
	Electric Heat Pump	664.6	264.3	400.3	60.2%	168.9	20.3	40.7	61.0	81.4	101.7
	Electric Heater	1088.7	264.3	824.3	75.7%	1,020.7	154.6	309.1	463.7	618.3	772.8
	Natural gas	493.0	264.3	228.6	46.4%	3,784.5	351.1	702.1	1,053.2	1,404.2	1,755.3
	Propane/LPG	1182.3	264.3	918.0	77.6%	915.7	142.2	284.4	426.6	568.8	711.0
	Fuel Oil	1157.8	264.3	893.4	77.2%	485.3	74.9	149.8	224.7	299.6	374.5
	Space Cooling					**2,720.6**	**333.6**	**667.3**	**1,000.9**	**1,334.6**	**1,668.2**
	Central air conditioner	283.3	111.0	172.4	60.8%	2,550.8	310.3	620.6	930.9	1,241.3	1,551.6
	Room air conditioner	368.0	111.0	257.0	69.8%	119.6	16.7	33.4	50.1	66.8	83.5
	Both central and room AC	325.7	111.0	214.7	65.9%	50.3	6.6	13.3	19.9	26.5	33.1
	Water Heating					**5,651.1**	**(99.3)**	**(198.6)**	**(297.9)**	**(397.2)**	**(496.5)**
	Electric	536.3	356.3	180.0	33.6%	1,314.1	88.2	176.4	264.6	352.8	441.0
	Natural gas	262.9	356.3	-93.5	-35.6%	3,549.2	(252.4)	(504.8)	(757.3)	(1,009.7)	(1,262.1)
	Propane/LPG	609.0	356.3	252.6	41.5%	764.5	63.4	126.8	190.3	253.7	317.1
	Fuel Oil	524.9	356.3	168.6	32.1%	23.3	1.5	3.0	4.5	6.0	7.5
	Regional Total SH-SC-WH					**14,746.8**	**977.4**	**1,954.8**	**2,932.2**	**3,909.6**	**4,887.0**
National Total of Energy Expenditure Savings [Billion $]							**10.7**	**21.4**	**32.1**	**42.7**	**53.4**
Percentage Savings							**9.9%**	**19.7%**	**29.6%**	**39.4%**	**49.3%**

4. Valuing Investment in GHP Systems Compared to Alternatives

In this section, the GHP retrofit investment is valued in two different ways based on the predicted energy savings and installed cost premium of the GHP retrofit compared with alternative retrofit solutions. The first evaluation focuses on the net present value (NPV) over the life of the GHP retrofit investment, which is the difference between the installed cost premium of the GHP retrofit and the discounted present value of the saved energy costs over the life of the investment. The NPV is calculated with Equation 6:

$$NPV = \sum_{j=1}^{m}(E_j \cdot CEC_j) \times \sum_{i=1}^{n} \frac{(1+e)^{i-1}}{(1+d)^i} - CP \qquad \text{(Eq. 6)}$$

Where

j is the index number of various types of saved delivered energy, including electricity, natural gas, fuel oil, and propane/LPG;

E_j is the annual savings of energy type j;

CEC_j is the current energy cost per unit of energy type j;

i is the year;

e is the average annual escalation rate of energy prices;

d is the discount rate;

n is the service life of the GHP retrofit (i.e., the period of the calculation); and

CP is the cost premium of the GHP retrofit compared with alternative systems.

The second evaluation calculates the levelized cost of energy efficiency (**LCOEE**) of the GHP retrofit. **LCOEE** is analogous to the levelized cost of energy (LCOE), which is widely used in the utility industry to assess the investment of energy-generation systems, including all the costs over its lifetime: initial investment, operation and maintenance, and cost of capital. An NPV equation is written and solved to determine the value of LCOE such that the project's net present value is zero. This means that the LCOE is the minimum price at which energy must be sold for an energy project to break even. Similar to LCOE, LCOEE is the minimum price at which the **saved energy** must be valued for the investment in the GHP retrofit to break even. The calculation of **LCOEE** is expressed in Equation 7:

$$LCOEE = \frac{\sum_{i=1}^{n} \frac{I_i + M_i}{(1+d)^i}}{ES \cdot \sum_{i=1}^{n} \frac{(1+e)^{i-1}}{(1+d)^i}} \qquad \text{(Eq. 7)}$$

Where

I_i is the investment expenditure (including principal and interest) in year i;

M_i is the operation and maintenance expenditures in year i; and

ES is the annual energy savings achieved by the energy efficiency system (i.e., the GHP retrofit).

In the following sections, energy consumption and expenditures are presented for a few alternative retrofit solutions (section 4.1), the retrofit costs of the state-of-the-art GHP system and the alternatives are summarized (section 4.2), the financial parameters used in the evaluations are discussed (section 4.3), and finally the estimated NPV and **LCOEE** of the GHP retrofit at various discount rates are determined (sections 4.4 and 4.5).

4.1 Energy Consumption and Expenditures of Alternative Retrofit Solutions

Five alternative retrofit solutions are compared with the state-of-the-art GHP system. Brief descriptions of each alternative are provided in Table 13. All of these retrofit solutions are intended to reduce energy consumption and cost for space heating and cooling. However, unlike the conventional alternatives, the state-of-the-art GHP system also has an integral component called a desuperheater, which generates hot water very efficiently whenever the unit operates for heating or cooling. As discussed in section 3, the desuperheater usually works with an electric storage-type water heater, and the desuperheater-assited electric water heater will reduce the primary energy consumption for water heating when replacing the existing electric water heater (without desuperheater). However, since the desuperheater-assisted electric water heater may consume more primary energy than conventional fossil-fuel fired water heater, it is assumed in this study that the existing conventional fossil-fuel fired water heaters are not replaced with the desuperheater-assisted electric water heater.

Table 13 List of alternative SH-SC systems for residential retrofit.

Name	Description	Note
Alt #1	SEER 13 AC and 80 AFUE natural gas furnace	Minimum allowed
Alt #2	SEER 21 AC and 93 AFUE natural gas furnace	State-of-the-art
Alt #3	SEER 13 ASHP with supplemental electrical heater	Minimum allowed
Alt #4	SEER 19 ASHP with supplemental electrical heater	State-of-the-art
Alt #5	SEER 19 ASHP with supplemental 93 AFUE natural gas furnace	State-of-the-art

As stated previously, source energy consumption accounts for all the primary energy consumed in generating and delivering energy to the building site. It thus is used as a metric to compare the various retrofit solutions. The national total annual source energy consumption for SH-SC-WH that would occur after retrofitting all existing U.S. single-family homes with each of the five alternative solutions is calculated using the same procedure as described in section 3, and the results are listed in Table 14. Also shown in Table 14 is the national total source energy consumption of existing SH-SC-WH systems in all U.S. single-family homes, which is calculated from the delivered energy consumption data in RECS (2005). Based on these data and the total number of existing U.S. single-family homes with SH/SC/WH systems (79.3 million households), the average annual source energy savings per single-family home achieved from the GHP retrofit compared with the alternative solutions are calculated and listed in the last column of Table 14.

Table 14. Source energy savings from GHP retrofits vs. alternatives.

System Type	National Total Annual Source Energy Consumption for SH-SC-WH in U.S. Single-family Homes	National Total Annual Source Energy Savings (Compared with Existing Systems)	National Average of Annual Source Energy Savings per Single-Family Home (Compared with Existing Systems)	National Average of Annual Source Energy Savings per Single-Family Home from GHP Retrofit (Compared with Alternatives)
	Quad BTU	Quad BTU	MBTU	MBTU
Existing SH-SC-WH Systems	9.3			
State-of-the-art GHP System	5.1	4.2	53.0	
Alt #1	8.3	1.0	12.6	40.4
Alt #2	7.3	2.0	25.2	27.7
Alt #3	10.2	**-0.9**	**-11.3**	64.3
Alt #4	10	**-0.7**	**-8.8**	61.8
Alt #5	7.3	2.0	25.2	27.7

As shown in Table 14, retrofitting the existing SH-SC systems with Alt #3 and Alt #4, which use ASHPs and auxiliary electric resistance heaters, actually increases the annual source energy consumption due to increased use of electricity at an efficiency level too low to offset the high source energy conversion factor (3.365) for electricity. This result indicates that retrofitting existing SH-SC systems with Alt #3 and Alt #4 may not be a good strategy for reducing source energy consumption and greenhouse gas emissions, especially when the electricity is generated with fossil fuels and the auxiliary electric resistance heater has to run frequently to supplement the ASHP[5]. The table also shows that Alt #5 (19 SEER ASHP supplemented with 93 AFUE gas furnace) consumes almost the same amount of source energy as Alt #2 does, which is a combination of SEER 21 AC and 93 AFUE gas furnace. As a result, in the following economic analysis, only Alt #1 and Alt #2 are included.

The national total annual savings in energy expenditures resulting from the GHP retrofit versus the two alternatives (Alt #1 and Alt #2) are summarized in Table 15. In the same table, the average annual energy expenditures for the state-of-the-art GHP system and the two alternatives per single-family home are also presented. The last column of the table shows the average savings per home in annual energy expenditures from the GHP retrofit versus the two alternatives. On average, retrofitting the existing SH-SC systems with the state-of-the-art GHP system saves $469 and $332 each year compared with Alt #1 and Alt #2, respectively.

[5] The heating capacity and efficiency of ASHPs degrade significantly at low ambient temperatures, and the "defrosting operation" often results in uncomfortable "cold air blow" inside the building. It is thus common that electric resistance heat will kick in to override the heat pump when the ambient temperature is below 35°F.

Table 15. Annual savings in energy expenditures resulting from GHP retrofits vs. alternatives.

System Type	National Total Annual Energy Expenditure for SH-SC-WH in U.S. Single-family Homes	National Total Annual Energy Expenditure Savings (Compared with Existing Systems)	National Average of Annual Energy Expenditure for SH-SC-WH per Single-family Home	National Average of Annual Energy Expenditure Savings per Single-Family Home from Various Retrofits (Compared with Alternative Systems)
	Billion $	Billion $	$	$
Existing SH-SC-WH Systems	108.4		1367.0	
State-of-the-art GHP System	56.2	52.2	708.7	
Alt #1	93.4	15.0	1177.8	469.1
Alt #2	82.5	25.9	1040.4	331.7

Figure 5 shows annual savings in electricity and natural gas from the GHP retrofit compared with Alt #1 and Alt #2 in each of the four census regions. As shown in Figure 5, the GHP retrofit significantly reduces the consumption of natural gas (due to displacement of the natural gas furnaces), but it slightly increases the electricity consumption in all the census regions except in the south, where savings in electricity for space cooling and water heating (only in homes with existing electric water heaters) more than offsets the electricity consumed by the GHP units for space heating.

