Performance Comparison of Residential Heating Systems: Energy, Economics, Emissions, and Comfort

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This research project was conducted by Newport Partners LLC of Davidsonville, MD. Newport Partners performs technical, regulatory, and market research and analysis related to the built environment, with a specific focus on the energy performance of buildings and building systems.

Executive Summary

Building professionals and home owners face a myriad of options for home heating systems. Traditional furnaces and boilers, high efficiency models, heat pumps (both air-source and ground-source), and even hybrid heat pump / propane furnace systems are all options. Sorting out the best choice for a home requires consideration of system costs, efficiency levels, energy rates, comfort levels, the severity of the climate, and any applicable incentives or credits. Carbon emissions are evolving as another critical system characteristic, whether the emissions result from combusting a fossil fuel on-site or from an upstream electric power generation plant.

When considering residential heating systems on a national basis, the importance of these issues is even greater. America's 132 million housing units are responsible for 22% of the nation's total energy use each year, while generating 21% of the nation's carbon emissions.[1] Residential heating systems present a unique and high impact opportunity to influence existing homes' energy performance and carbon emissions, because they are replaced on a regular interval and represent the largest energy end-use in the home in much of the country.

At a time when energy prices are rising, new technologies are emerging in the residential market, and programs and regulations are developing to recognize high performance homes, this study provides unique insights into the performance of home heating systems. This 2013 release of the study updates the previous report (2011) with more current energy prices (2012 data) from the U.S. Energy Information Administration. In analyzing 15 heating systems in 20 different locations across the U.S., the study allows comparisons of key metrics such as annual energy costs, CO_2 emissions, comfort, and simple paybacks for higher first cost, more efficient systems. The heating systems assessed include mainstream system types such as furnaces, boilers, and air-source heat pumps, as well as less common options including hybrid heat pump-propane furnace systems and ground-source heat pumps. The energy sources are electricity, heating oil, and propane, and most of the systems are evaluated at a high efficiency and a standard efficiency level. Each of these systems is analyzed in a typical new U.S. home as well as a typical existing home, so that the results speak to new construction as well as options for heating system replacements. Due to the extensive number of variables involved (e.g. efficiency ratings, energy costs, system costs, prototype house characteristics), the study followed a detailed methodology that treated such variables in a consistent and logical manner.

The findings reveal that system selection is a balance of several factors. For instance, the lowest first cost system for new homes – a high efficiency propane furnace with standard efficiency central A/C – has roughly equivalent annual energy costs to the standard efficiency air-source heat pump (within $50 of each other in the Cold Climate zone). However, this air-

[1] U.S. EIA Annual Energy Outlook 2013. U.S. Department of Commerce's American Housing Survey, 2011.

source heat pump (ASHP) also costs about $980 more up front and emits about 1.5 times the quantity of CO_2 emissions in heating mode as the high efficiency propane furnace. In another example, the attractive energy costs for ground-source heat pumps (GSHPs) must be weighed against a significantly higher first cost compared to other high efficiency alternatives such as a hybrid ASHP propane furnace system (i.e., an ASHP with 95 AFUE propane furnace backup) or a 95 AFUE propane furnace. In fact, selecting a GSHP system over a 95 AFUE propane furnace for a new home in the Cold Climate results in about $19,900 more in first costs, and 19 years are needed to recoup this initial investment through energy savings.

A comfort study using U.S. Department of Energy software quantifying heating system supply temperatures across the heating season provides a strong argument for the comfort of propane forced-air furnaces versus standard efficiency ASHPs. The study shows that ASHP supply temperatures drop to levels which may feel less comfortable at least 60% of the time in the mixed-humid and cold climate locations evaluated, and up to 20% of the time even in hot climates.

Significantly, across all cases evaluated, the lowest first cost system is consistently a propane system. Some systems emerge as strong candidates for applications in new and/or existing homes due to a combination of high energy efficiency, reasonable first costs, reasonable energy rates, and better carbon emissions than competing systems. For instance, the graph below evaluates different heating and cooling system replacement options for an existing home in the Cold Climate zone. It is assumed that the main replacement system under consideration is a standard efficiency air-source heat pump.

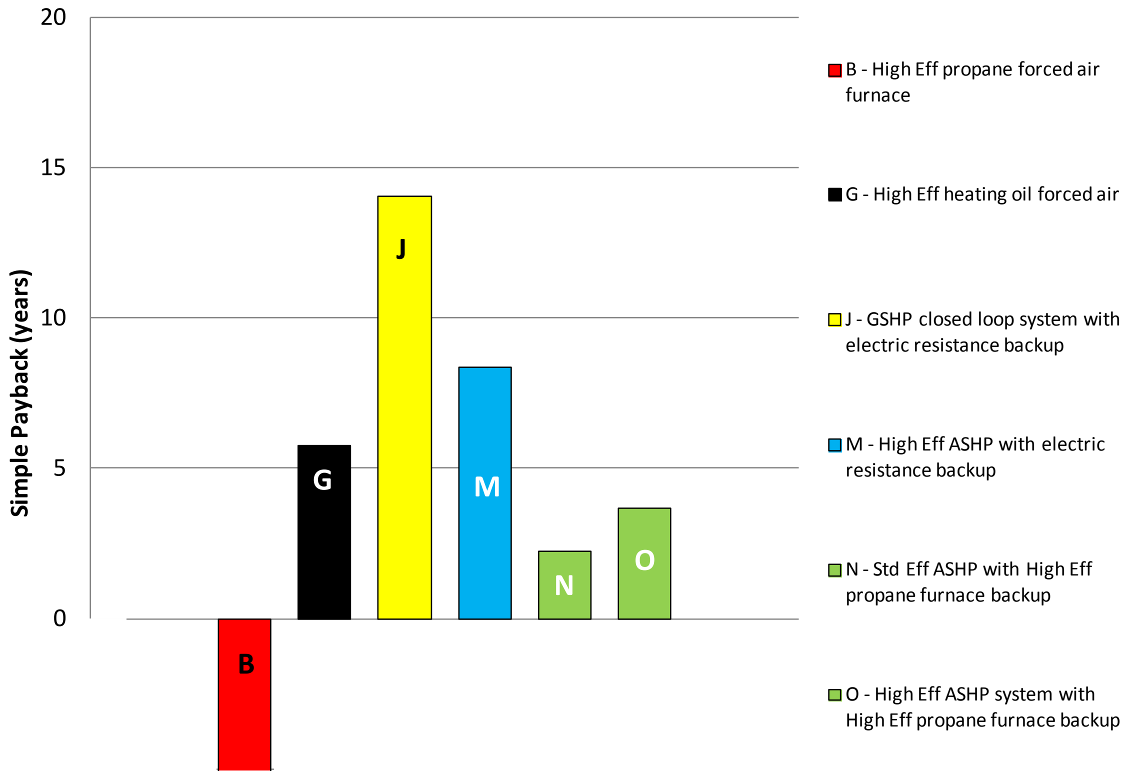

Figure ES1: Simple Payback of Various Heating and Cooling Systems for Cold Climate Existing Homes, assuming a Standard Efficiency Air-Source Heat Pump as the Baseline Replacement System.

In this scenario, a high efficiency propane furnace coupled with a standard central A/C has both lower first cost and lower energy costs compared to the baseline ASHP system, and thus offers an immediate payback.

The carbon emissions from heating system operation show significantly lower emissions from high efficiency propane-based systems and hybrid heat pump propane furnace systems. Air-source heat pumps experience much higher emission rates, especially in the coal-based Midwest, due to less efficient operation at colder temperatures. Considering these findings along with the system replacement scenario shown above, excellent opportunities exist to simultaneously improve efficiency and lessen the environmental footprint in existing homes.

This report is available in PDF form at www.buildwithpropane.com.

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Introduction

Builders, contractors, and homeowners today face a myriad of options for home heating systems. Traditional furnaces and boilers, high efficiency models, heat pumps (both air-source and ground-source), and even hybrid heat pump propane furnace systems are all options. Sorting out the best choices requires taking a close look at system costs, efficiency levels, energy rates, comfort considerations, the severity of the climate, and any applicable incentives including tax credits. In addition to these considerations, one other factor is more important now than ever before: how "green" a system is – especially in terms of the carbon emissions which result from its operation.

Beyond homeowners and builders, energy and environmental advocates also have a keen interest in the energy/environmental performance of residential heating systems. Collectively, America's 132 million housing units have a tremendous impact on the nation's energy consumption and carbon emissions, representing 22% and 21% of the nation's total, respectively. Residential heating systems are generally replaced on a regular interval (~12-18 years), and heating system replacements far outweigh the number of new home installations. This means that there exists an ongoing opportunity to positively affect the energy and environmental performance of residential heating systems in America's homes. This is important to note given that most housing characteristics which impact heating energy use are more challenging to alter after the initial construction of the home (e.g. wall insulation, foundation insulation, duct location). Heating system efficiency upgrades represent a unique and high impact opportunity.

This research project examined the performance of 15 heating systems in 20 different locations across the U.S. The 15 heating systems included mainstream types of units and fuel sources, as well as a few less common systems. The heating systems were analyzed in terms of their first cost, energy cost, emissions, and simple payback. "Energy cost" is defined as the cost for heating and cooling energy within this study. Due to their high variability, maintenance costs were not considered. Systems were evaluated for new homes as well as retrofits in existing homes. The study was conducted according to a detailed research methodology which created a consistent analysis framework, and also utilized third-party data for most inputs into the analysis.

2013 Analysis Update

This report, referred to as the "2013 Analysis Update," is the third update to the original study, which was released in June 2009 and updated in 2010 and 2011. This update builds upon the 2011 version through several improvements:

- New comfort study component that quantifies heating supply temperatures of air-source heat pumps versus propane forced-air furnaces across multiple climates.
- Improved efficiency levels in standard propane and heating oil heating equipment, based on recent U.S. Department of Energy adjustments to the minimum equipment efficiency levels permitted, and reduced energy use associated with these efficiency improvements.
- New residential energy rates for propane, heating oil, and electricity based on the latest calendar year data available from the U.S. Energy Information Administration (2012)
- Revised installed costs of systems based on most recent industry data
- Updated emissions factors associated with electricity and propane energy consumption, based on the most recent U.S. Environmental Protection Agency data

These changes affect the expected energy consumption of the homes, the cost of that energy used, and the resultant economics of system selection. Higher energy prices place a greater emphasis on the economic benefits of energy saved by high efficiency equipment. Additionally, the new comfort study component provides rich data on the expected supply temperatures of electric air-source heat pumps as compared to propane forced-air furnaces - quantifying the percent of heating equipment run time that is expected to feel cool and hence, uncomfortable to occupants across multiple climate zones. With all facets of the study affected by these changes, the 2013 Analysis Update provides new information on methodology, comfort, economics, emissions, and energy use associated with the various systems analyzed.

It should be noted that the 2013 Analysis Update does not contain a running discussion of how the research results differ or may have changed from previous versions of the study. This approach was adopted because it is PERC's intent to make the study as up to date as possible, and its findings already offer a rich set of analyses allowing readers to compare different HVAC systems in a variety of ways. As PERC continues to update this study in the future, each update will continue to show a robust analysis of residential heating systems using current energy pricing, building characteristics, and system pricing to make the study's findings valuable to construction professionals.

Methodology and Background Data

A detailed methodology was developed to guide this analysis of a broad array of heating systems across multiple locations in the U.S., for both new and existing homes. This methodology provided for a consistent approach to the analysis across the many variables which were involved. A basic overview of the analysis methodology is shown below in Figure 1.

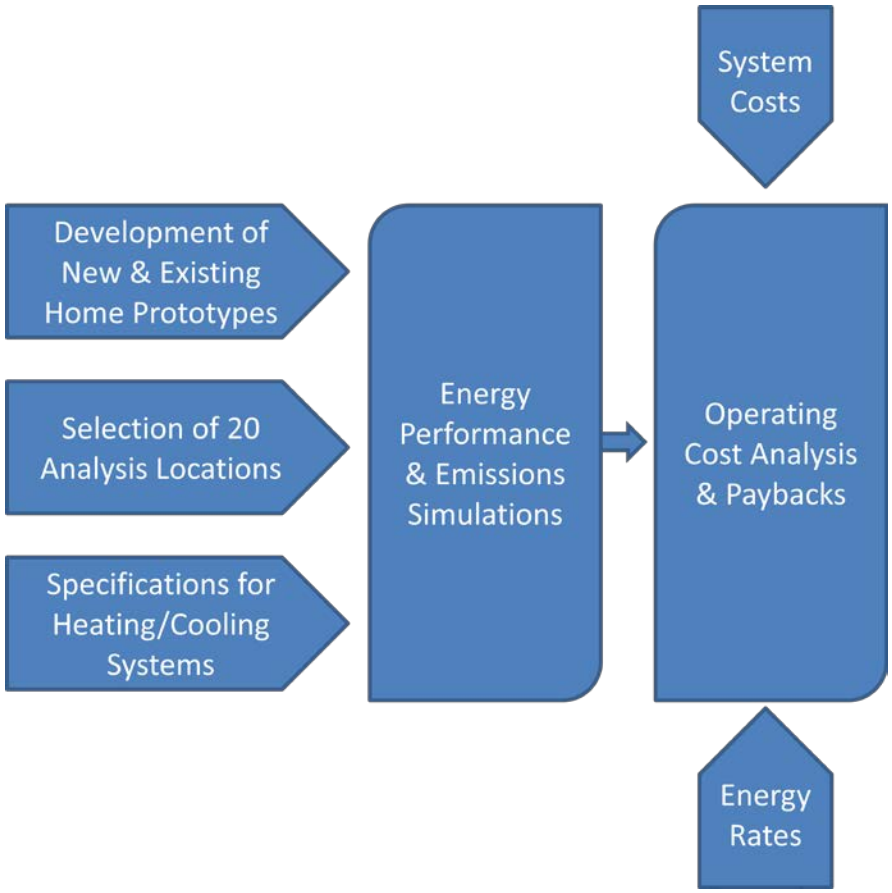

Figure 1: Analysis Methodology and Sequence of Analysis

As indicated in Figure 1, the main sections of the methodology fall into these categories:

Development of House Prototypes

The analysis called for assessing heating system performance in both new and existing homes. To facilitate this, prototype home designs were developed using historical housing characteristics data. This data helped to define a "typical" house in terms of square footage, number of stories, foundation type, window area, insulation values, duct location, air tightness, etc. Characteristics such as foundation type, insulation levels, and window specifications were varied by location. Also, housing characteristics for the existing home prototype were based roughly on a 1973 home, as this was the median date of construction for the existing U.S. housing stock when this analysis was initially conducted in 2008-2009.