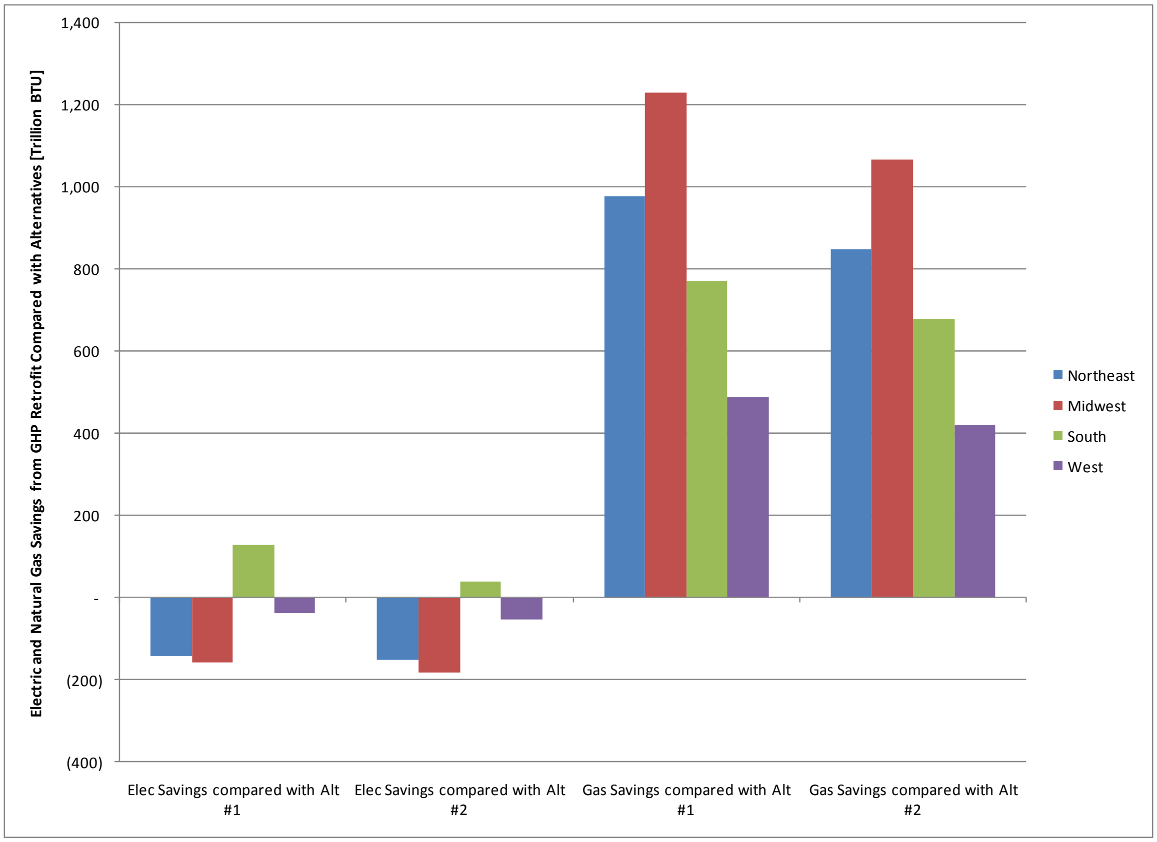

Fig. 5. Saved electricity and natural gas from GHP retrofits vs. alternatives in each census region.

4.2 Retrofit Cost of the GHP System and Alternatives

Only a few published papers and reports were found that documented the installed cost of GHP systems. Kavanaugh (1995) reported that the average cost of a 3-ton GHP system with vertical ground heat exchanger was $8,997. The average cost of the vertical ground heat exchanger was $1,028 per installed cooling ton. These average costs were in 1995 U.S. dollars and obtained from a national survey of the cost of purchasing and installing GHP systems. The average cost of each major component of the GHP system and an analysis of the potential for cost reduction were presented in the report and are summarized in Table 16.

Table 16. Components of GHP system cost and estimated potential cost reductions.

Itemized Cost	3-Ton GHP System Installed Cost (Kavanaugh 1995)		3-Ton GHP System Cost Reduction Potential (Kavanaugh 1995)	
	1995 $	2010 $	1995 $	2010 $
Ground loop	$3,077	$4,330	$360	$507
Heat pump (including loop pump)	$2,717	$3,823	$1,160	$1,632
Indoor installation	$1,898	$2,671	$540	$760
Ductwork	$1,305	$1,836	$0	$0
Total Installed Cost	**$8,997**	**$12,661**		

A recent report (DOD 2007) indicates that the average cost of GHP systems installed in residences of Department of Defense Facilities is $4,600 in 2006 dollars for each cooling ton of capacity or $13,800 for a 3-ton system. This cost is higher than that reported in the table above but includes the extra costs associated with projects at DOD facilities (Davis Beacon wages, secure facility access costs, training costs, transactions costs for multiple levels of oversight, etc.). When these factors are considered, the DOD experience appears comparable to the table above.

As described in the Buildings Energy Data Book (DOE-EIA 2009), the typical size of U.S. single-family homes is 1,900 ft^2. Given the floor space, insulation, and air-tightness characteristics typical of the existing housing stock, a 3-ton GHP system is assumed in this study to be the average for U.S. single-family homes.

In this study, except for the cost of the state-of-the-art GHP unit, all other cost components of the 3-ton GHP system with vertical ground heat exchanger are adopted from Kavanaugh (1995), with correction for 2.47% annual inflation between 1995 and 2010. The cost of the state-of-the-art GHP unit (with desuperheater), central air conditioners, and gas furnaces are the typical list prices available in the current market. The costs of indoor installation and adaptation to existing ductwork are assumed to be identical for the GHP system and the alternatives, so they were not included in the calculation of the cost premium for the GHP retrofit.

The total retrofit and comparable costs of the 3-ton state-of-the-art GHP system and the two alternative systems are presented in 2010 dollars in Table 17. As shown in the table, the national average cost of retrofitting existing SH-SC systems with the 3-ton state-of-the-art GHP system is more than double the cost ($11,241 *vs.* $4,500) of Alt #1 — a new, minimum-code-compliant, conventional SH-SC system. However, if the estimated cost reduction potential (Kavanaugh 1995) is fully realized, the cost of the GHP retrofit will be reduced by 19%, to $9,102. Though it is still about double the cost for Alt #1, it is very close to the cost of Alt #2 — the state-of-the-art conventional SH-SC system ($9,102 *vs.* $8,642).

Table 17. Costs of the state-of-the-art GHP system and alternative systems.

System	Itemized Cost	Average Market Price	Reduced Price
State-of-the-Art GHP System	Ground loop	$4,330	$3,823
	Heat pump (include pump)	$6,911	$5,279
	Indoor installation	$2,671	$1,911
	Ductwork	$1,836	$1,836
	Total Installed Retrofit Cost	$15,748	$12,849
	Comparable Cost (without indoor installation and ductwork)	**$11,241**	**$9,102**
Alternatives	**Itemized Cost**	**Alternative #1** SEER 13 AC and 80 AFUE gas furnace	**Alternative #2** SEER 21 AC and 93 AFUE gas furnace
	AC unit	$2,500	$5,142
	Gas furnace	$2,000	$3,500
	Indoor installation	$2,671	$2,671
	Ductwork	$1,836	$1,836
	Total Installed Retrofit Cost	$9,007	$13,149
	Comparable Cost (without indoor installation and ductwork)	**$4,500**	**$8,642**

4.3 Variables and Parameters Used in the Calculations

In this study, we assume that the homeowner pays for the retrofit with cash at the beginning of year one so that there is no interest cost. It is also assumed that the life of the investment is 20 years, which is the typical service life of the GHP unit. Although the ground heat exchanger would typically remain in service for a much longer time period than the GHP unit, this simplified analysis does not address this value. And although the maintenance cost of a GHP system is typically lower than that of conventional systems, it is also not accounted for in this study. As a result, calculations for NPV and LCOEE of the GHP retrofit are simplified to only include four variables — cost premium of the 3-

ton GHP retrofit (obtained from Table 17), annual savings in energy consumption or energy expenditures from the GHP retrofit, average annual energy escalation rate, and discount rate over the life of the investment. The predicted annual savings in energy expenditures per single-family home listed in Table 15 are used to calculate the NPV of the GHP retrofit. The predicted savings in delivered energy include both natural gas and electricity. To calculate LCOEE of the GHP retrofit, the avoided natural gas consumption is converted to "indirect electricity savings" as described in section 4.5 and the total (direct and indirect) electricity savings from the GHP retrofit compared with the alternatives is listed in Table 19.

The two key financial parameters, average annual energy escalation rate and discount rate over the life of the investment, are discussed in the following paragraphs.

<u>Energy Escalation Rate</u>

The average annual energy escalation rate for 2010 through 2030 was determined with the Energy Escalation Rate Calculator developed for the DOE's Federal Energy Management Program (FEMP 2010). This tool calculates the average rate (across all energy forms) of energy price escalation over the duration of the analysis period, weighted by the proportions of each energy type saved by the project. Since, as shown in Figure 5, most energy savings from the GHP retrofit comes from avoided natural gas consumption, the calculated average escalation rate is appropriately weighted toward the escalation rate of natural gas price over the 20-year period, which is 5.14% based on the 3.4% inflation rate.

<u>Discount Rate</u>

The 2010 real discount rate for public investment and regulatory analysis is 7%. However, historical data show that the discount rate has varied widely in past years from 0.5% to 14% (Federal Reserve Bank of New York 2010). As a result, instead of assuming a particular discount rate, a series of discount rates ranging from 0 to 15% with an interval of 3% are used in the calculations for the NPV and LCOEE of the GHP retrofit.

4.4 Predicted NPV from Investment in GHP Retrofits

NPV of GHP retrofits in four scenarios are calculated with various discount rates using Equation 6. The four scenarios are:

- State-of-the-Art GHP system *vs.* Alt #1
- State-of-the-Art GHP system (with reduced cost) *vs.* Alt #1
- State-of-the-Art GHP system *vs.* Alt #2
- State-of-the-Art GHP system (with reduced cost) *vs.* Alt #2

The predicted national average NPV gained from retrofitting a typical existing single-family home with the state-of-the-art GHP system in the above four scenarios and with various discount rates are listed in Table 18. As indicated in Equation 6, a positive value of the calculated NPV means the discounted present values of the saved future energy costs exceed the cost premium of the GHP retrofit. Correspondingly, a negative for NPV means the cost premium is not offset by future energy cost savings. The calculated NPV is also presented in Figure 6 to illustrate its relationship with the discount rate.

As a sanity check, the simple payback periods[6] of the investments are also calculated and summarized in Table 18. As shown in the table, compared with Alt #1, the national average simple payback period for the GHP retrofit at current market prices is 14.4 years and falls to 9.8 years if the 19% cost reduction potential suggested by Kavanaugh (1995) is fully realized. Considering the higher cost of the state-of the-art GHP units, these results are in line with the 8.6- to 12-year simple payback periods indicated in the DoD (2007) report. The simple payback period for the GHP retrofit becomes much shorter when compared with the state-of-the-art conventional system (Alt #2). With the 19% cost reduction, the simple payback period of the GHP retrofit is only 2.4 years.

Data in Table 18 and Figure 6 show that the NPV of the GHP retrofit is higher when compared with the state-of-the-art conventional system (Alt #2) than with the minimum-code-compliant conventional system (Alt #1). This result is not surprising since the cost premium of the GHP retrofit is much lower versus Alt #2, especially when the 19% cost reduction potential of the GHP system is fully realized. When compared with Alt #2, investments in the GHP retrofit at current market prices show a positive NPV over the 20-year life even when future energy cost savings are discounted at rates as high as 14%. However, when compared with Alt #1, investment in the GHP retrofit at current market prices will only yield a positive NPV when the discount rate is lower than 8%. If the 19% cost reduction potential of GHP systems can be fully realized, investments in the GHP retrofit generally have positive NPVs even with high discount rates, especially when compared with the state-of-the-art conventional system (Alt #2). This result implies that with currently enacted federal tax credits, which offset 30% of the installed cost of GHP systems (valid through 2016), investments in GHP retrofits are currently quite attractive across the board, presuming homeowners are earning income and paying taxes.

Table 18. Simple payback period and NPV for GHP retrofits at various discount rates.

Profit of GHP Retrofit	Simple Payback Period	Discount Rate					
	Year	0%	3%	6%	9%	12%	15%
State-of-the-Art GHP System *vs.* Alt #1	14.4	$ 9,002	$ 4,411	$ 1,460	$ (497)	$ (1,834)	$ (2,775)
State-of-the-Art GHP System (with Reduced Cost) vs. Alt #1	9.8	$ 11,141	$ 6,550	$ 3,599	$ 1,642	$ 305	$ (636)
State-of-the-Art GHP System vs. Alt #2	8.9	$ 8,189	$ 4,943	$ 2,857	$ 1,474	$ 528	$ (137)
State-of-the-Art GHP System (with Reduced Cost) vs. Alt #2	2.4	$ 10,328	$ 7,082	$ 4,996	$ 3,612	$ 2,667	$ 2,002

[6] Simple payback is calculated by dividing the cost premium of the GHP retrofit by the energy expenditure savings in the first year, with neither energy cost escalation nor discount rate accounted for.

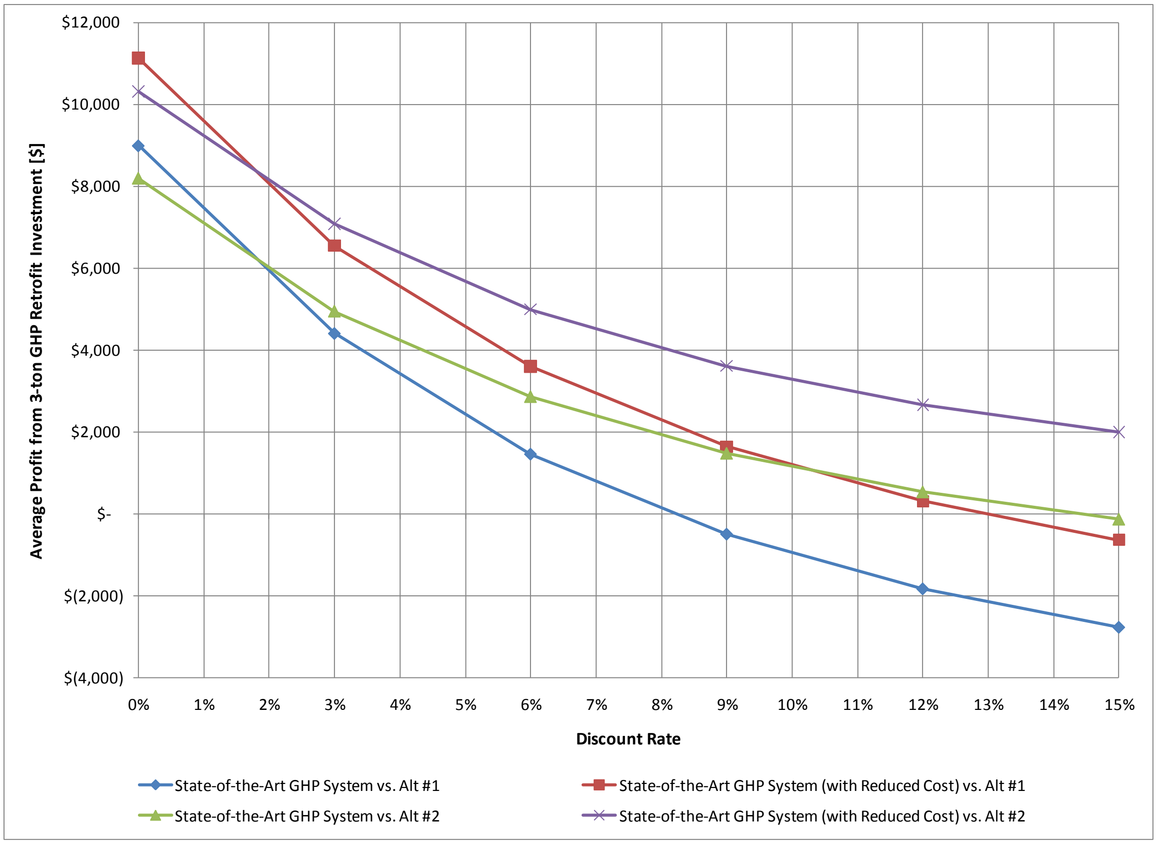

Fig. 6. Calculated profits of 3-ton GHP retrofit at various discount rates.

4.5 Predicted Levelized Cost of Energy Efficiency of GHP Retrofits

Typically, levelized costs are calculated based on the savings of one type of energy, such as electricity. However, as shown in Figure 5, while the GHP retrofit reduces natural gas consumption, it also increases or decreases the consumption of electricity. To account for these two types of energy in the LCOEE calculation, the avoided natural gas consumption is converted to "indirect electricity savings," which is the electricity that can be generated and delivered to a residence using the avoided natural gas consumption at the residence. Therefore the total saved energy used in the LCOEE calculation is the sum of the indirect electricity savings (representing savings in natural gas) and the direct savings (positive or negative) of delivered electricity at the residence. The typical thermal efficiency of combined-cycle natural gas power plants (50%)[7] and the national average of transmission and distribution losses of electricity (9.9%) (NREL 2007) are used to calculate the indirect electricity savings. The estimated total (direct and indirect) electricity savings from the GHP retrofit compared with Alt #1 and Alt #2 are listed in Table 19.

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[7] From http://www.naturalgas.org/overview/uses_eletrical.asp .

Table 19. Total (direct and indirect) electricity savings from the GHP retrofit compared with Alt #1 and Alt #2.

Base Case	National Total (Direct and Indirect) Electricity Savings from GHP Retrofit	National Average of Annual (Direct and Indirect) Electricity Savings per Single-Family Home from GHP Retrofit
	Trillion W-Hr	kWh
Alt #1	432.0	5447.7
Alt #2	340.0	4287.5

The LCOEE of the GHP retrofit in the four scenarios described in section 4.4 and at various discount rates are calculated using Equation 7, and the results are listed in Table 20. Similar to LCOE (for energy generation systems), which is the minimum price at which the **generated energy** must be sold for an energy project to break even, LCOEE is the minimum price at which the **saved energy** must be valued for the investment in GHP retrofits to break even. As shown in Table 20, the LCOEE of the GHP retrofit is always less than the annual average residential electricity price in 2010 (11.5 cents per kWh)[8] when compared with Alt #2. When compared with Alt #1, the state-of-the-art GHP at current market prices is better than break-even up to a discount rate of 7%, and with the previously discussed 19% cost reduction, is better than break-even up to a discount rate of 12%.

Table 20. LCOEE of GHP retrofit in four scenarios and at various discount rates.

LCOEE (Cents per kWh)	Discount Rate					
	0%	3%	6%	9%	12%	15%
State-of-the-Art GHP System vs. Alt #1	6.2	8.3	10.8	13.6	16.6	19.8
State-of-the-Art GHP System (with Reduced Cost) vs. Alt #1	4.2	5.7	7.4	9.3	11.3	13.5
State-of-the-Art GHP System vs. Alt #2	3.0	4.1	5.3	6.6	8.1	9.7
State-of-the-Art GHP System (with Reduced Cost) vs. Alt #2	0.5	0.7	0.9	1.2	1.4	1.7

4.6 Uncounted Values and Benefits

Due to the lack of established valuing mechanisms and insufficient resources to develop the methods, the calculations for NPV and LCOEE for the GHP retrofit in this analysis do not account for several benefits achieved from the GHP retrofits, including reduction

[8] EIA Short-Term Energy and Summer Fuels Outlook (April 6, 2010). Available at http://www.eia.doe.gov/steo#Electricity_Markets

of CO_2 emissions and summer peak electrical demand. In addition, the residual value of the vertical ground loop heat exchanger, which has a service life far longer than 20 years, was not accounted for. These unincluded benefits are believed to be substantial.