The primary data sources used for the development of house prototypes were U.S. Energy Information Administration's (EIA) Residential Energy Consumption Survey (RECS), data from U.S. DOE's Building America program, U.S. Census Bureau, and current building codes such as the 2009 International Energy Conservation Code (IECC), which has been adopted as the residential energy code for the majority of U.S. States.

Table 1 below illustrates the basic characteristics of both the new and existing home prototypes.

Building Characteristic	Existing Home Prototype	New Home Prototype
Above-Grade square footage	1,660 SF	2,402 SF
Number of stories	1	1 or 2, depending on location
Foundation Type	Slab, crawlspace, and basement – depending on location	Slab or basement – depending on location
Window Area	15% of above-grade gross wall area	15% of above-grade gross wall area
Attic R-Value	R-7 up to R-22, depending on location	R-30 up to R-49, depending on location
Wall R-Value	R-9	R-13 to R-21, depending on location

Table 1: Characteristics of Existing and New Prototype Homes

In general, the smaller size of the existing homes was outweighed by the lower insulating values of building shell components, which typically resulted in higher heating loads and larger capacity HVAC systems for the existing homes.

Selection of Analysis Locations

A total of 20 analysis locations were selected from across the U.S. The locations span the majority of the climate zones typically referenced in U.S. building codes, from warm climates to cold. The majority of the locations are concentrated within the Cold Climate zone, where heating energy use and associated costs can be a significant concern for home owners. A map of the analysis locations is shown below in Figure 2.

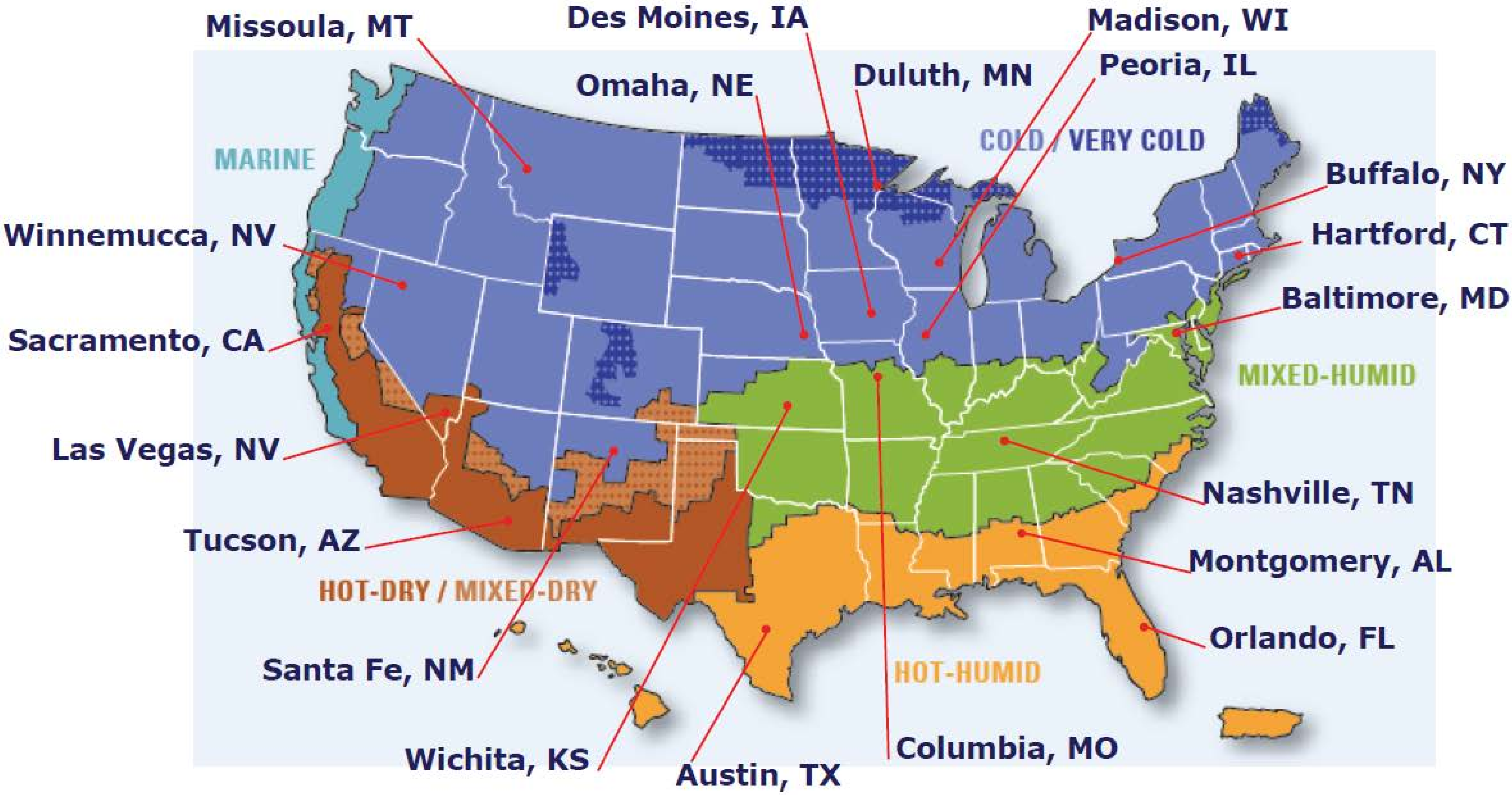

Figure 2: Analysis Locations. *Map Source: U.S. DOE Building America Program: "Guide to Determining Climate Regions by County," 2007.*

Specifications for Heating/Cooling Systems

For each system, specific parameters such as efficiency levels were determined to define the system for the energy modeling. For "standard" equipment, the system efficiency levels were generally based on federally regulated minimum levels (e.g. an 80% efficient propane furnace – also known as an 80 "AFUE" furnace – was the federal and market minimum as of 2013). Because ground-source heat pumps (GSHPs) are not addressed as a separate product class within federal regulations, their efficiency levels were based on Tier 1 ENERGY STAR criteria. In the case of "high efficiency" equipment, system efficiency ratings were based on the thresholds set by the federal tax credits for energy efficiency, which were included within the American Taxpayer Relief Act of 2012. In most cases, these efficiency levels were adopted into the study to define a high efficiency system, such as a 95 AFUE propane furnace. In one case, the efficiency level of a system was adjusted because it was very difficult to identify such equipment in the marketplace at the specified efficiency using industry equipment databases such as the AHRI equipment directory[2]. So for this particular system, a high efficiency heating oil boiler, the efficiency rating used in the study was adjusted to reflect products widely available in the marketplace. The heating systems examined in the study along with their associated efficiency ratings are shown below in Table 2.

Additionally, overall system design parameters were also developed for the analyses. The capacity of each heating system (e.g., a 48 MBH furnace) was based on a Manual J load calculation for each home in the analysis, as determined using Right-J software which utilizes the 8th edition of the Manual J load analysis procedure. Manual J is the residential industry's standard analysis method for determining the heating and cooling loads for a home. Over-sizing limits for the capacity of the systems (e.g., how much larger the furnace should be than the exact heating design load) was based on common industry guidance from groups such as the Air-Conditioning Contractors of America (ACCA) and the ENERGY STAR Homes program.

System J, the traditional GSHP system with backup electric resistance heating, was sized to cover 100% of the cooling load, and 80% of the heating load, with the remaining 20% covered by the electric resistance heat. Sizing the system to cover most, but not all, of the heating load helps to reduce the first costs associated with the loop field. For System K, the hybrid GSHP system with high efficiency propane furnace backup, the heat pump was first sized to accommodate 100% of the cooling load, and as close as possible to 40% of the heating energy load. This sizing guidance was designed to further reduce both the loop field size and the associated high first cost of the GSHP system. A 95 AFUE propane furnace was then sized to cover 100% of the heating *design* load, and 60% of the heating *energy* load.

[2] Air-Conditioning, Heating, and Refrigeration Institute equipment directory: www.ahridirectory.org/

Other components of each heating system were also specified, including general characteristics of the distribution system (forced-air ducts or hydronic tubing). And in the case of GSHPs, a loop field design was developed using common GSHP design software (Right-Radiant) to estimate the depth of vertical wells and the total length of piping. A vertical well system was assumed in the loop field analysis (as opposed to another configuration such as horizontal) because it was a safe assumption that nearly all building sites can accommodate a vertical well system, whether for new construction or retrofit and regardless of lot size. In the absence of site-specific data, average values were assumed for items such as soil conductivity (1.0 Btu/h*ft*°F). The system characteristics and specifications were input into both the energy modeling software (REM/Rate) as well as the cost estimating phases of the project.

Another set of assumptions deals with the system configurations with respect to cooling. In the new homes analysis, it was assumed that each of the 15 systems would include both heating *and* cooling functions. So a propane furnace, for example, was also coupled with a central A/C unit. This was done to create a level playing field in terms of first costs, since heat pump systems (air-source or ground-source) provide both heating and cooling in a single unit. To treat these systems fairly in terms of first cost, heating-only systems like a furnace were combined with a cooling system, the cost of which was included in the first cost estimate for that system. The only exception to this treatment of cooling equipment was for two locations with very modest cooling demands: Duluth, MN and Missoula, MT. In these locations, no central cooling system was included.

In existing homes, the assumptions on first cost for new equipment were different. Unless an air-source heat pump was designated as the system for replacement in the existing home analysis, it was assumed that a heating system change-out was limited to heating *only*, so no first cost was applied for a cooling system. For example, the first cost associated with installing a new high efficiency propane furnace in Buffalo, NY was limited to the cost of the furnace, without including the cost of a new cooling system as well. Also in existing homes, it was assumed that the distribution system for a new heating system, whether central ducts or hydronic tubing, was already in place. Thus the first cost for a new heating system in an existing home did not incorporate costs for purchasing and installing distribution system components.

Finally, heating systems which rely on heating oil were only evaluated in those markets where this energy source is most common (the Northeast U.S.).

System Type	Heating System Description*	System Efficiency Ratings
Furnaces* (with central A/C)	• Standard Efficiency Propane • High Efficiency Propane • Standard Efficiency Heating Oil • High Efficiency Heating Oil	• 80 AFUE & 13 SEER A/C • 95 AFUE & 13 SEER A/C • 83 AFUE & 13 SEER A/C • 95 AFUE & 13 SEER A/C
Boilers* (with central A/C)	• High Efficiency Propane with Forced-Air (water/air heat HX) • High Efficiency Heating Oil w/ Forced-air (water/air HX) • Standard Efficiency Propane Hydronic with Baseboard Radiant • High Efficiency Propane Hydronic with In-Floor Radiant • High Efficiency Heating Oil Hydronic with In-Floor Radiant	• 95 AFUE & 13 SEER A/C • 85 AFUE & 13 SEER A/C • 82 AFUE & 13 SEER A/C • 95 AFUE & 13 SEER A/C • 85 AFUE & 13 SEER A/C
GSHP	• GSHP Closed Loop System with Electric Resistance Backup	• EER=14.1; COP=3.3
ASHPs	• Standard Efficiency ASHP with Electric Resistance Backup • High Efficiency ASHP with Electric Resistance Backup	• 13 SEER; 7.7 HSPF • 15 SEER; 8.5 HSPF
Hybrids	• GSHP Closed Loop System with High Efficiency Propane Furnace Backup • Standard Efficiency ASHP with High Efficiency Propane Furnace Backup • High Efficiency ASHP with High Efficiency Propane Furnace Backup	• EER=14.1; COP=3.3; 95 AFUE • 13 SEER; 7.7 HSPF; 95 AFUE • 15 SEER; 8.5 HSPF; 95 AFUE

Table 2: Heating Systems and Efficiency Ratings. *Heating-only systems (boilers and furnaces) were combined with a standard central cooling system in all locations except Missoula, MT and Duluth, MN for the purpose of cost estimating systems in new homes and assessing overall system energy costs.

Emissions Factors

Beyond energy performance, another very important performance metric of residential heating systems is their environmental footprint in terms of carbon emissions. The CO_2 emissions which are associated with the operation of each heating system in each location were analyzed as part of this study. This analysis was conducted through the use of "emissions factors" which were applied to the energy consumption projections developed through building energy simulations performed in REM/Rate. Propane and heating oil emissions factors were sourced from U.S. EPA's Fuel Emission Coefficients sourced from the Voluntary Reporting of Greenhouse Gases Program.

Electricity emissions factors were sourced from U.S. EPA's Emissions & Generation Resource Integrated Database (eGRID 2012 Version 1.0). These emission factors provided a multiplier to estimate the emissions which result from the production of a unit of electricity in any given state. The electricity emissions factor accounts for the mix of fuel sources used to generate electricity in that state (e.g., coal, nuclear, hydro) and develops the state's emission factor based on this blend of sources. For this reason, a unit of electricity in a state with a high proportion of hydropower-generated electricity results in lower emissions than a unit of electricity in a state heavily reliant on coal-generated electricity.

Energy Rates

While the energy simulations were used to develop projections of the energy consumption of each system in each location, actual energy rates (e.g., cents per kWh of electricity) were needed to develop energy cost data. Energy rates used in the study were derived from market data which is regularly collected and made available by the U.S. Energy Information Administration (EIA).