As shown in Table 21, compared with Alt #1 (SEER 13 AC), the state-of-the-art GHP system reduces summer peak electrical demand by 0.5 – 1 kW per cooling ton depending on where the building is located. However, the reduction of summer peak electrical demand is less than 0.3 kW/ton when the GHP system is compared with Alt #2 (SEER 21 AC). When deployed on a large scale, the GHP retrofit could defer or avoid the need for significant amounts of new electricity generation capacity. According to a recent report (Lazard 2008), the capital cost of a new combined-cycle natural gas power plant is $900 – $1,100 per kW, and the cost is 3 – 5 times higher if the electricity is generated with renewable energy or in de-carbonized fossil-fuel power plants. Obviously, if the summer peak electrical demand reduction from GHP retrofits is valued more highly by including the avoided capital cost of new electricity generation capacity, the cost premium of the GHP retrofit would be significantly reduced.

Table 21. Peak electrical demand for cooling in four U.S. census regions.

System	Peak Electrical Demand for Cooling [kW/ton]			
	Northeast	Midwest	South	West
State-of-the-Art GHP	0.96	0.96	0.98	1.09
Atl #1	1.95	1.89	1.55	1.76
Atl #2	1.23	1.16	1.20	1.27

Table 22 compares the CO_2 emissions of the state-of-the-art GHP system with those of Alt #1 and Alt #2 in the four U.S. census regions. Data in Table 22 indicate that the state-of-the-art GHP system can reduce CO_2 emissions by an average of 2.5 and 1.6 metric tons per U.S. single-family home compared with Alt #1 and Alt #2, respectively.

Table 22. CO_2 reduction potential of GHP retrofits compared with alternatives.

System Type	National Total Annual CO2 Emissions for SH-SC-WH in U.S. Single-family Homes	National Total Annual CO2 Emissions Reduction (Compared with Existing Systems)	National Average of Annual CO2 Emissions Reduction per Single-Family Home (Compared with Existing Systems)	National Average of Annual CO2 Emissions Reduction per Single-Family Home from GHP Retrofit (Compared with Alternatives)
	Million Metric Ton	Million Metric Ton	Metric Ton	Metric Ton
Existing SH-SC-WH Systems	599.7			
State-of-the-art GHP System	328	271.7	3.4	
Alt #1	522.9	76.8	1.0	2.5
Alt #2	458.7	141.0	1.8	1.6

If the residual value of the ground heat exchangers and the reductions in summer peak electrical demand and CO_2 emissions can be fairly valued in the economic analysis, GHP retrofits will appear more favorable using the NPV and LCOEE metrics.

5. Conclusions

This report assesses the potential of national benefits from retrofitting U.S. single-family homes with state-of-the-art GHP systems at various penetration rates. The assessment is conducted using energy consumption data for SH-SC-WH in existing U.S. single-family homes obtained from the Residential Energy Consumption Survey (RECS 2005) and relative differences in annual energy consumption between the state-of-the-art GHP system and existing residential SH-SC-WH systems. The impacts of various climate and geological conditions, as well as efficiency and market share of existing residential SH-SC-WH systems, have been taken into account in the assessment.

The analysis shows that replacing all SH-SC-WH systems in existing U.S. single-family homes with properly designed, installed, and operated state-of-the-art GHP systems would yield significant benefits each year, including savings of 4.2 quad Btu primary energy, reduction of 271.7 million metric tons of CO_2 emissions, savings of $52.2 billion in energy expenditures, and reduction of 202.1 gigawatt in summer peak electrical demand. The analysis also shows that the benefits of GHP retrofits are significant even at lower market penetration rates.

An economical analysis shows that, compared with conventional residential space heating and cooling systems, investments in retrofitting existing single-family homes with the state-of-the-art GHP system will yield a positive NPV over a 20-year period at current market prices and without any financial incentives when the discount rate is lower than 8%. The levelized cost analysis shows that saving energy with the GHP retrofit is cheaper than generating and delivering electricity to residences when the discount rate is lower than 8%. With the enacted federal tax credits for 30% of the installed cost of a GHP system (valid through 2016), investments in the state-of-the-art GHP system could be profitable even at higher discount rates. The GHP retrofit investment would be more favorable should the residual value of the ground loop heat exchanger and the value of reduced CO_2 emissions and summer peak electrical demand be accounted for.

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Appendix A – Description of Reference Single-family Home

The selected reference single-family home, a one-story, slab-on-grade, wood-frame house, is depicted in Figure A-1. Its key characteristics are listed in Table A-1.

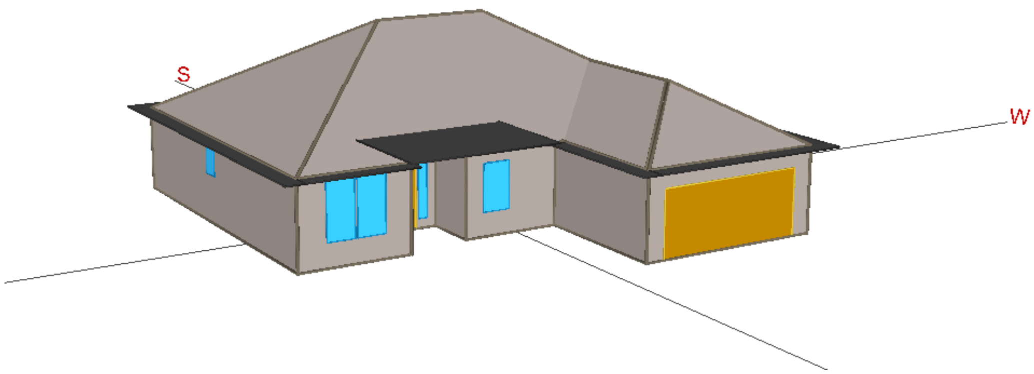

Fig. A-1. Illustration of the selected reference single-family home.

Table A-1. Key characteristics of the selected reference single-family house

Main entrance orientation	North
Conditioned floor area	1618 sf
Construction	Wood frame
Story	One
Ceiling insulation	R-38 blown cellulose at ceiling
Walls insulation	R-19 blown cellulose + R-3 insulating sheathing
Foundation insulation	Slab on grade, R-4 perimeter insulation
Windows	Double-glazed; U = 0.5, SHGC = 0.57; Mostly south-facing with overhang
Infiltration rate	0.19 ACH
Lighting	90% compact fluorescent lighting
Appliances and miscellaneous	ENERGY STAR refrigerator, clothes washer, dishwasher, TV, computer
Air-handler location	In conditioned space (utility room)
Ducts	In vented attic, R-6 insulation, 5% or less leakage to the outside

Appendix B – Description of GeoDesigner Software

GeoDesigner estimates annual energy consumption and expenditures for space heating, space cooling, and water heating (SH-SC-WH) in single-family homes that use geothermal heat pump (GHP) system or other typical residential SH-SC-WH systems.

GeoDesigner utilizes the ASHRAE modified bin analysis method to calculate space heating and cooling loads (the amount of heat needs to be removed from or added into the space to maintain a certain temperature set point) of a single-family home at various outdoor dry-bulb temperatures, which are sorted into discrete groups (bins) with the number of hours of occurrence of each temperature bin. The calculation is based on user-specified peak heat loss and heat gain from building envelop at design conditions (the highest and lowest outdoor dry-bulb temperature), and approximations for miscellaneous electric load, solar heat gain, occupancy level, and the construction quality (air tightness of the building). GeoDesigner has a library of the bin weather data for most major cities in the United States as well as the design outdoor dry-bulb temperature (adopted from handbook of American Society of Heating Refrigeration and Air-Conditioning Engineers [ASHRAE]), the deep earth temperature, surface soil temperature swing and delay (adopted from the design and installation manual of International Ground Source Heat Pump Association [IGSHPA]) at each of the locations.

GeoDesigner calculates domestic hot water load of a single-family home based on average city water supply temperature where the building is located, user-specified hot water supply temperature, and the number of occupants in the building. The calculated domestic hot water load is constant over all temperature bins.

GeoDesigner has a library of performance data for GHP units and conventional SH-SC-WH equipments, including air source heat pump units, air conditioners, furnaces/boilers, and water heaters. The library covers a wide range of equipments with efficiencies varied from less than current code allowed minimum to the highest available from the state-of-the-art equipments, and fuel types of furnace/boiler and water heater includes electricity, natural gas, heating oil, and propane/LPG.

GeoDesigner allows user to select ground heat exchangers from a large collection including vertical bores, horizontal loops, pond loop, and well water. It offers two options for the design of selected ground heat exchangers: auto-sized by itself or user-specified. The sizing algorithms implemented in GeoDesigner for various types of ground heat exchangers are adopted from the design and installation manual of IGSHPA.

To simulate the annual energy consumption of a GHP system, GeoDesigner calculates the ground heat exchanger leaving fluid temperature (LFT), which is the entering fluid temperature (EFT) of the heat pump unit, based on the design of the selected ground heat exchanger and the space heating/cooling loads at each temperature bin. With these calculated EFT and the performance curves of the user-selected heat pump unit (obtained from manufacturer’s catalog data), which correlate the heat pump capacity and efficiency to the EFT, GeoDesigner calculates power consumption of the GHP system for providing space heating/cooling loads at each temperature bin and over the entire year. The heat pump efficiency accounts for all the power consumptions from the heat pump compressor, fan, and circulation pump[9]. The efficiency degradation due to the cycling loss of the heat pump at part load conditions is also taken into account in the calculation with a part-load performance curve for the selected heat pump. When the de-super-heater option is selected, GeoDesigner calculates the contribution of the de-super-heater for water heating and the associated power consumption.

Similarly, the annual energy consumption of air source heat pump (ASHP) or air conditioner (AC) is determined based on the space heating/cooling loads and the outdoor dry-bulb temperature at each temperature bin as well as the performance curves of the user-selected ASHP/AC unit (obtained from manufacturer's catalog data), which correlate the ASHP/AC capacity and efficiency to the outdoor dry-bulb temperature. The Auxiliary heating, either supplementing or overriding the ASHP, is accounted for in the energy calculation for ASHP system.

The energy consumption of furnace/boiler and water heater (non-heat pump type) is calculated straight forwardly with the total space heating and water heating loads and the efficiencies of the selected furnace/boiler and water heater. Electric consumptions associated with the fossil fuel fired furnace/boiler and water heater are included in the energy calculation.

With decades of continued development, GeoDesigner becomes very user-friendly and robust in performing energy analysis for residential SH-SC-WH systems. It has been widely used in the design and energy analysis for residential GHP applications. A recent report shows that the energy consumption predicted by GeoDesigner matches the metered data fairly well (Ellis 2008).

GeoDesigner still has some limitations. First, compared with more sophiscated hourly energy simulation, the bin analysis utilized by GeoDesigner is relatively less accurate in estimating the impacts of other weather elements (i.e. solar, wind, precipitation, and etc.) and the heat gain from activities inside the building (i.e. lighting, cooking, showering, and etc.) on the building heating/cooling loads. The bin analysis also limits the capability for more detailed analysis of electrical demand of the building. Second, the algorithm used by GeoDesigner for calculating the ground heat exchanger LFT does not account for the loading history of the ground and, as a result, it may underestimate the LFT at some temperature bins, especially those most likely occurring at the end of a heating/cooling season.

Comparison results with other more sophisticated hourly energy analysis programs show that, while there are some discrepancies in the predicted total energy consumption of a particular SH-SC-WH system between GeoDesigner and the more sophisticated

[9] The fan power is adopted from manufacturers' catalog data for 0.5 External Static Pressure and the pumping power is estimated for typical total length/depth of the loop/ well plus head loss in heat pump (condenser) and assuming typical pump efficiencies.

programs, the relative difference in energy consumption between different SH-SC-WH systems predicted by GeoDesigner and the more sophisticated programs are fairly close.

Appendix C – Population-Weighted Average of Energy Consumptions, CO_2 Emissions, and Energy Expenditures of each Typical SH-SC-WH System in each Census Region

C-1 Northeast Region

Delivered Energy

		Main Heating Fuel Type					Geothermal (with electric Aux Heater)			Heat Pump (with electric Aux Heater)			Electric (with central AC)			Natural Gas (with central AC)				Propane (with central AC)				Oil (with central AC)			
Cen Region	Clm Zone	State	City	County	Population	P.W.F.	Heat MWh	Cool MWh	HW MWh	Heat MWh	Cool MWh	HW MWh	Heat MWh	Cool MWh	HW MWh	Heat MWh	Heat Mcf	Cool MWh	HW Mcf	Heat MWh	Heat Gal	Cool MWh	HW Gal	Heat MWh	Heat Gal	Cool MWh	HW Gal
Northeast	4A	PA	Philadelphia	Philadelphia	21,879,116	40.1%	3.6	0.8	3.3	10.0	2.4	5.2	14.3	2.5	5.2	0.5	64.1	2.5	27.0	0.5	700.8	2.5	295.1	0.7	537.5	2.5	195.9
Northeast	5A	MA	Boston	Suffolk	28,102,970	51.6%	4.2	0.4	3.6	12.1	1.5	5.6	16.6	1.6	5.6	0.6	74.6	1.6	28.8	0.6	815.6	1.6	314.7	0.7	625.6	1.6	209.0
Northeast	6A	ME	Bangor	Penobscot	4,515,671	8.3%	7.2	0.2	3.5	22.8	0.9	5.9	26.9	0.9	5.9	0.9	120.9	0.9	30.5	0.9	1,321.9	0.9	333.3	1.1	1,013.9	0.9	221.4
				Total	54,497,757	100%																					
				Pop Wgt Avg			4.2	0.5	3.5	12.1	1.8	5.5	16.5	1.9	5.5	0.6	74.2	1.9	28.2	0.6	811.5	1.9	308.4	0.7	622.4	1.9	204.8
				Arithmatic Average			5.7	0.3	3.6	17.5	1.2	5.7	21.8	1.3	5.7	0.7	97.8	1.3	29.7	0.7	1,069	1.3	324	0.9	820	1.3	215

Utility Cost

		Main Heating Fuel Type					Geothermal (with electric Aux Heater)			Heat Pump (with electric Aux Heater)			Electric (with central AC)			Natural Gas (with central AC)				Propane (with central AC)				Oil (with central AC)			
Cen Region	Clm Zone	State	City	County	Population	P.W.F.	Heat $	Cool $	HW $	Heat $	Cool $	HW $	Heat $	Cool $	HW $	Heat $	Heat $	Cool $	HW $	Heat $	Heat $	Cool $	HW $	Heat $	Heat $	Cool $	HW $
Northeast	4A	PA	Philadelphia	Philadelphia	21,879,116	40.1%	550.1	130.1	520.2	1,550.4	395.0	832.5	2,209.2	412.6	832.5	80.4	956.1	412.6	433.5	80.4	1,859.5	412.6	783.6	104.4	1,568.4	412.6	563.6
Northeast	5A	MA	Boston	Suffolk	28,102,970	51.6%	656.5	63.8	578.5	1,869.2	254.5	888.0	2,571.1	265.9	888.0	85.5	1,112.7	265.9	462.4	85.5	2,164.1	265.9	835.8	111.0	1,825.4	265.9	601.2
Northeast	6A	ME	Bangor	Penobscot	4,515,671	8.3%	1,117.1	35.7	562.8	3,529.7	148.4	937.9	4,166.8	154.9	937.9	135.5	1,803.3	154.9	489.7	135.5	3,507.2	154.9	885.2	175.9	2,958.3	154.9	636.7
				Total	54,497,757	100%																					
				Pop Wgt Avg			652.0	88.1	553.8	1,878.8	302.1	869.9	2,558.0	315.6	869.9	87.6	1,107.1	315.6	453.1	87.6	2,153.1	315.6	818.9	113.7	1,816.1	315.6	589.1
				Arithmatic Average			886.8	49.7	570.6	2,699.4	201.4	913.0	3,368.9	210.4	913.0	110.5	1,458.0	210.4	476.1	110.5	2,836	210.4	860	143.4	2,392	210.4	619

Primary Energy

		Main Heating Fuel Type					Geothermal (with electric Aux Heater)			Heat Pump (with electric Aux Heater)			Electric (with central AC)			Natural Gas (with central AC)				Propane (with central AC)				Oil (with central AC)			
Cen Region	Clm Zone	State	City	County	Population	P.W.F.	Heat MBTU	Cool MBTU	HW MBTU	Heat MBTU	Cool MBTU	HW MBTU	Heat MBTU	Cool MBTU	HW MBTU	Heat MBTU	Heat MBTU	Cool MBTU	HW MBTU	Heat MBTU	Heat MBTU	Cool MBTU	HW MBTU	Heat MBTU	Heat MBTU	Cool MBTU	HW MBTU
Northeast	4A	PA	Philadelphia	Philadelphia	21,879,116	40.1%	40.9	9.1	37.5	115.1	27.6	60.0	164.1	28.8	60.0	6.0	70.7	28.8	29.8	6.0	73.4	28.8	30.9	7.8	86.3	28.8	31.5
Northeast	5A	MA	Boston	Suffolk	28,102,970	51.6%	48.8	4.5	41.7	138.8	17.8	63.9	190.9	18.6	63.9	6.4	82.3	18.6	31.8	6.4	85.4	18.6	33.0	8.2	100.5	18.6	33.6
Northeast	6A	ME	Bangor	Penobscot	4,515,671	8.3%	83.0	2.5	40.5	262.1	10.4	67.5	309.4	10.8	67.5	10.1	133.3	10.8	33.6	10.1	138.5	10.8	34.9	13.1	162.8	10.8	35.6
				Total	54,497,757	100%																					
				Pop Wgt Avg			48.4	6.2	39.9	139.5	21.1	62.6	190.0	22.1	62.6	6.5	81.9	22.1	31.1	6.5	85.0	22.1	32.3	8.4	100.0	22.1	32.9
				Arithmatic Average			65.9	3.5	41.1	200.5	14.1	65.7	250.2	14.7	65.7	8.2	107.8	14.7	32.7	8.2	112	14.7	34	10.7	132	14.7	35

Emission

		Main Heating Fuel Type					Geothermal (with electric Aux Heater)			Heat Pump (with electric Aux Heater)			Electric (with central AC)			Natural Gas (with central AC)				Propane (with central AC)				Oil (with central AC)			
Cen Region	Clm Zone	State	City	County	Population	P.W.F.	Heat Lb	Cool Lb	HW Lb	Heat Lb	Cool Lb	HW Lb	Heat Lb	Cool Lb	HW Lb	Heat Lb	Heat Lb	Cool Lb	HW Lb	Heat Lb	Heat Lb	Cool Lb	HW Lb	Heat Lb	Heat Lb	Cool Lb	HW Lb
Northeast	4A	PA	Philadelphia	Philadelphia	21,879,116	40.1%	5,940.2	1,322.6	5,447.5	16,741.8	4,014.7	8,717.4	23,855.2	4,193.4	8,717.4	868.4	9,666.3	4,193.4	4,071.6	868.4	11,255.5	4,193.4	4,738.7	1,127.3	14,460.0	4,193.4	5,271.0
Northeast	5A	MA	Boston	Suffolk	28,102,970	51.6%	7,089.2	648.0	6,057.1	20,183.6	2,586.8	9,298.6	27,762.9	2,702.1	9,298.6	923.5	11,249.7	2,702.1	4,343.0	923.5	13,099.2	2,702.1	5,054.6	1,198.8	16,828.7	2,702.1	5,622.4
Northeast	6A	ME	Bangor	Penobscot	4,515,671	8.3%	12,062.4	362.4	5,893.4	38,114.4	1,508.0	9,821.3	44,993.7	1,574.8	9,821.3	1,462.9	18,231.7	1,574.8	4,599.4	1,462.9	21,229.2	1,574.8	5,353.0	1,899.0	27,273.3	1,574.8	5,954.3
				Total	54,497,757	100%																					
				Pop Wgt Avg			7,040.0	895.2	5,798.8	20,287.6	3,070.7	9,108.6	27,621.8	3,207.4	9,108.6	946.1	11,192.5	3,207.4	4,255.3	946.1	13,032.7	3,207.4	4,952.5	1,228.1	16,743.2	3,207.4	5,508.9
				Arithmatic Average			9,575.8	505.2	5,975.3	29,149.0	2,047.4	9,559.9	36,378.3	2,138.4	9,559.9	1,193.2	14,740.7	2,138.4	4471.2	1,193.2	17,164	2,138.4	5,204	1,548.9	22,051	2,138.4	5,788