At the time of the 2013 Analysis Update, data from the U.S. Energy Information Administration for the 2012 calendar year was obtained for deriving estimates of residential rates for heating oil, propane, and electricity. EIA's energy rate data is arranged by geographic regions such as states, regions, and other geographic groupings, which allowed this study to develop rates for each location in the study as a function of the state or region/district. Electricity prices were determined for each state as the average of monthly electricity prices across the entire year. Heating oil and propane prices were estimated based on historic ratios of annual average monthly prices to annual average weekly heating season prices, applied to 2012 annual average weekly heating season prices. Where state level data were not available, regional pricing was used as a proxy.

The results of this effort – which are the energy rates used in the analysis – are shown in Table 3. Heating oil prices are only provided for those locations (Hartford, CT and Buffalo, NY) where these systems were analyzed.

City	State	Residential Propane Price ($/gal)	Residential Heating Oil Price ($/gal)	Residential Electricity Price ($/kWh)
Montgomery	AL	2.46	N/A	0.11
Tucson	AZ	2.70	N/A	0.11
Sacramento	CA	2.70	N/A	0.15
Hartford	CT	2.81	3.72	0.17
Orlando	FL	2.85	N/A	0.12
Des Moines	IA	1.44	N/A	0.11
Peoria	IL	1.71	N/A	0.11
Wichita	KS	1.71	N/A	0.11
Baltimore	MD	3.14	N/A	0.13
Duluth	MN	1.60	N/A	0.11
Columbia	MO	1.65	N/A	0.10
Missoula	MT	2.13	N/A	0.10
Santa Fe	NM	2.46	N/A	0.11
Las Vegas	NV	2.70	N/A	0.12
Winnemucca	NV	2.70	N/A	0.12
Buffalo	NY	2.88	3.80	0.18
Omaha	NE	1.35	N/A	0.10
Nashville	TN	1.71	N/A	0.10
Austin	TX	2.46	N/A	0.11
Madison	WI	1.54	N/A	0.13
Average		**$2.24**	**$3.76**	**$0.12**

Table 3: Energy Rates used in the Analysis.

Scope Limitations

This study covered a wide array of heating systems, new and existing homes, and locations throughout the U.S. The scope did not cover several issues however, including financial incentives or tax credits for systems, the ability of some systems to provide domestic hot water supply in certain configurations, or costs for maintenance. Incentives and credits for systems were not included in the analysis because federal, state, and utility-based incentives vary widely, are temporary measures subject to change, and will have different financial impacts for individuals depending on their financial and tax status. The ability of some systems to produce domestic hot water was not assessed because the vast majority of heating systems do not provide this function, and even among those systems capable of providing hot water, they are not always configured to do so. Even in cases where a system is capable of providing hot water and is configured to do so, the efficiency and energy-savings benefit of this system depends heavily on the actual hot water demand in the home, which may vary widely. Further, system maintenance was not included in the analysis of system costs because it is applied inconsistently in the real world, and its overall significance relative to first costs and heating/cooling energy costs is modest. For this reason "energy costs" within the context of this report excludes maintenance and only includes heating and cooling energy.

Finally, it should be noted that sophisticated energy modeling simulation tools, such as REM/Rate which was used for this analysis, are quite useful for predicting *relative* performance differences across different system options. Predicting *actual* performance, or how a building performs in the real world, is not as exact. The actual energy performance of a home varies (sometimes quite significantly) as a function of such factors as occupancy behavior, local climatic conditions, building geometry and materials, energy rates, the quality of the system installation, and system maintenance. Due to the number of variables involved, the results of this study are best taken as relative comparisons across systems in different locations and not as absolute predictors.

Key Findings

Given the breadth of this analysis, with hundreds of energy simulations conducted and each simulation generating data of interest, an extensive data set was generated by this study. This section extracts key findings and trends from this data set, organized into First Costs, Energy Costs, Paybacks, Comfort, and Emissions. Many of the findings concentrate either on the Cold Climate or the Midwest region, as these areas contain the most data in the analysis and represent most of the country's heating-dominated areas (see Figure 2).

First Costs

Equipment and installation costs (referred to as "First Costs"), for both new installations and system change-outs in existing homes, were estimated for each system using industry cost estimating data with location factors. As mentioned above, in the case of the new home analysis, the system cost included both heating and cooling equipment (in all but two locations). In the case of heat pumps, these functions were covered with a single heat pump system, whereas for boilers and furnaces a separate central A/C unit was added.

The cost components included in the estimate of a system's first cost included the following:

- Equipment cost, as a function of equipment type and system size (e.g., 48 MBH)

- Equipment installation cost
- Distribution system cost (e.g., forced-air ducts or hydronic tubing for hot water systems) for new construction applications
- Distribution system installation cost, for new construction applications
- Loop field cost for GSHP systems, including drilling costs, pump costs, and tubing costs

Most of these cost estimates were available through R.S. Means 2013 Mechanical Cost Data and R.S. Means 2013 Residential Cost Data. Location factors were applied to cost data to reflect labor costs in particular regions. For those cost data which were not available from industry cost estimating resources, independent surveys were conducted to obtain average costs. Such surveys including researching pricing of equipment through online resources, or in the case of GSHP drilling costs involved pricing data obtained through directly contacting several dozen contractors.

For the 15 systems analyzed, the average first cost of each system across all 20 locations for new homes is shown in Table 4.

System*	**Average Weighted First Costs of System**
A - Standard efficiency (80 AFUE) propane forced-air furnace & 13 SEER A/C	$12,792
B - High efficiency (95 AFUE) propane forced-air furnace & 13 SEER A/C	$12,694
C - High efficiency (95 AFUE) propane boiler with forced-air (water/air HX) & 13 SEER A/C	$19,506
D - Standard efficiency (82 AFUE) propane boiler system w/ baseboard radiation & 13 SEER A/C	$27,242
E - High efficiency (95 AFUE) propane boiler system with in-floor radiant heat & 13 SEER A/C	$29,068
F - Standard efficiency (83 AFUE) heating oil forced-air furnace & 13 SEER A/C	$13,818
G - High efficiency (95 AFUE) heating oil forced-air furnace & 13 SEER A/C	$15,195
H - High efficiency (85 AFUE) heating oil boiler with forced-air (water/air HX) & 13 SEER A/C	$18,936
I - High efficiency (85 AFUE) heating oil boiler system with in-floor radiant heat & 13 SEER A/C	$29,078
J - GSHP closed loop system (14.1 EER; 3.3 COP) with electric resistance backup	$31,682
K - GSHP closed loop system (14.1 EER; 3.3 COP) with high efficiency (95 AFUE) propane furnace backup	$25,941
L - Standard efficiency (13 SEER; 7.7 HSPF) ASHP with electric resistance backup	$13,658
M - High efficiency (15 SEER; 8.5 HSPF) ASHP with electric resistance backup	$15,074
N - Standard efficiency (13 SEER; 7.7 HSPF) ASHP with high efficiency propane furnace backup	$15,539
O - High efficiency (13 SEER; 7.7 HSPF) ASHP with high efficiency propane furnace backup	$16,954

Table 4: Average Weighted First Cost for Heating/Cooling Systems of New Homes. *Average weighted system costs across all 20 locations are shown. Note that for the 2 coldest locations, furnace and boiler systems did *not* include a central cooling system.

For the systems listed above, the system costs include heating plus cooling equipment. Thus, all of the first costs for boiler and furnace systems also include a cost for an accompanying central A/C system. The only exception to this is for the two climates (Missoula, MT and Duluth, MN) where cooling systems were not added to furnaces and boilers. The first costs for these two locations are averaged in with the other 20 locations. Weightings were applied to the systems which were not modeled across all climate zones (i.e., systems F, G, H, I, and K) to arrive at a more representative first cost across the 20 locations.

Highlights of the first cost estimates for the 15 systems include the following:

- The 95 AFUE high efficiency propane fired furnace is the least expensive system, among heating oil, ASHP, or GSHP alternatives. The high efficiency propane fired furnace actually achieved a slightly lower first cost than the 80 AFUE standard efficiency propane furnace due to reduced venting costs.
- The higher first cost of the ground-source heat pump (System J) is driven significantly by the cost of the ground loop drilling and materials. Opting for a GSHP system with a high efficiency propane furnace as backup (System K) can be an attractive alternative for a home owner, as it provides the efficiency of a GSHP while reducing first cost by about $5,700, due to a significantly reduced loop field.
- The high efficiency heating oil fired furnace (System G) is more expensive than the low efficiency heating oil fired furnace (System F) unit, despite having a lower cost venting system. This higher first cost is due to a significant price premium for the high efficiency unit material cost versus the standard efficiency unit material cost. Overall, the cost premium for the high efficiency unit is 10%.
- The marginal first cost for upgrading from an air-source heat pump to an air-source heat pump with a high efficiency propane furnace backup (System L vs. N; System M vs. O) is modest, at about 14%. Such a system enables provides a home owner with a built in hedge against energy price volatility by permitting the home owner to switch between fuel sources when financially beneficial.
- The higher first cost for in-floor radiant systems (Systems E and I) is largely driven by the cost of the in-floor hydronic distribution system plus that fact that these homes also incorporate forced-air duct work for central cooling in all but 2 locations.

Energy Costs

Energy costs are the costs of the energy used to provide space heating and cooling to the prototype house. System first costs are not included in energy costs. Energy costs in the study are presented on an annual basis. Table 5 lists the annual energy costs for the heating/cooling systems in new homes in the Cold Climate zone. The data are derived from the analysis for all study locations located in the Cold Climate zone (nine total).

Most of the systems' energy costs are bunched within roughly a $400 band between ~$1,800 and $2,200. Systems beyond this range on the higher side are the standard propane furnace (System A: $2,552); the standard efficiency and high efficiency heating oil furnaces (System F: $3,320 and System G: $2,927); the high efficiency heating oil boiler system with in-floor radiant heat (System H); and the high efficiency heating oil boiler (System I: $2,559). Notably, the four heating oil systems have the four highest annual energy costs across all systems, regardless of equipment efficiency. On the lower end of energy costs, the GSHP system's (System J) annual energy costs are estimated at $1,119, the hybrid GSHP propane furnace system's (System K) energy costs are estimated at $1,729, and the high efficiency propane boiler system with in-floor radiant heat system's (System E) energy costs are estimated at $1,730.

System	Annual Energy Cost
A - Standard efficiency propane forced-air furnace w/ standard A/C	$2,552
B - High efficiency propane forced-air furnace w/ standard A/C	$2,163
C - High efficiency propane boiler with forced-air (water/air HX) w/ standard A/C	$2,163
D - Standard eff. propane boiler system with baseboard radiation w/ standard A/C	$1,974
E - High efficiency propane boiler system with in-floor radiant heat w/ standard A/C	$1,730
F - Standard efficiency heating oil forced-air furnace w/ standard A/C	$3,320
G - High efficiency heating oil forced-air furnace w/ standard A/C	$2,927
H - High efficiency heating oil boiler with forced-air (water/air HX) w/ standard A/C	$3,231
I - High efficiency heating oil boiler system with in-floor radiant heat w/ standard A/C	$2,559
J - GSHP closed loop system with electric resistance back-up	$1,119
K - GSHP closed loop system with high efficiency propane furnace back-up	$1,729
L - Standard efficiency ASHP with electric resistance back-up	$2,114
M - High efficiency ASHP with electric resistance back-up	$1,987
N - Standard efficiency ASHP with high efficiency propane furnace back-up	$1,805
O - High efficiency ASHP with high efficiency propane furnace back-up	$1,759

Table 5: New Home Annual Heating and Cooling System Energy Costs, Cold Climate. Heating Oil analysis is provided only for the two cities analyzed for this fuel type, versus 9 cities analyzed across other fuel types. Average Cold Climate Utility Prices: Propane: $2.11/gal; Electricity: $0.13/kWh; Heating oil: $3.76/gal

The lowest energy cost system is the ground-source heat pump system (System J). This system achieves higher rated performance by utilizing thermal energy from the earth, although the ground loop which makes this possible also results in a significantly higher first cost for the system (Table 4). The tradeoffs between performance and first cost are examined in the section below. Within the GSHP family of options, a more affordable first cost alternative is System K, which has its ground loop sized to cover 40% of the heating energy load of the home, and uses a high efficiency propane furnace to cover the remaining 60%. This system has annual energy costs of $1,729.

Among the systems in the most common energy cost price range ($1700-$2200), the propane system with in-floor radiant heat distribution (System E) and hybrid air-source heat pump/propane furnace systems (Systems N and O) show lower energy costs. In-floor radiant systems perform well due to lower distribution losses and high efficiency equipment; however first costs for such systems are among the highest (see Table4). Hybrid systems utilize electricity for heating (via heat pump operation) during milder outdoor temperatures when heat pumps can provide more heating capacity. When outdoor temperatures grow colder, these systems switch over to a propane furnace system for heating.

While energy costs provide a portion of the economic picture of system selection, they should also be balanced in light of first costs. The lowest energy cost systems shown in Table 5 also happen to be among the highest first cost systems, which begs the question of which system(s) – whether they be low, medium, or high energy cost systems - provide best overall economic value in different scenarios. These issues are explored further in the payback analysis below.

Simple Paybacks

Simple payback is a tool to evaluate how long it will take to “pay back” a higher first cost of a more efficient heating system. In other words, if a homebuyer is willing to spend more money up front for a system which will have lower monthly utility bills, the payback analysis indicates how long it takes for the resulting savings to outweigh the higher first cost. Given the number of heating systems analyzed as well analyses for both new and existing homes, a large number of payback analysis scenarios can be drawn from this study. A selection of payback analyses, which concentrate on common scenarios in new construction and for existing homes, is presented below.