C-2 Midwest Region

Delivered Energy

Cen Region	Clm Zone	State	City	County	Population	P.W.F.	Geothermal (with electric Aux Heater) Heat MWh	Geothermal Cool MWh	Geothermal HW MWh	Heat Pump (with electric Aux Heater) Heat MWh	Heat Pump Cool MWh	Heat Pump HW MWh	Electric (with central AC) Heat MWh	Electric Cool MWh	Electric HW MWh	Natural Gas (with central AC) Heat MWh	Natural Gas Heat Mcf	Natural Gas Cool MWh	Natural Gas HW Mcf	Propane (with central AC) Heat MWh	Propane Heat Gal	Propane Cool MWh	Propane HW Gal	Oil (with central AC) Heat MWh	Oil Heat Gal	Oil Cool MWh	Oil HW Gal
		Main Heating Fuel Type																									
Midwest	4A	MO	Kansas	Jackson	12,501,407	19.3%	2.7	2.0	3.2	8.1	4.5	5.0	10.4	4.7	5.0	0.4	46.8	4.7	25.9	0.4	511.7	4.7	283.0	0.6	392.5	4.7	188.0
Midwest	5A	IL	Chicago	Cook	39,992,232	61.8%	5.2	0.6	3.3	16.5	2.1	5.5	19.6	2.1	5.5	0.6	87.9	2.1	28.5	0.6	961.1	2.1	311.5	0.8	737.1	2.1	206.8
Midwest	6A	MN	Minneapolis	Hennepin	12,213,811	18.9%	7.0	0.4	3.5	23.0	1.5	5.8	26.1	1.5	5.8	0.9	117.1	1.5	29.9	0.9	1,280.3	1.5	326.8	1.1	982.0	1.5	217.0
				Total	64,707,450	100%																					
				Pop Wgt Avg			5.1	0.8	3.3	16.1	2.4	5.5	19.0	2.5	5.5	0.6	85.5	2.5	28.3	0.6	934.5	2.5	308.9	0.8	716.8	2.5	205.1
				Arithmatic Average			6.1	0.5	3.4	19.8	1.8	5.6	22.8	1.8	5.6	0.7	102.5	1.8	29.2	0.7	1,121	1.8	319	1.0	860	1.8	212

Utility Cost

Cen Region	Clm Zone	State	City	County	Population	P.W.F.	Geothermal (with electric Aux Heater) Heat $	Geothermal Cool $	Geothermal HW $	Heat Pump (with electric Aux Heater) Heat $	Heat Pump Cool $	Heat Pump HW $	Electric (with central AC) Heat $	Electric Cool $	Electric HW $	Natural Gas (with central AC) Heat $	Natural Gas Heat $	Natural Gas Cool $	Natural Gas HW $	Propane (with central AC) Heat $	Propane Heat $	Propane Cool $	Propane HW $	Oil (with central AC) Heat $	Oil Heat $	Oil Cool $	Oil HW $
		Main Heating Fuel Type																									
Midwest	4A	MO	Kansas	Jackson	12,501,407	19.3%	266.4	212.3	324.4	796.1	470.9	510.5	1,021.9	491.8	510.5	43.1	511.5	491.8	316.8	43.1	976.9	491.8	530.7	56.0	1,109.2	491.8	528.4
Midwest	5A	IL	Chicago	Cook	39,992,232	61.8%	511.7	63.1	335.6	1,618.4	216.9	560.1	1,919.3	226.6	560.1	62.3	960.7	226.6	348.7	62.3	1,834.9	226.6	583.9	80.9	2,083.4	226.6	581.4
Midwest	6A	MN	Minneapolis	Hennepin	12,213,811	18.9%	689.2	40.1	357.6	2,253.0	155.9	588.5	2,556.9	162.9	588.5	83.8	1,279.8	162.9	365.8	83.8	2,444.4	162.9	612.6	108.7	2,775.5	162.9	610.0
				Total	64,707,450	100%																					
				Pop Wgt Avg			497.8	87.6	337.6	1,579.3	254.5	555.9	1,866.3	265.8	555.9	62.7	934.1	265.8	345.7	62.7	1,784.2	265.8	579.1	81.3	2,025.8	265.8	576.6
				Arithmatic Average			600.4	51.6	346.6	1,935.7	186.4	574.3	2,238.1	194.7	574.3	73.0	1,120.2	194.7	357.2	73.0	2,140	194.7	598	94.8	2,429	194.7	596

Primary Energy

Cen Region	Clm Zone	State	City	County	Population	P.W.F.	Geothermal (with electric Aux Heater) Heat MBTU	Geothermal Cool MBTU	Geothermal HW MBTU	Heat Pump (with electric Aux Heater) Heat MBTU	Heat Pump Cool MBTU	Heat Pump HW MBTU	Electric (with central AC) Heat MBTU	Electric Cool MBTU	Electric HW MBTU	Natural Gas (with central AC) Heat MBTU	Natural Gas Heat MBTU	Natural Gas Cool MBTU	Natural Gas HW MBTU	Propane (with central AC) Heat MBTU	Propane Heat MBTU	Propane Cool MBTU	Propane HW MBTU	Oil (with central AC) Heat MBTU	Oil Heat MBTU	Oil Cool MBTU	Oil HW MBTU
		Main Heating Fuel Type																									
Midwest	4A	MO	Kansas	Jackson	12,501,407	19.3%	31.2	23.0	36.6	93.3	51.1	57.6	119.8	53.4	57.6	5.1	51.6	53.4	28.6	5.1	53.6	53.4	29.6	6.6	63.0	53.4	30.2
Midwest	5A	IL	Chicago	Cook	39,992,232	61.8%	60.0	6.9	37.8	189.7	23.6	63.1	225.0	24.6	63.1	7.3	96.9	24.6	31.4	7.3	100.7	24.6	32.6	9.5	118.4	24.6	33.2
Midwest	6A	MN	Minneapolis	Hennepin	12,213,811	18.9%	80.8	4.4	40.3	264.1	16.9	66.3	299.7	17.7	66.3	9.8	129.2	17.7	33.0	9.8	134.1	17.7	34.2	12.7	157.7	17.7	34.9
				Total	64,707,450	100%																					
				Pop Wgt Avg			58.3	9.5	38.1	185.1	27.6	62.7	218.8	28.9	62.7	7.3	94.3	28.9	31.2	7.3	97.9	28.9	32.3	9.5	115.1	28.9	32.9
				Arithmatic Average			70.4	5.6	39.1	226.9	20.2	64.7	262.3	21.1	64.7	8.6	113.0	21.1	32.2	8.6	117	21.1	33	11.1	138	21.1	34

Emission

Cen Region	Clm Zone	State	City	County	Population	P.W.F.	Geothermal (with electric Aux Heater) Heat Lb	Geothermal Cool Lb	Geothermal HW Lb	Heat Pump (with electric Aux Heater) Heat Lb	Heat Pump Cool Lb	Heat Pump HW Lb	Electric (with central AC) Heat Lb	Electric Cool Lb	Electric HW Lb	Natural Gas (with central AC) Heat Lb	Natural Gas Heat Lb	Natural Gas Cool Lb	Natural Gas HW Lb	Propane (with central AC) Heat Lb	Propane Heat Lb	Propane Cool Lb	Propane HW Lb	Oil (with central AC) Heat Lb	Oil Heat Lb	Oil Cool Lb	Oil HW Lb
		Main Heating Fuel Type																									
Midwest	4A	MO	Kansas	Jackson	12,501,407	19.3%	4,540.7	3,351.7	5,317.3	13,568.8	7,434.8	8,368.4	17,416.9	7,765.5	8,368.4	734.8	7,057.4	7,765.5	3,905.7	734.8	8,217.7	7,765.5	4,545.7	953.8	10,557.4	7,765.5	5,056.3
Midwest	5A	IL	Chicago	Cook	39,992,232	61.8%	8,720.7	997.0	5,501.0	27,583.4	3,425.2	9,181.7	32,712.5	3,577.1	9,181.7	1,062.1	13,255.3	3,577.1	4,297.8	1,062.1	15,434.6	3,577.1	5,002.0	1,378.7	19,829.0	3,577.1	5,563.9
Midwest	6A	MN	Minneapolis	Hennepin	12,213,811	18.9%	11,746.8	632.9	5,861.7	38,400.0	2,461.6	9,647.6	43,579.5	2,571.8	9,647.6	1,427.9	17,658.7	2,571.8	4,508.9	1,427.9	20,561.9	2,571.8	5,247.7	1,853.5	26,416.1	2,571.8	5,837.2
				Total	64,707,450	100%																					
				Pop Wgt Avg			8,484.3	1,383.2	5,533.6	26,917.5	4,018.0	9,112.5	31,808.6	4,196.6	9,112.5	1,067.9	12,889.0	4,196.6	4,261.9	1,067.9	15,008.1	4,196.6	4,960.2	1,386.2	19,281.0	4,196.6	5,517.4
				Arithmatic Average			10,233.8	815.0	5,681.3	32,991.7	2,943.4	9,414.6	38,146.0	3,074.5	9,414.6	1,245.0	15,457.0	3,074.5	4403.4	1,245.0	17,998	3,074.5	5,125	1,616.1	23,123	3,074.5	5,701

C-3 South Region

Delivered Energy

		Main Heating Fuel Type					Geothermal (with electric Aux Heater)			Heat Pump (with electric Aux Heater)			Electric (with central AC)			Natural Gas (with central AC)				Propane (with central AC)				Oil (with central AC)			
							Heat	Cool	HW	Heat	Cool	HW	Heat	Cool	HW	Heat	Heat	Cool	HW	Heat	Heat	Cool	HW	Heat	Heat	Cool	HW
		State	City	County	Population	P.W.F.	MWh	MWh	MWh	MWh	MWh	MWh	MWh	MWh	MWh	MWh	Mcf	MWh	Mcf	MWh	Gal	MWh	Gal	MWh	Gal	MWh	Gal
Northea	**2A**	**TX**	**Houston**	**Harris**	**30,898,043**	**31.6%**	**1.1**	**2.4**	**2.3**	**2.5**	**5.4**	**4.1**	**5.4**	**5.6**	**4.1**	**0.2**	**24.4**	**5.6**	**21.3**	**0.2**	**266.8**	**5.6**	**232.8**	**0.3**	**204.6**	**5.6**	**154.6**
Northea	**3A**	**GA**	**Atlanta**	**Fulton**	**37,141,601**	**37.9%**	**2.2**	**1.3**	**3.0**	**5.4**	**3.5**	**4.7**	**9.9**	**3.7**	**4.7**	**0.4**	**44.4**	**3.7**	**24.5**	**0.4**	**485.4**	**3.7**	**267.7**	**0.5**	**372.3**	**3.7**	**177.8**
Northea	**4A**	**TN**	**Nashville**	**Davidson**	**29,844,870**	**30.5%**	**3.5**	**1.4**	**2.7**	**10.4**	**3.7**	**4.9**	**14.6**	**3.8**	**4.9**	**0.5**	**65.4**	**3.8**	**25.2**	**0.5**	**715.1**	**3.8**	**275.4**	**0.7**	**548.4**	**3.8**	**182.9**
				Total	**97,884,514**	**100%**																					
				Pop Wgt Avg			**2.3**	**1.7**	**2.7**	**6.0**	**4.2**	**4.6**	**9.9**	**4.4**	**4.6**	**0.4**	**44.5**	**4.4**	**23.7**	**0.4**	**486.4**	**4.4**	**259.0**	**0.5**	**373.1**	**4.4**	**172.0**
				Arithmatic Average			2.3	1.7	2.7	6.1	4.2	4.6	10.0	4.4	4.6	0.4	44.7	4.4	23.7	0.4	489	4.4	259	0.5	375	4.4	172

Utility Cost

		Main Heating Fuel Type					Geothermal (with electric Aux Heater)			Heat Pump (with electric Aux Heater)			Electric (with central AC)			Natural Gas (with central AC)				Propane (with central AC)				Oil (with central AC)			
							Heat	Cool	HW	Heat	Cool	HW	Heat	Cool	HW	Heat	Heat	Cool	HW	Heat	Heat	Cool	HW	Heat	Heat	Cool	HW
Cen Regic	Clm Zone	State	City	County	Population	P.W.F.	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$
Northea	**2A**	**TX**	**Houston**	**Harris**	**30,898,043**	**31.6%**	**119.3**	**260.4**	**252.7**	**269.3**	**596.6**	**443.9**	**575.8**	**623.2**	**443.9**	**21.2**	**357.8**	**623.2**	**356.0**	**21.2**	**647.9**	**623.2**	**553.4**	**27.5**	**586.5**	**623.2**	**432.8**
Northea	**3A**	**GA**	**Atlanta**	**Fulton**	**37,141,601**	**37.9%**	**236.2**	**146.7**	**321.7**	**573.8**	**388.7**	**511.7**	**1,047.8**	**405.9**	**511.7**	**38.7**	**651.2**	**405.9**	**409.5**	**38.7**	**1,179.0**	**405.9**	**636.6**	**50.2**	**1,067.3**	**405.9**	**497.9**
Northea	**4A**	**TN**	**Nashville**	**Davidson**	**29,844,870**	**30.5%**	**374.0**	**149.5**	**295.4**	**1,099.7**	**406.5**	**526.7**	**1,543.4**	**424.6**	**526.7**	**55.5**	**959.1**	**424.6**	**421.2**	**55.5**	**1,736.7**	**424.6**	**654.8**	**72.0**	**1,572.1**	**424.6**	**512.1**
				Total	**97,884,514**	**100%**																					
				Pop Wgt Avg			**241.3**	**183.4**	**291.9**	**638.0**	**459.8**	**494.9**	**1,049.9**	**480.2**	**494.9**	**38.3**	**652.5**	**480.2**	**396.2**	**38.3**	**1,181.4**	**480.2**	**615.9**	**49.7**	**1,069.4**	**480.2**	**481.7**
				Arithmatic Average			305.1	148.1	308.5	836.7	397.6	519.2	1,295.6	415.2	519.2	47.1	805.1	415.2	415.4	47.1	1,458	415.2	646	61.1	1,320	415.2	505

Primary Energy

		Main Heating Fuel Type					Geothermal (with electric Aux Heater)			Heat Pump (with electric Aux Heater)			Electric (with central AC)			Natural Gas (with central AC)				Propane (with central AC)				Oil (with central AC)			
							Heat	Cool	HW	Heat	Cool	HW	Heat	Cool	HW	Heat	Heat	Cool	HW	Heat	Heat	Cool	HW	Heat	Heat	Cool	HW
Cen Regic	Clm Zone	State	City	County	Population	P.W.F.	MBTU	MBTU	MBTU	MBTU	MBTU	MBTU	MBTU	MBTU	MBTU	MBTU	MBTU	MBTU	MBTU	MBTU	MBTU	MBTU	MBTU	MBTU	MBTU	MBTU	MBTU
Northea	**2A**	**TX**	**Houston**	**Harris**	**30,898,043**	**31.6%**	**12.9**	**27.1**	**26.8**	**29.2**	**62.1**	**47.2**	**62.4**	**64.9**	**47.2**	**2.3**	**26.9**	**64.9**	**23.5**	**2.3**	**27.9**	**64.9**	**24.4**	**3.0**	**32.9**	**64.9**	**24.8**
Northea	**3A**	**GA**	**Atlanta**	**Fulton**	**37,141,601**	**37.9%**	**25.6**	**15.3**	**34.2**	**62.2**	**40.5**	**54.4**	**113.6**	**42.3**	**54.4**	**4.2**	**49.0**	**42.3**	**27.0**	**4.2**	**50.8**	**42.3**	**28.0**	**5.4**	**59.8**	**42.3**	**28.6**
Northea	**4A**	**TN**	**Nashville**	**Davidson**	**29,844,870**	**30.5%**	**40.6**	**15.6**	**31.4**	**119.3**	**42.3**	**56.0**	**167.4**	**44.2**	**56.0**	**6.0**	**72.1**	**44.2**	**27.8**	**6.0**	**74.9**	**44.2**	**28.8**	**7.8**	**88.1**	**44.2**	**29.4**
				Total	**97,884,514**	**100%**																					
				Pop Wgt Avg			**26.2**	**19.1**	**31.0**	**69.2**	**47.9**	**52.6**	**113.9**	**50.0**	**52.6**	**4.2**	**49.1**	**50.0**	**26.1**	**4.2**	**50.9**	**50.0**	**27.1**	**5.4**	**59.9**	**50.0**	**27.6**
				Arithmatic Average			33.1	15.4	32.8	90.7	41.4	55.2	140.5	43.2	55.2	5.1	60.6	43.2	27.4	5.1	63	43.2	28	6.6	74	43.2	29

Emission

		Main Heating Fuel Type					Geothermal (with electric Aux Heater)			Heat Pump (with electric Aux Heater)			Electric (with central AC)			Natural Gas (with central AC)				Propane (with central AC)				Oil (with central AC)			
							Heat	Cool	HW	Heat	Cool	HW	Heat	Cool	HW	Heat	Heat	Cool	HW	Heat	Heat	Cool	HW	Heat	Heat	Cool	HW
Cen Regic	Clm Zone	State	City	County	Population	P.W.F.	Lb	Lb	Lb	Lb	Lb	Lb	Lb	Lb	Lb	Lb	Lb	Lb	Lb	Lb	Lb	Lb	Lb	Lb	Lb	Lb	Lb
Northea	**2A**	**TX**	**Houston**	**Harris**	**30,898,043**	**31.6%**	**1,882.1**	**3,941.2**	**3,902.8**	**4,246.8**	**9,031.4**	**6,857.0**	**9,080.6**	**9,433.8**	**6,857.0**	**334.0**	**3,679.5**	**9,433.8**	**3,212.0**	**334.0**	**4,284.5**	**9,433.8**	**3,738.3**	**433.6**	**5,504.3**	**9,433.8**	**4,158.3**
Northea	**3A**	**GA**	**Atlanta**	**Fulton**	**37,141,601**	**37.9%**	**3,724.1**	**2,221.1**	**4,969.9**	**9,048.1**	**5,883.4**	**7,904.1**	**16,523.7**	**6,143.9**	**7,904.1**	**609.6**	**6,695.5**	**6,143.9**	**3,694.6**	**609.6**	**7,796.3**	**6,143.9**	**4,299.9**	**791.2**	**10,016.0**	**6,143.9**	**4,783.0**
Northea	**4A**	**TN**	**Nashville**	**Davidson**	**29,844,870**	**30.5%**	**5,898.4**	**2,262.9**	**4,562.4**	**17,341.3**	**6,154.0**	**8,136.2**	**24,339.0**	**6,427.8**	**8,136.2**	**875.1**	**9,862.3**	**6,427.8**	**3,800.2**	**875.1**	**11,483.8**	**6,427.8**	**4,422.8**	**1,135.9**	**14,753.3**	**6,427.8**	**4,919.6**
				Total	**97,884,514**	**100%**																					
				Pop Wgt Avg			**3,805.6**	**2,776.8**	**4,508.8**	**10,061.1**	**6,959.6**	**7,644.4**	**16,557.1**	**7,269.0**	**7,644.4**	**603.5**	**6,709.0**	**7,269.0**	**3,574.5**	**603.5**	**7,812.1**	**7,269.0**	**4,160.1**	**783.4**	**10,036.2**	**7,269.0**	**4,627.4**
				Arithmatic Average			4,811.3	2,242.0	4,766.2	13,194.7	6,018.7	8,020.2	20,431.4	6,285.9	8,020.2	742.3	8,278.9	6,285.9	3747.4	742.3	9,640	6,285.9	4,361	963.6	12,385	6,285.9	4,851