Scenario A: *For a New home, what is the payback for a ground-source heat pump system compared to a more typical high efficiency system, which is assumed to be a 95 AFUE propane furnace with 13 SEER central A/C?*

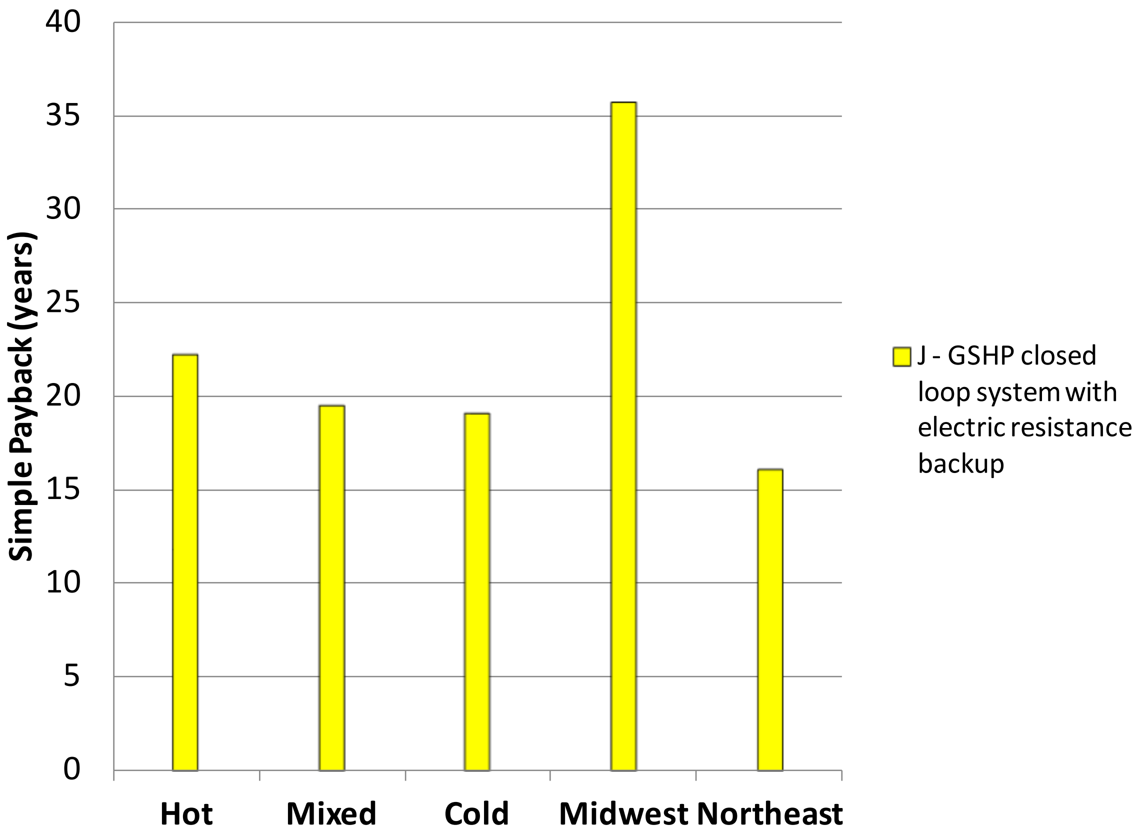

Figure 3: Payback Period for a GSHP System in a New Home Compared to a 95 AFUE Propane Furnace System

The payback scenario in Figure 3 shows that although GSHP systems will generally produce significantly lower heating and cooling bills to condition a home (Table 5), the significantly higher up-front cost can take roughly 16-36 years to recover in the form of energy savings, depending on the climate zone. This payback scenario is based on using building energy simulation software to model the GSHP performance using the manufacturer-rated efficiency level as an input; however, recent studies sponsored by the Department of Energy indicate that the actual coefficient of performance of GSHP systems can be up to 50% less than the rated performance.[3]

It should be noted that this payback analysis reflects both the heating *and* cooling energy costs of the two comparison systems: a GSHP compared to a high efficiency 95 AFUE propane furnace with standard efficiency 13 SEER A/C. So the GSHP system has the "opportunity" to pay back its higher initial cost through both lower heating *and* cooling bills. Even with costs savings through both heating and cooling however, the payback period for a GSHP system

[3] Stecher, D. et al. 2012. *Residential Ground Source Heat Pumps with Integrated Domestic Hot Water Generation: Performance Results from Long-Term Monitoring*. Golden, CO: National Renewable Energy Laboratory.

compared to the high efficiency propane furnace with a standard A/C system may be beyond the timeframe that many homeowners will stay in a home.

<u>Scenario B</u>: For a New home in the Cold Climate, what is the payback for various heating systems compared to an 80 AFUE propane furnace with 13 SEER central A/C?

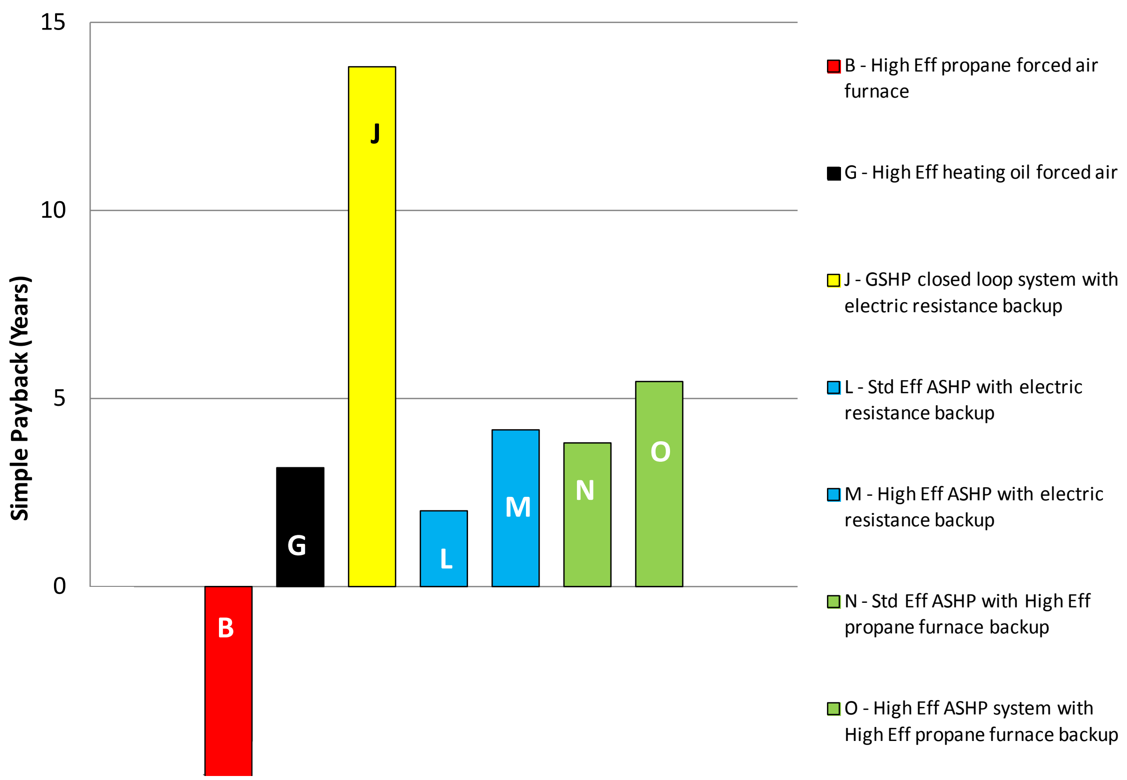

Figure 4: Payback Period for Various Heating Systems in a New, Cold Climate Home Compared to an 80 AFUE Propane Furnace System.

This Cold Climate scenario for new homes shows favorable paybacks, and in once case, an "instant payback", for various systems as opposed to an 80 AFUE propane furnace. Based on lower estimated costs for combustion venting of a 95 AFUE propane furnace versus an 80 AFUE furnace, the 95 AFUE propane furnace is expected to provide not only lower energy costs than the 80 AFUE propane furnace, but also lower first costs, resulting in an instant payback.

Additionally, there are several options that have paybacks of less than 5 years, including both ASHPs (Systems L and M), the high efficiency heating oil furnace (System G), and the standard efficiency air-source heat pump with the high efficiency propane furnace backup (System N). It should be noted that new federal air-source heat pump regulations, which will go into effect in 2015, will require heat pumps in cold climates to be rated at 14 SEER and 8.2 HSPF or better, meaning that System L and System N will be obsolete at that time. System J, which specifies a ground-source heat pump, has the longest payback of the systems evaluated, at 14 years.

Scenario C: For an Existing home in the Mixed Climate or Cold Climate where the homeowner needs to replace a standard efficiency propane furnace, what is the payback for various heating systems assuming that the main system under consideration is a standard 80 AFUE propane furnace?

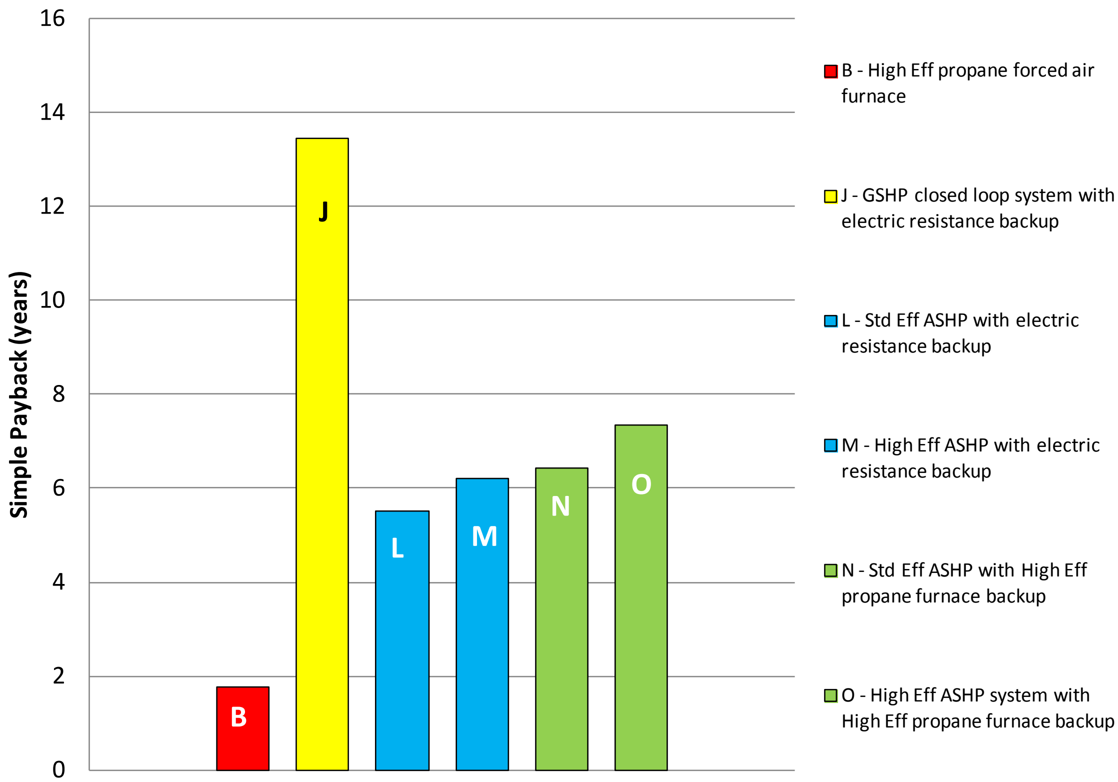

Figure 5: Simple Payback of Various High Efficiency Heating Systems for the Mixed Climate Existing Homes, Assuming Replacement of a Standard Efficiency Propane Furnace, with an 80 AFUE Propane Furnace as the Baseline System.

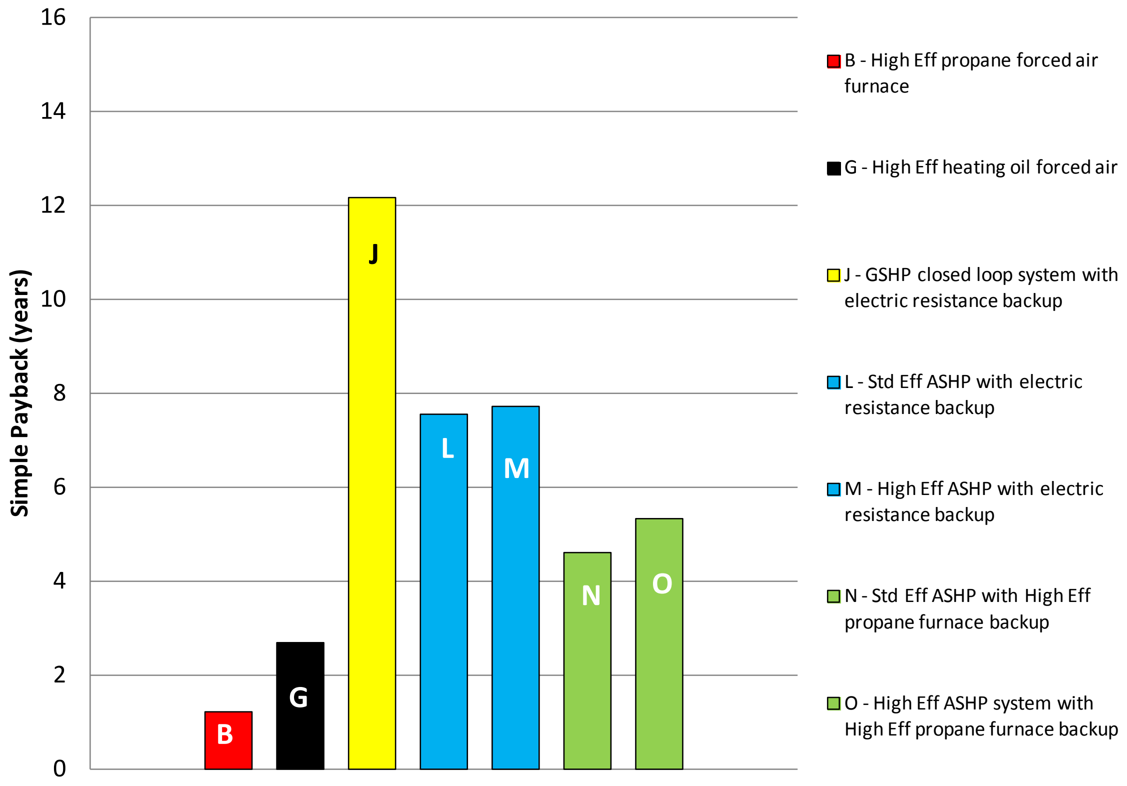

Figure 6: Simple Payback of Various High Efficiency Heating Systems for Cold Climate Existing Homes, Assuming Replacement of a Standard Efficiency Propane Furnace, with an 80 AFUE Propane Furnace as the Baseline System.