C-4 West Region

Delivered Energy

		Main Heating Fuel Type					Geothermal (with electric Aux Heater)			Heat Pump (with electric Aux Heater)			Electric (with central AC)			Natural Gas (with central AC)				Propane (with central AC)				Oil (with central AC)			
		State	City	County	Population	P.W.F.	Heat MWh	Cool MWh	HW MWh	Heat MWh	Cool MWh	HW MWh	Heat MWh	Cool MWh	HW MWh	Heat MWh	Heat Mcf	Cool MWh	HW Mcf	Heat MWh	Heat Gal	Cool MWh	HW Gal	Heat MWh	Heat Gal	Cool MWh	HW Gal
West	2B	AZ	Phoenix	Maricopa	4,970,848	8.1%	0.9	2.9	2.1	2.1	6.5	4.0	4.5	6.8	4.0	0.2	20.3	6.8	20.5	0.2	222.0	6.8	224.0	0.2	170.2	6.8	148.8
West	3B	CA	Sacramento	Sacramento	29,832,102	48.7%	1.6	1.0	3.0	3.2	2.3	4.5	6.8	2.5	4.5	0.2	30.5	2.5	23.1	0.2	333.5	2.5	252.4	0.3	255.8	2.5	167.6
West	3C	CA	San Francisco	San Francisco	7,694,875	12.6%	1.5	0.8	3.2	3.0	1.9	4.5	6.3	2.0	4.5	0.2	28.3	2.0	23.1	0.2	309.4	2.0	252.4	0.2	237.3	2.0	167.6
West	4C	OR	Portland	Clackmas	7,844,547	12.8%	3.7	0.2	3.5	7.7	0.7	5.3	14.7	0.8	5.3	0.4	65.9	0.8	27.4	0.4	720.5	0.8	299.4	0.6	552.6	0.8	198.9
West	5B	CO	Denver	Denver	10,934,600	17.8%	5.2	0.5	3.4	16.8	1.6	5.4	20.2	1.7	5.4	0.6	90.7	1.7	28.1	0.6	991.7	1.7	307.1	0.8	760.6	1.7	203.9
				Total	61,276,972	100%																					
				Pop Wgt Avg			2.4	0.9	3.1	6.1	2.3	4.7	10.0	2.4	4.7	0.3	44.7	2.4	24.3	0.3	488.4	2.4	265.9	0.4	374.6	2.4	176.6
				Arithmatic Average			3.4	0.5	3.4	9.2	1.4	5.1	13.7	1.5	5.1	0.4	61.6	1.5	26.2	0.4	674	1.5	286	0.5	517	1.5	190

Utility Cost

		Main Heating Fuel Type					Geothermal (with electric Aux Heater)			Heat Pump (with electric Aux Heater)			Electric (with central AC)			Natural Gas (with central AC)				Propane (with central AC)				Oil (with central AC)			
Cen Regic	Clm Zone	State	City	County	Population	P.W.F.	Heat $	Cool $	HW $	Heat $	Cool $	HW $	Heat $	Cool $	HW $	Heat $	Heat $	Cool $	HW $	Heat $	Heat $	Cool $	HW $	Heat $	Heat $	Cool $	HW $
West	2B	AZ	Phoenix	Maricopa	4,970,848	8.1%	100.6	345.0	243.1	228.7	771.4	452.7	494.7	805.7	452.7	18.0	209.2	805.7	221.5	18.0	522.5	805.7	513.1	23.4	506.9	805.7	442.3
West	3B	CA	Sacramento	Sacramento	29,832,102	48.7%	171.5	119.7	347.7	348.5	279.1	509.1	743.3	291.5	509.1	21.5	314.4	291.5	249.6	21.5	785.1	291.5	578.1	28.0	761.7	291.5	498.4
West	3C	CA	San Francisco	San Francisco	7,694,875	12.6%	162.7	92.6	361.5	324.8	223.0	509.1	689.7	233.0	509.1	20.0	291.7	233.0	249.6	20.0	728.4	233.0	578.1	26.0	706.7	233.0	498.4
West	4C	OR	Portland	Clackmas	7,844,547	12.8%	403.4	25.1	404.2	845.2	85.4	603.6	1,606.0	89.2	603.6	46.6	679.3	89.2	296.0	46.6	1,696.2	89.2	685.7	60.5	1,645.7	89.2	591.1
West	5B	CO	Denver	Denver	10,934,600	17.8%	563.8	55.4	393.4	1,834.5	190.0	619.6	2,210.4	198.4	619.6	67.8	934.9	198.4	303.6	67.8	2,334.6	198.4	703.3	88.0	2,265.0	198.4	606.2
				Total	61,276,972	100%																					
				Pop Wgt Avg			264.3	111.0	356.3	664.6	271.3	536.3	1,088.7	283.3	536.3	32.5	460.4	283.3	262.9	32.5	1,149.8	283.3	609.0	42.2	1,115.5	283.3	524.9
				Arithmatic Average			376.6	57.7	386.4	1,001.5	166.1	577.4	1,502.1	173.5	577.4	44.8	635.3	173.5	283.1	44.8	1,586	173.5	656	58.2	1,539	173.5	565

Primary Energy

		Main Heating Fuel Type					Geothermal (with electric Aux Heater)			Heat Pump (with electric Aux Heater)			Electric (with central AC)			Natural Gas (with central AC)				Propane (with central AC)				Oil (with central AC)			
Cen Regic	Clm Zone	State	City	County	Population	P.W.F.	Heat MBTU	Cool MBTU	HW MBTU	Heat MBTU	Cool MBTU	HW MBTU	Heat MBTU	Cool MBTU	HW MBTU	Heat MBTU	Heat MBTU	Cool MBTU	HW MBTU	Heat MBTU	Heat MBTU	Cool MBTU	HW MBTU	Heat MBTU	Heat MBTU	Cool MBTU	HW MBTU
West	2B	AZ	Phoenix	Maricopa	4,970,848	8.1%	10.6	33.3	24.5	24.0	74.5	45.6	52.0	77.8	45.6	1.9	22.4	77.8	22.6	1.9	23.2	77.8	23.5	2.5	27.3	77.8	23.9
West	3B	CA	Sacramento	Sacramento	29,832,102	48.7%	18.0	11.6	35.0	36.6	27.0	51.2	78.1	28.2	51.2	2.3	33.6	28.2	25.5	2.3	34.9	28.2	26.4	2.9	41.1	28.2	26.9
West	3C	CA	San Francisco	San Francisco	7,694,875	12.6%	17.1	8.9	36.4	34.1	21.5	51.2	72.4	22.5	51.2	2.1	31.2	22.5	25.5	2.1	32.4	22.5	26.4	2.7	38.1	22.5	26.9
West	4C	OR	Portland	Clackmas	7,844,547	12.8%	42.4	2.4	40.7	88.8	8.2	60.7	168.7	8.6	60.7	4.9	72.7	8.6	30.2	4.9	75.5	8.6	31.4	6.4	88.8	8.6	31.9
West	5B	CO	Denver	Denver	10,934,600	17.8%	59.2	5.4	39.6	192.7	18.4	62.4	232.1	19.2	62.4	7.1	100.0	19.2	31.0	7.1	103.9	19.2	32.2	9.2	122.2	19.2	32.8
				Total	61,276,972	100%																					
				Pop Wgt Avg			27.8	10.7	35.9	69.8	26.2	54.0	114.3	27.4	54.0	3.4	49.3	27.4	26.8	3.4	51.2	27.4	27.9	4.4	60.2	27.4	28.4
				Arithmatic Average			39.6	5.6	38.9	105.2	16.0	58.1	157.7	16.8	58.1	4.7	68.0	16.8	28.9	4.7	71	16.8	30	6.1	83	16.8	31

Emission

		Main Heating Fuel Type					Geothermal (with electric Aux Heater)			Heat Pump (with electric Aux Heater)			Electric (with central AC)			Natural Gas (with central AC)				Propane (with central AC)				Oil (with central AC)			
Cen Regic	Clm Zone	State	City	County	Population	P.W.F.	Heat Lb	Cool Lb	HW Lb	Heat Lb	Cool Lb	HW Lb	Heat Lb	Cool Lb	HW Lb	Heat Lb	Heat Lb	Cool Lb	HW Lb	Heat Lb	Heat Lb	Cool Lb	HW Lb	Heat Lb	Heat Lb	Cool Lb	HW Lb
West	2B	AZ	Phoenix	Maricopa	4,970,848	8.1%	1,536.4	4,846.3	3,557.1	3,492.0	10,836.6	6,624.9	7,554.8	11,317.6	6,624.9	275.6	3,061.2	11,317.6	3,091.4	275.6	3,564.5	11,317.6	3,597.9	357.7	4,579.4	11,317.6	4,002.1
West	3B	CA	Sacramento	Sacramento	29,832,102	48.7%	2,618.6	1,681.7	5,088.5	5,322.3	3,921.2	7,449.9	11,350.8	4,094.8	7,449.9	329.0	4,599.4	4,094.8	3,483.5	329.0	5,355.6	4,094.8	4,054.2	427.1	6,880.4	4,094.8	4,509.7
West	3C	CA	San Francisco	San Francisco	7,694,875	12.6%	2,485.0	1,300.9	5,290.6	4,959.9	3,132.9	7,449.9	10,532.0	3,273.2	7,449.9	305.6	4,267.6	3,273.2	3,483.5	305.6	4,969.3	3,273.2	4,054.2	396.7	6,384.1	3,273.2	4,509.7
West	4C	OR	Portland	Clackmas	7,844,547	12.8%	6,160.6	352.4	5,915.1	12,907.4	1,199.1	8,832.6	24,525.1	1,252.5	8,832.6	711.4	9,937.7	1,252.5	4,131.9	711.4	11,571.6	1,252.5	4,808.9	923.5	14,866.1	1,252.5	5,349.1
West	5B	CO	Denver	Denver	10,934,600	17.8%	8,608.9	778.2	5,756.5	28,014.3	2,668.7	9,066.4	33,754.6	2,787.2	9,066.4	1,035.4	13,677.6	2,787.2	4,237.5	1,035.4	15,926.3	2,787.2	4,931.8	1,344.0	20,460.6	2,787.2	5,485.8
				Total	61,276,972	100%																					
				Pop Wgt Avg			4,036.4	1,559.2	5,214.7	10,148.6	3,811.2	7,848.4	16,624.4	3,980.4	7,848.4	496.7	6,736.3	3,980.4	3,669.2	496.7	7,843.8	3,980.4	4,270.4	644.8	10,077.0	3,980.4	4,750.1
				Arithmatic Average			5,751.5	810.5	5,654.1	15,293.9	2,333.5	8,449.6	22,937.2	2,437.6	8,449.6	684.1	9,294.3	2,437.6	3951.0	684.1	10,822	2,437.6	4,598	888.1	13,904	2,437.6	5,115