This scenario is a common one for many thousands of homes per year that consider an "efficiency upgrade" when replacing an old forced-air furnace. In evaluating this scenario, it was assumed that the existing home has forced-air duct work, a standard efficiency furnace, and associated combustion venting in place. The systems evaluated represent a range of different forced-air systems that could be considered as possible replacements for the home.

Figures 5 and 6 clearly show that when replacing an existing standard efficiency propane furnace, investing in a high efficiency propane furnace is a good option, as it should very quickly - within an average of 1.2 years - result in cumulative heating energy savings which are greater than the added cost for the 95 AFUE propane furnace, in both the Mixed and Cold Climates. The GSHP system provides significant heating energy savings relative to an 80 AFUE propane furnace; however the sizable up-front system costs take over 12 years to recover through reduced heating bills in both the Mixed and Cold Climates. Note that applying potential tax credits, rebates, or other incentives to this scenario would benefit several of the high efficiency systems, as credits are available for multiple system types when used in replacement applications. More information on potential tax credits is found at www.dsireusa.org.

Air-source heat pump systems are less effective change-out options relative to the baseline furnace (or the high efficiency propane furnace), with paybacks of around 6-8 years in the Mixed and Cold Climates. Hybrid systems which couple ASHPs with high efficiency back-up furnaces (Systems O and N) are estimated to have paybacks in the 4-5 year range in the Cold Climate and the 6-7 year range in the Mixed Climate.

High efficiency heating oil furnaces (i.e., 95 AFUE) have a payback of about 3 years in the Cold Climate. Because these heating systems are not typically employed in the Mixed Climate, they were omitted from the Mixed Climate analysis.

Other system replacement considerations which are not quantified in this scenario include comfort preferences (addressed later in the Comfort section), and complications and costs from fuel switching (e.g., tank siting) or a GSHP system (lot and landscaping disturbance from ground loop drilling). Heating oil systems were not considered in the Mixed Climate scenario, as they are not commonly used for residential heating in mixed climates.

Scenario D: For an existing home in the Hot or Mixed Climate where the homeowner is replacing an existing ASHP, what is the payback for heating and cooling system alternatives assuming that the main system under consideration is an 80 AFUE propane furnace with a 13 SEER central A/C?

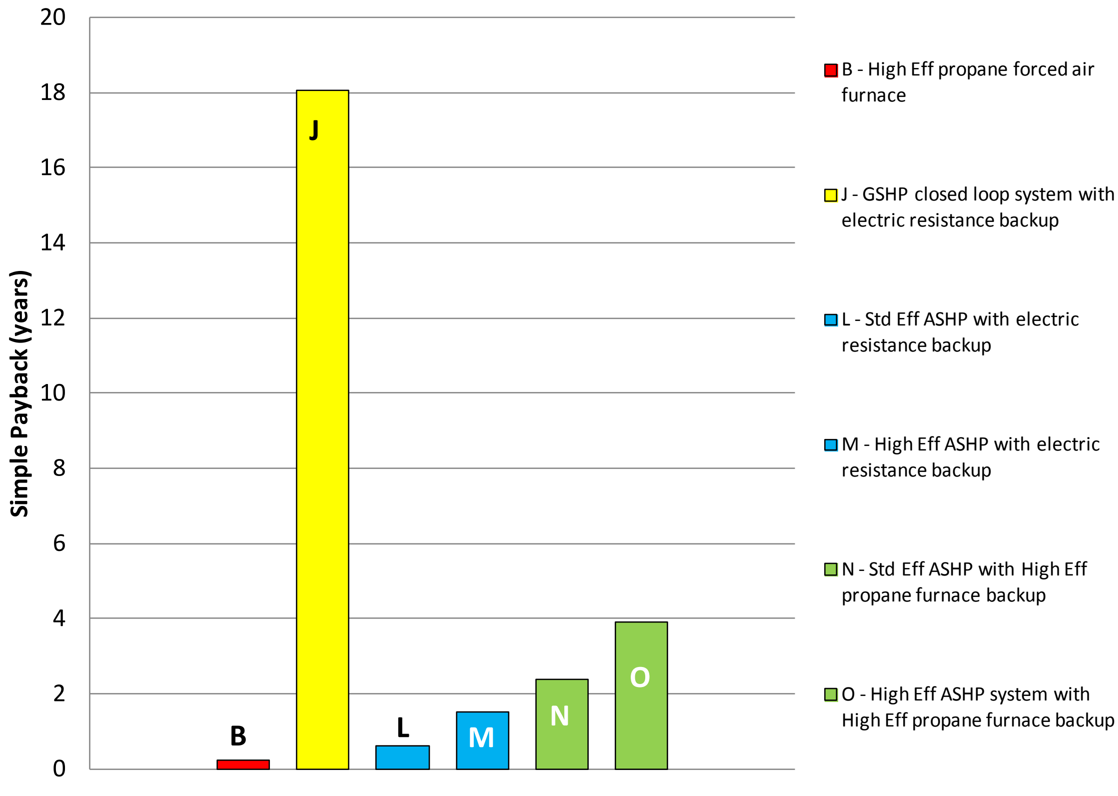

Figure 7: Simple Payback of Various High Efficiency Heating Systems for Hot Climate Existing Homes, Assuming Replacement of an Air-Source Heat Pump, with an 80 AFUE Propane Furnace & 13 SEER A/C as the Baseline System.

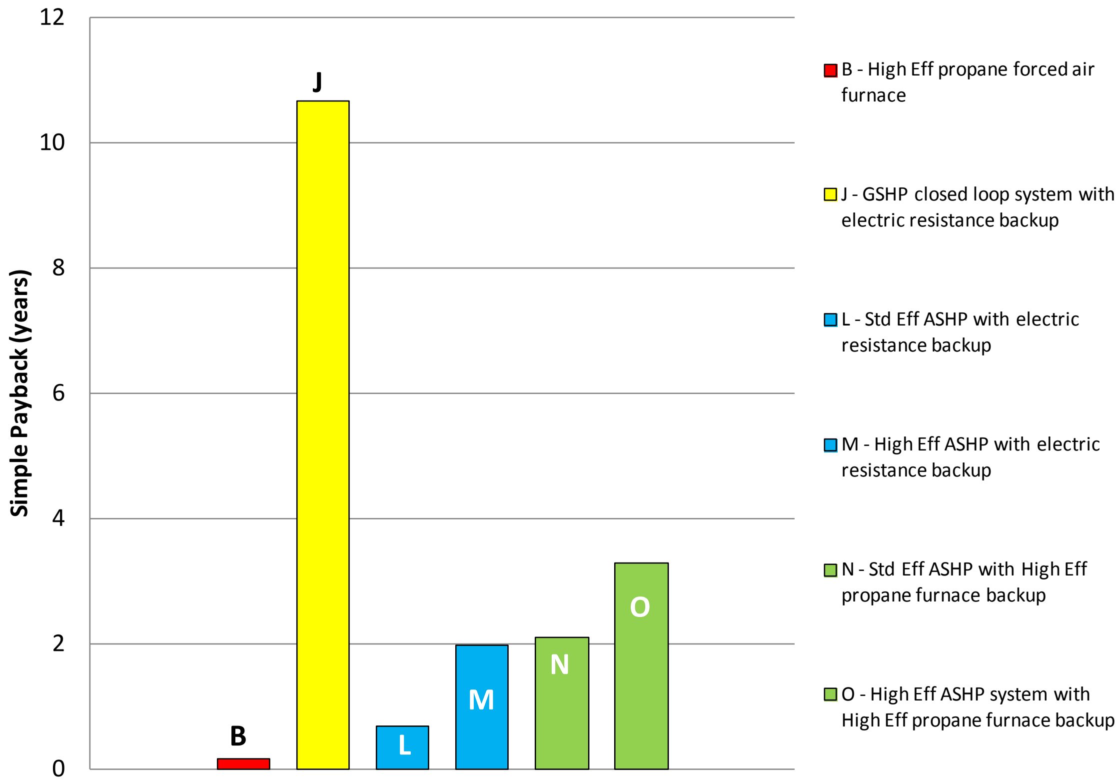

Figure 8: Simple Payback of Various High Efficiency Heating Systems for Mixed Climate Existing Homes, Assuming Replacement of an Air-Source Heat Pump, with an 80 AFUE Propane Furnace & 13 SEER A/C as the Baseline System.

Scenario D is representative of the case of a home owner who is planning to replace an existing air-source heat pump, and is primarily considering a standard efficiency propane furnace & 13 SEER A/C (System A) as the replacement. This is a decision typically made by home owners who are looking for improved heating comfort through the delivery of warmer air that is provided by propane forced-air furnaces versus air-source heat pumps.

The scenario borne out in Figures 7 and 8 shows several attractive heating and cooling replacement systems, with paybacks under four years. For the Hot and Mixed Climates, when an existing home has an ASHP that needs to be replaced, the system with the shortest payback versus the 80 AFUE propane forced-air furnace & 13 SEER A/C is the 95 AFUE propane furnace & 13 SEER A/C (System B), with a payback of just a few months. The standard efficiency heat pump provides the second best payback, at a little over ½ year.

Consumers looking to hedge against volatility in future energy prices will want to consider the hybrid ASHP with high efficiency propane furnace, which has a payback of just over 2-4 years, and permits switching between the electric ASHP and the propane furnace as the primary source of heat, depending on energy prices.

Least attractive of the systems considered is the GSHP, which has a payback of 11-18 years, largely due to the high first cost of the loop field. Heating oil systems were not considered for this climate zone, as they are not commonly specified in this area.

<u>Scenario E:</u> For an existing home in the Cold Climate where the homeowner is strongly interested in an efficiency upgrade and needs to replace the old forced-air heating system, what is the payback for alternatives assuming that the main heating system under consideration is a 95 AFUE propane furnace?

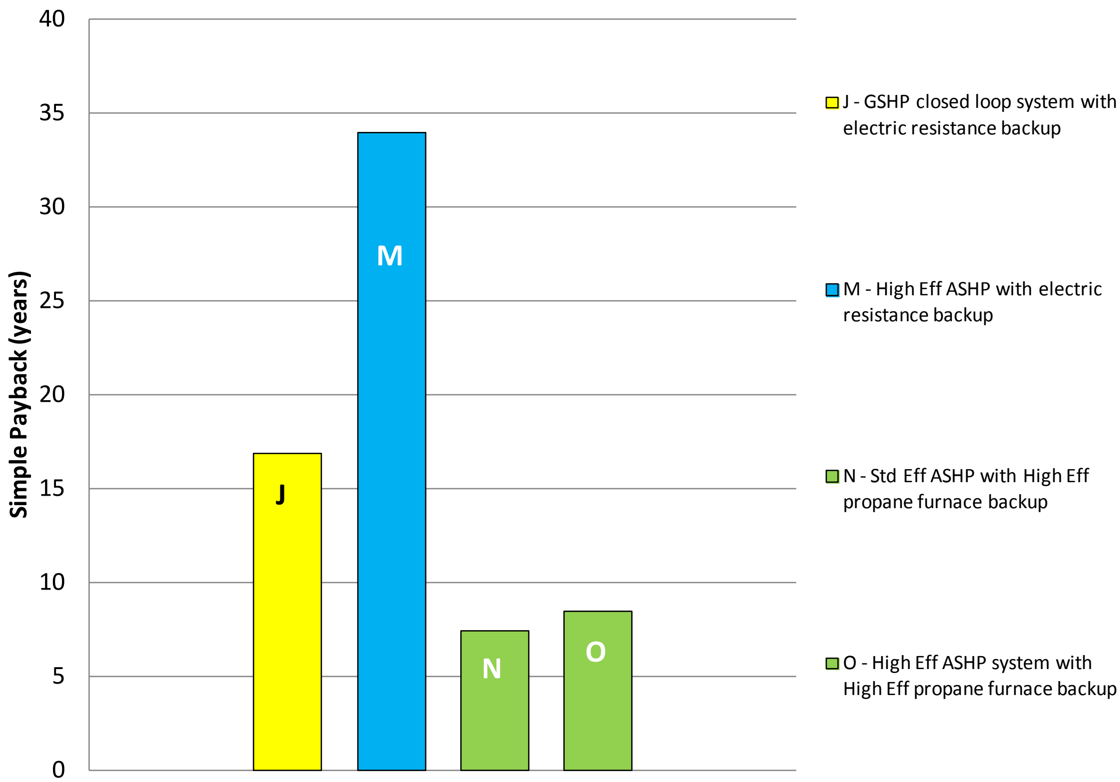

Figure 9: Simple Payback of Various Higher Efficiency Heating Systems for Cold Climate Existing Homes, Assuming a 95 AFUE Propane Furnace as the Baseline System.

In Figure 9, the baseline system – a 95 AFUE propane furnace – is a competitive high efficiency replacement option given lengthy paybacks (8-34 years) for higher efficiency alternatives. The paybacks for alternatives such as a GSHP (System J, 17+ years) or a hybrid ASHP with high efficiency propane furnace (System N and O with paybacks of ~ 8 years) are generally not in a range attractive to home owners. The standard efficiency ASHP systems (System L) is not shown because, on average in the Cold Climate zone, System L's energy costs are <u>higher</u> than the baseline furnace system - so there is no payback.

The long payback periods for the high efficiency ASHP system is due to fairly comparable energy cost performance between the high efficiency propane furnace and System M. Thus, the ability to make up for added first cost is limited. And in the case of the GSHP system, its relatively lower energy costs are offset by the higher initial investment which is required, which extends the payback.

<u>Scenario F</u>: For an existing home in the Cold Climate where the homeowner needs to replace an old air-source heat pump, what is the payback for various <u>heating and cooling</u> system alternatives assuming that the main system under consideration is a new, standard efficiency air-source heat pump?

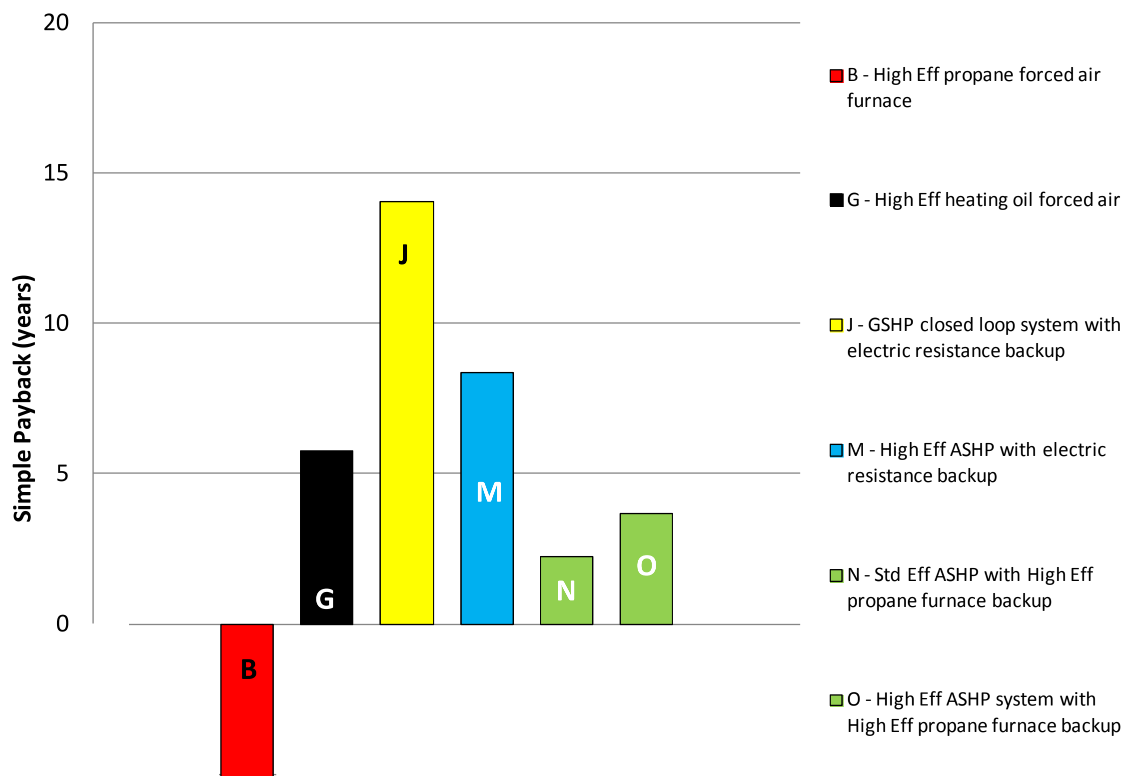

Figure 10: Payback of Various Heating and Cooling Systems for Cold Climate Existing Homes, Assuming a Standard Efficiency Air-Source Heat Pump as the Baseline System.

Within scenario F, since the HVAC system being replaced (an ASHP) provides both heating and cooling to the home, each of the replacement options also provide both heating and cooling. For furnace systems, this means that the first cost of a new A/C system is also included as part of the economic analysis. Further, both the heating and cooling energy costs are considered in the payback analysis.

Examining the results reveals that a high efficiency propane furnace coupled with a standard efficiency 13 SEER central A/C is a better option than simply replacing the old ASHP with a new, standard efficiency ASHP. The propane furnace and A/C combination has both lower first cost and lower energy costs, so the payback on this system is immediate. Any fuel switching costs (if the home does not already have propane) are not included, although propane switching costs are typically minor due to flexible tank placement, little/no trenching, and leasing arrangements with propane suppliers which avoid the need to purchase the propane tank.

Another system alternative with a relatively short (< 2 years) payback is the hybrid standard efficiency ASHP with high efficiency propane furnace backup system (System N). System N is particularly interesting because it uses the heat pump until colder outdoor temperatures develop, at which point the propane furnace provides the home's heating. These systems also can provide a hedge against future swings in energy rates, by permitting the homeowner to operate either the high efficiency furnace or the ASHP based on the most favorable economic conditions.

Scenario G: For a new home in the Cold Climate (whether Midwest, Northeast, or other region) where the homeowner intends to install a GSHP system, what is the payback for the GSHP + electric resistance system versus the hybrid GSHP with propane furnace backup?

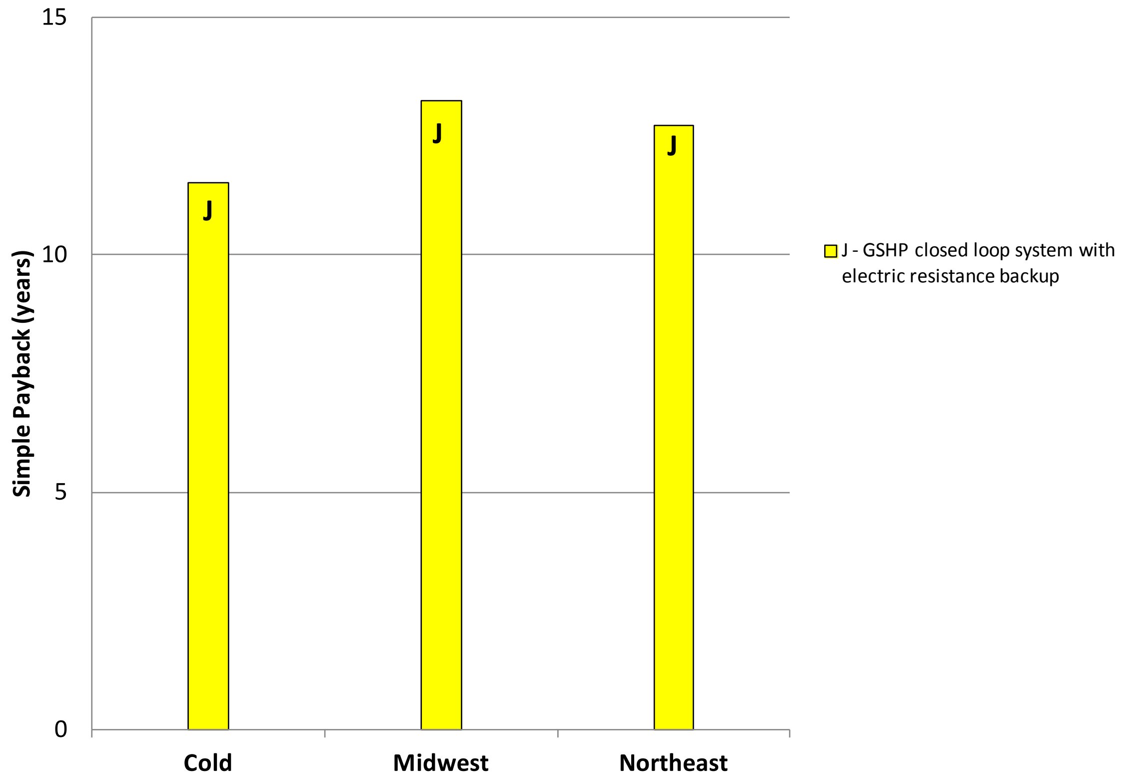

Figure 11: Payback of GSHP with Electric Resistance Backup, Assuming a GSHP with High Efficiency Propane Furnace Backup as the Baseline System.

This scenario assumes that the home owner is very interested in installing a GSHP system, and is simply trying to decide between alternative systems. In this case, the more expensive first cost GSHP system is the GSHP with electric resistance backup, System J. The system with the lower first cost is the hybrid GSHP with propane furnace backup, System K. System K has a lower first cost due to the installation of a smaller loop field than System J. System K's loop field is sized to cover 100% of the cooling load and at least 40% of the heating load (with the balance covered by 95 AFUE propane furnace), while System J's loop field is sized to cover 100% of the cooling load and at least 80% of the heating load (balance covered by electric resistance heat). System K's smaller loop field results in substantially lower first costs, on the order of $5,700 on average across the new homes.

System J has lower annual heating energy costs than system K, so it is able to eventually recoup the additional investment in the loop field. However, the payback is unattractive, at 12-13 years, depending on the region.

In each of the payback scenarios above, it is incumbent upon individual homeowners to make decisions about how they should best invest their capital. Cost estimates for different systems may vary based upon local market conditions. It should also be noted that a significant factor in the economics of different systems is the availability of federal, state, and utility-based incentives and tax credits for high efficiency systems. Such incentives and credits will often make the investment in a more efficient model over a standard efficiency model more attractive, and in some cases could cause a homeowner to select a different category of system all together. Tax credits and incentives are not included in the payback analyses above, but interested readers can review available offers at the Database of State Incentives for Renewables & Efficiency (DSIRE) www.dsireusa.org.

Comfort

While energy, emissions, and economics are all important considerations when selecting a heating system, the importance of comfort cannot be overlooked, especially from a home owner's perspective. In fact, comfort is often a deciding factor for homeowners faced with selecting a new system or deciding between repairs and replacement. The reputation of heating systems for providing comfort varies greatly across systems, with systems such as propane in-floor radiant heat and forced-air furnaces expected to provide greater comfort than ASHPs, especially in cold climates. If there is consensus on comfort, it is that comfort is highly subjective, and can be difficult to quantify.

However, recent developments in building energy simulation tools supported by the U.S. Department of Energy (DOE) can be used to help quantify the expected comfort level associated with various systems. By creating a model of a new house using DOE's BeOpt software v2.0, importing the model into DOE's EnergyPlus software v8.0.0.008, and running an annual energy simulation with detailed, ten minute time steps across multiple climate zones, it is possible to simulate the heating supply temperatures of forced-air systems such as furnaces and ASHPs. Within this study, the comfort analysis is confined to comparing the heating supply temperatures of standard efficiency propane forced-air furnaces versus those of standard efficiency air-source heat pumps. Supply temperatures at or below typical body temperature (approximated as ≤ 100°F) are assumed to feel cool and be uncomfortable. This assumption seems reasonable, especially since supply temperatures that are output by EnergyPlus are provided just downstream of the heating system's heat exchanger, and are therefore higher than the temperature of the supply air when it actually reaches the living space at the supply registers.

Simulations conducted for the locations of Las Vegas, NV (DOE climate zone 3, a "hot-dry" climate); Columbia, MO (DOE climate zone 4, a "mixed-humid" climate); and Des Moines, IA (DOE climate zone 5, a "cold" climate) reveal that the propane forced-air furnace is expected to consistently deliver supply temperatures of 115-125°F throughout the heating season, regardless of outdoor temperatures. Unlike propane forced-air furnaces, the supply temperature of a standard ASHP decrease as outdoor temperatures decrease – making them less comfortable when heating loads are the greatest.

Simulations show that across the three climate zones analyzed, the ASHP supplies air that varies in temperature from 90-120°F, even when the ASHP's backup electric resistance heating element is taken into account. In the mixed and cold climates, the supply air from the ASHP feels "cool" over 60% of the heating season (Figures 12 and 13). Even in a hot-dry climate like Las Vegas, the supply air from the ASHP feels "cool" roughly 20% of the heating season (Figure 14). Overall, the simulations support the industry perspective that supply air from propane forced-air furnaces are typically warmer than ASHPs, which is likely to be perceived as more comfortable by occupants.

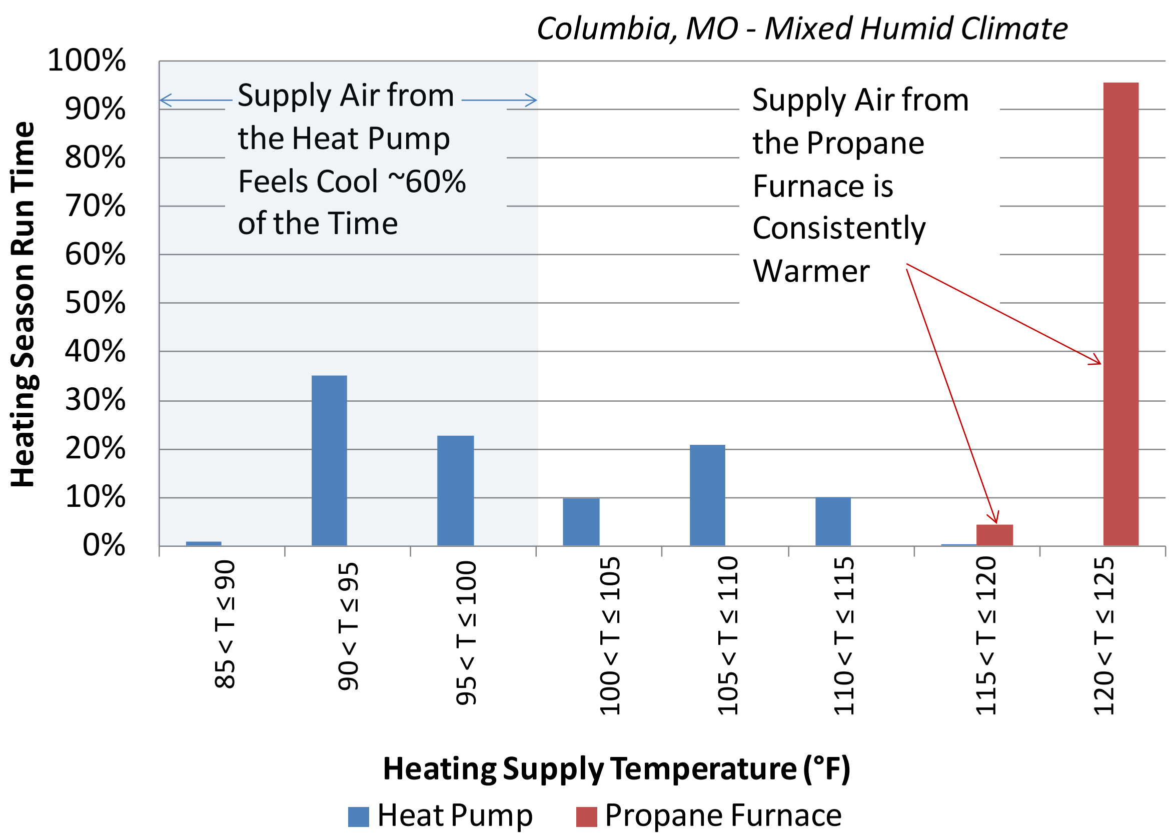

Figure 12: Distribution of Heating Supply Temperatures throughout the Heating Season for Propane Furnaces and ASHPs in a Mixed Humid Climate.

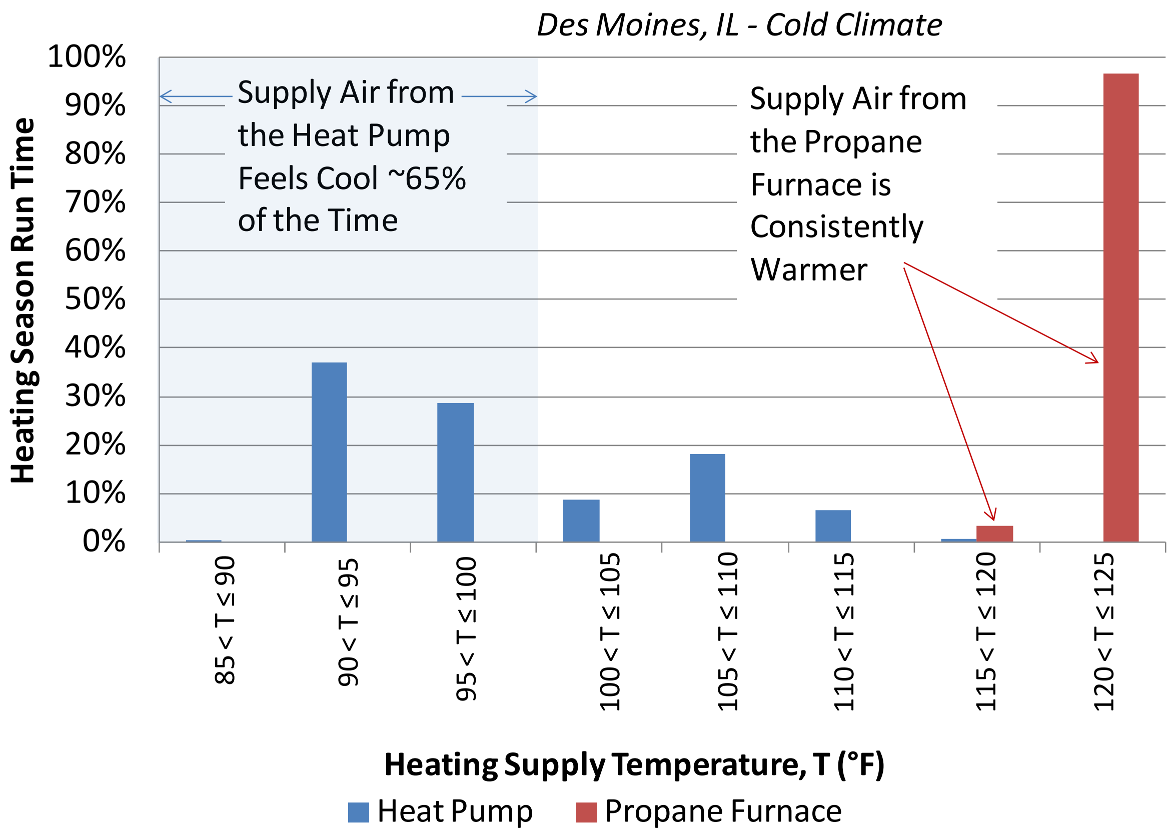

Figure 13: Distribution of Heating Supply Temperatures throughout the Heating Season for Propane Furnaces and ASHPs in a Cold Climate.

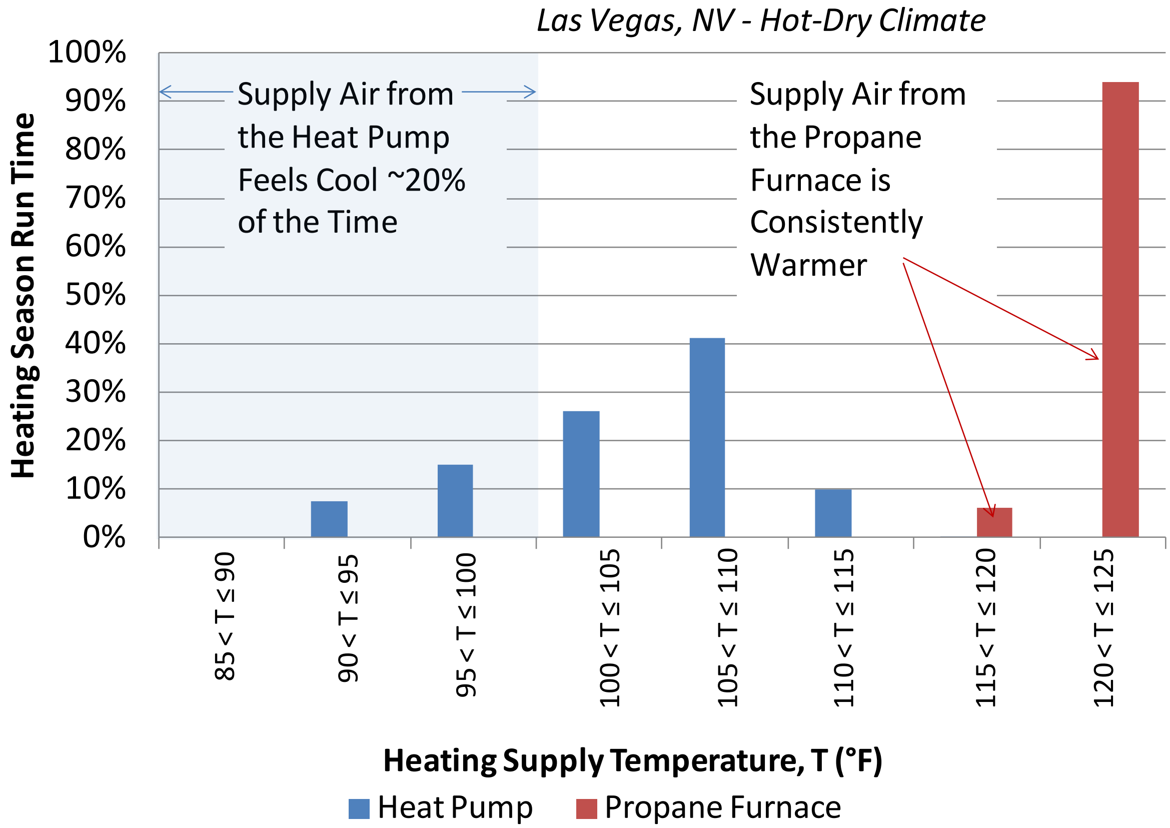

Figure 14: Distribution of Heating Supply Temperatures throughout the Heating Season for Propane Furnaces and ASHPs in a Hot-Dry Climate.

Emissions

All heating systems – regardless of the energy source – result in carbon emissions in most parts of the country. Fossil-fuel heating systems, like those which use propane, heating oil, or other fossil sources for combustion, release green house gasses (GHGs) such as CO_2 as a result of the combustion of the fuel. This is obvious to most homeowners since the combustion occurs at the home in the heating unit, and combustion products are vented to outdoors through a flue pipe or vent.

What may be less obvious is that electricity-based heating systems also result in carbon emissions which are often much greater than a fossil heating system like a propane furnace. Most electricity in the United States is produced from power plants which rely on fossil fuels to create thermal energy, which is then converted to electrical energy. As shown in Figure 12 below, roughly three-quarters of the electricity generated in the United States is from fossil-based sources. Further, these power plants will typically consume roughly 3 units of energy to produce 1 output unit of electricity, so the resulting emissions from the production of electricity are often significant.

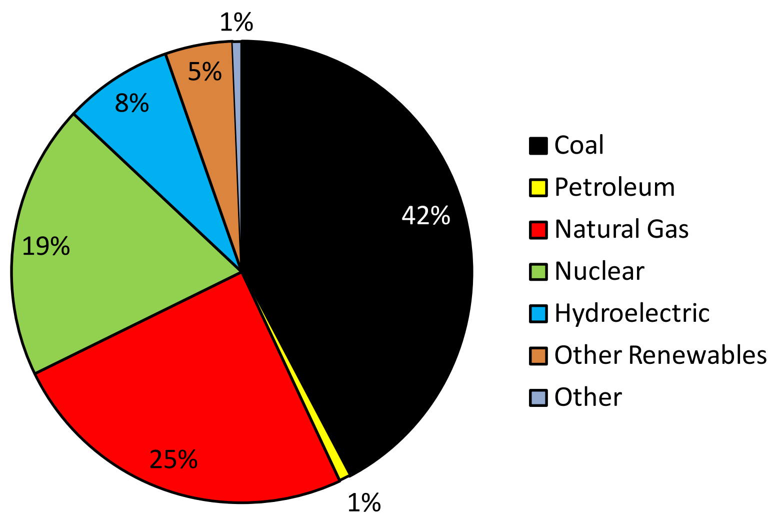

Figure 12: Electric Power Industry Electricity Generation by Energy Source, 2011. *Source: U.S. Energy Information Administration, Electric Power Annual 2013.*

Thus, systems like air-source heat pumps and ground-source heat pumps are also associated with GHG emissions, even though these systems utilize thermal energy from the air and ground, respectively, and no fuel combustion occurs at the home. The electricity which is used to run their pumps, fans, and compressors comes from an upstream power generation plant, which in most cases is combusting a fuel like coal and producing GHG emissions.

Figure 13 illustrates the CO_2 emissions which result from the operation of the various heating systems averaged across the 8 Midwest analysis locations. A full data table of emissions results for the different regions of the U.S. is included in Appendix A. As described above, the modeling software used for the energy analysis incorporates state-level emissions factors from EPA's eGRID database. These emission factors take into account the mix of energy sources used to generate electricity in a given state (e.g. coal, nuclear, hydro) to develop an average emission factor which reflects the quantity of GHGs that result from the generation of electricity in the state.

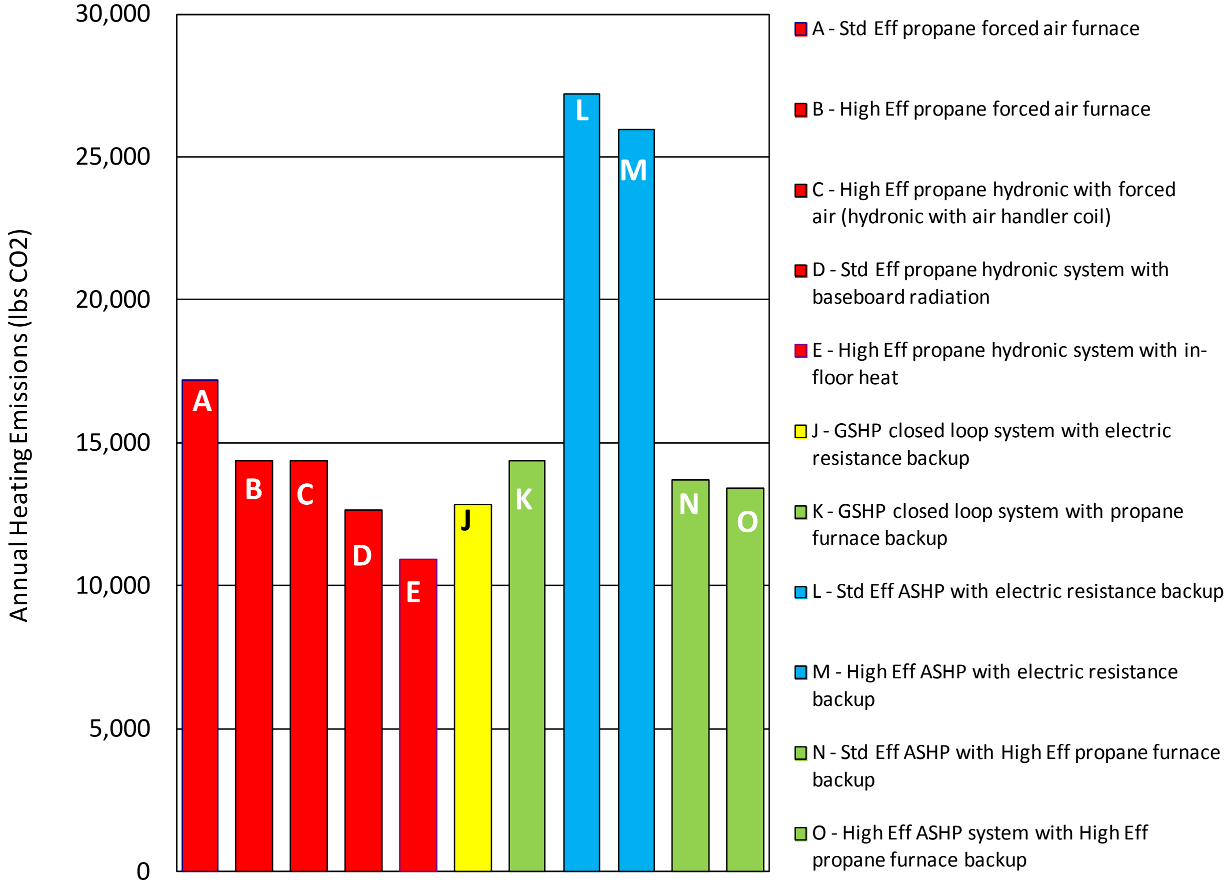

Figure 13: CO_2 Emissions for Heating Systems for New Home Analysis for the Midwest Region.

The graph clearly illustrates that electricity-based heating systems, and especially air-source heat pumps, result in much higher emissions than propane-based furnace and boiler systems in the Midwest. For example, the standard efficiency ASHP (System L) has roughly 1.6 times the CO_2 emissions compared to the standard efficiency propane furnace (System A). This is partly driven by the fact that during the colder parts of the winter, ASHP systems use increasingly more electric resistance heat to satisfy the home's heating demand. This form of heating is much less efficient and uses more electricity, which in turn means greater carbon emissions.

To put these abstract quantities of "pounds of CO_2" into somewhat more understandable terms[4], the difference ***each year*** in carbon emissions between the standard efficiency propane furnace and the standard ASHP is roughly equal to the GHG emissions of a passenger vehicle for an entire year. It should also be noted that these are only annual numbers, so for each year of operation the propane furnace would result in recurring emissions benefits. So a homeowner in

[4] U.S. EPA's Greenhouse Gas Equivalencies Calculator: www.epa.gov/cleanenergy/energy-resources/calculator.html

the Midwest could essentially offset the carbon emissions from one of their passenger cars every year, by opting to use a propane furnace instead of a standard ASHP.

The graph also reveals several other important conclusions:

- The high efficiency propane boiler system with in-floor radiant heat (System E) results in the lowest emissions due to a less carbon-intensive energy source (propane), the high efficiency boiler (95 AFUE), and lower distribution system losses compared to forced-air ducted systems.
- The ground-source heat pump system (System J) has lower emissions compared to ASHPs and some propane systems due to more efficient operation, but greater emissions than other propane-based systems due to greater consumption of electricity.
- The hybrid ASHP propane furnace systems, which combine an ASHP with a high-efficiency propane back-up furnace (Systems N and O), avoid the problem of inefficient resistance heating by turning off the heat pump during colder outdoor conditions. As the outdoor temperature gets colder, the propane furnace cycles on and provides the heating to the home instead of the ASHP. As a result, the hybrid system emissions are similar to those of a high efficiency propane furnace.

It is worth noting that emissions levels from the systems will vary if a particular state has a high proportion of non-fossil electricity production capacity (e.g. hydropower in the Northwest). This is particularly true for all-electric systems like heat pumps (air or ground source). Even regions which are now heavily reliant on coal-fired electricity production may eventually start to shift their mix of power production facilities. However, for the foreseeable future, coal will continue to be the dominant source of electricity production in much of the U.S., meaning that electric-based heating systems will be reliant on a carbon-intensive energy source.

While Figure 13 compares a selection of propane- and electric-based heating system options, Figure 14 examines the emissions for heating oil- and propane-based systems in the two heating oil markets in the analysis. The results indicate that for propane and heating oil systems with comparable efficiencies, heating oil systems generate significantly higher CO_2 emissions. For example, the high efficiency heating oil furnace (System G) has CO_2 emissions roughly 15% higher than the high efficiency propane furnace (System B). Both of these furnace systems have rated efficiencies of 95 AFUE, so efficiency levels are not driving this difference in emissions. The difference in carbon emissions is driven by the fuel source, with heating oil combustion being more carbon-intensive than propane. The other propane- and heating oil-based systems in Figure 14 show this same trend, with propane systems resulting in lower carbon emissions for comparable heating systems.

In terms of absolute quantities, System B (high efficiency propane furnace) results in 2,213 fewer pounds of CO_2 emissions per year from heating operation, compared to System G (high efficiency heating oil furnace). Over a 20 year furnace life, this difference is roughly equal to the carbon which would be sequestered by about 514 tree seedlings over 10 years.

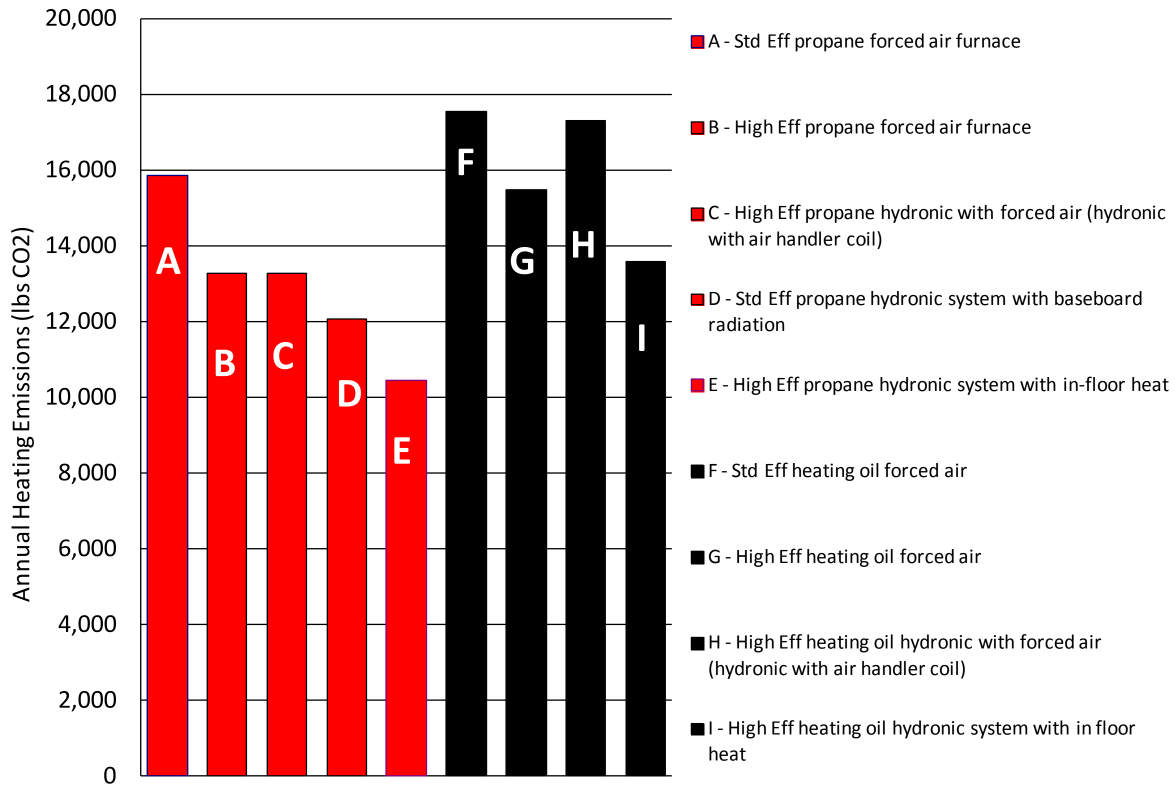

Figure 14: CO_2 Emissions for Heating Oil and Propane Heating Systems in New Homes in Heating Oil Markets (2) included in the Analysis.

Finally, while the emissions of all-electric heating systems like heat pumps may vary based on the mix of fuels used to generate electricity (see discussion above), the results shown for propane and heating oil in Figure 14 will remain steady in any market. This is due to the fact that the total carbon emissions from propane and heating oil heating systems are mostly (95% or higher) due to the combustion of the fuel. Very little (< 5%) of the emissions from these systems is due to the electrical energy used by the system for the blower, exhaust fan, and other components. Thus, shifting the analysis shown in Figure 14 to a region with a different electric power generation mix would have very little impact on the results; plus any shift in the carbon intensity of electric power would impact both the propane and heating oil heating systems roughly equally.

The Relationship between First Costs, Energy Costs, and CO_2 Emissions

The payback analyses above relate first cost and energy costs for different HVAC options. Another key consideration for heating and cooling systems is the level of carbon emissions which result from their operation. To illustrate this point, Table 6 shows system first costs and carbon emissions associated with heating over 20 years for a selection of HVAC options in new Midwest houses.

System	First Cost (Midwest locations)	Annual Heating Energy Costs (Midwest locations)	Heating Season CO_2 Emissions over 20 Years - Midwest Locations (tons)
B - High efficiency propane forced-air furnace	$15,692	$1,734	144
J - GSHP closed loop system with electric resistance back-up	$42,498	$961	128
M – High efficiency ASHP with electric resistance back-up	$18,661	$1,957	260
N – Standard efficiency ASHP with high efficiency propane furnace back-up	$19,104	$1,457	137

Table 6: First Costs, Heating Energy Costs, and Carbon Emissions for Heating in New, Midwest Homes for a Selection of High Efficiency Heating Systems.

The data indicate that the relationship between costs (first and energy) and emissions varies significantly across the different system types. For instance, the lowest first cost system of this set of high efficiency options – the high efficiency propane furnace - is also one of the lowest in terms of CO_2 emissions. So it does not have to “cost more” to have a heating system which also carries a small carbon footprint, when looking across high efficiency alternatives.

The highest first cost system and the one with the lowest energy costs – the GSHP system – has the lowest carbon emissions of the 4 systems. However, the GSHP’s first cost premium (its added cost) of ~$27,000 only translates to a 12% savings in carbon emissions versus the high efficiency propane furnace. So, paying a lot more up front for a very efficient system does not always translate to significant savings of carbon emissions over alternatives.

This table helps to illustrate that in some cases the “tradeoffs” between first costs, energy costs, and carbon emissions may be smaller than anticipated. Rather, the energy source can be the main driver for the carbon emissions, with high efficiency propane systems offering lower emissions generally.

Conclusions

Considering the extent of information generated in this analysis, a number of conclusions are found involving heating system performance. In reviewing first cost, energy cost, payback, comfort, and emissions analyses, systems which appear strong in one respect may not be the strongest performers in another area. This leads to perhaps the most prominent finding of the study: any heating system should be viewed in terms of all five of these factors.

The need to evaluate systems in terms of multiple factors is also found in some of the more specific conclusions below:

- A comfort study based on a bin analysis of supply temperatures from propane forced-air furnaces versus electric air-source heat pumps revealed superior performance for the propane system in three locations representing hot-dry, mixed-humid, and cold climate zones. Based on simulations performed with the U.S. Department of Energy's EnergyPlus software, ASHPs operating in heating mode are expected to supply air that feels cold approximately 20% of the time in hot-dry climates like Las Vegas, and from 60-65% of the time in mixed-humid and cold climates, with decreasing supply temperature coincident with decreasing outdoor temperature. On the other hand, propane forced-air furnaces are expected to supply very warm air (e.g., supply temperature between 115-125°F) 100% of the time.
- Annual heating and cooling energy cost for the systems in the Cold Climate (Table 5) shows the majority of systems within an annual cost range between ~$1800 and $2200. The four heating oil systems evaluated within this study (System F, G, H, and I), have the four highest energy cost. Lower energy costs (~$1800) were associated with hybrid systems that coupled ASHPs with high efficiency propane backup furnaces (N, O). The GSHP system with electric resistance backup carried the lowest annual energy cost; however this performance is tempered by the system's high first cost relative to other high efficiency systems such as propane or heating oil furnaces.
- From the perspective of first cost, propane systems account for the two best performing systems for new homes across the 20 sites evaluated. The lowest first cost belongs to the high efficiency 95 AFUE propane furnace, followed by the standard efficiency 80 AFUE propane furnace. The 95 AFUE propane furnace achieves a lower cost than the 80 AFUE propane furnace due to a lower cost venting system. When replacing an existing ASHP across all 20 sites, the 80 and 95 AFUE propane furnace with 13 SEER A/C are in a virtual tie for the lowest first cost system. When replacing an existing standard efficiency heating oil system, or standard efficiency propane system, the 80

AFUE propane furnace is the lowest first cost system, since it is able to reutilize the existing venting.

- Several typical payback scenarios, focusing on both new and existing homes, highlight that high efficiency systems with moderate first costs are typically the most attractive option. The high efficiency propane furnace is able to combine low first cost with high efficiency to compare favorably against lower energy cost options (e.g., GSHP) in the Cold and the Mixed Climates. Hybrid systems combining an air-source heat pump with a high efficiency propane furnace for back-up heat are a viable option in several scenarios as well. Ground source heat pumps have significantly higher paybacks than other systems despite markedly lower energy costs. This is due to the high first cost of the GSHP systems. Air-source heat pumps have relatively higher paybacks in some scenarios and an infinite payback in other scenarios, where their energy costs are higher than the baseline system under consideration.

- Greenhouse gas emissions, quantified in terms of CO_2, result from the operation of heating systems regardless of fuel source. Emissions data from heating systems in the Midwest show a relatively heavy carbon impact from air-source heat pump systems, while high efficiency propane systems and hybrid ASHP propane furnace systems result in much lower (~ ½) quantities of CO_2 emissions. Assessing costs (first and energy) along with emissions shows that propane-based systems are often better options than electric-based counterparts, especially in the Midwest where electricity is generated primarily from coal.

  Analysis of carbon emissions for heating oil systems in the 2 heating oil markets reveal that propane systems generate significantly less CO_2. When comparing heating oil- and propane-based furnaces of the same efficiency, the heating oil system has significantly higher (~15%) emissions. This illustrates that the fuel source is driving the higher emissions rates for heating oil systems, as opposed to equipment efficiency levels.

Looking ahead, several important variables affecting heating energy use in homes are likely to evolve in the coming years. These include potential upward pressure on residential electricity prices resulting from carbon emissions regulations and renewable portfolio standards, volatility in heating oil and propane energy pricing, increases in federally regulated minimum heating equipment efficiency, greater stringency in building energy codes, and a greater emphasis on the carbon emissions which result from home energy use. On this last issue, various efforts to reward efficiency (e.g., tax credits, labeling programs, green building rating systems) may gradually shift to also include consideration of a building's carbon emissions in addition to its energy use. In this increasingly complex environment, building professionals and home owners will be challenged to choose heating systems that meet their individual objectives of low first cost, low energy cost, favorable paybacks, comfort, and environmental performance.

Appendix A: Annual CO_2 Emissions Resulting from Heating Energy

System	Northeast	Midwest	Mid-Atlantic	Southeast	West
A - Std Eff propane forced-air furnace	14,469	17,656	13,987	5,190	9,611
B - High Eff propane forced-air furnace	11,825	14,420	11,374	4,165	7,718
C - High Eff propane hydronic with forced-air (hydronic with air handler coil)	11,825	14,420	11,374	4,165	7,718
D - Std Eff propane hydronic system with baseboard radiation	10,966	12,987	10,529	3,845	7,142
E - High Eff propane hydronic system with in-floor heat	9,255	10,961	8,882	3,244	6,028
F - Std Eff heating oil forced-air	16,463	N/A	21,104	N/A	N/A
G - High Eff heating oil forced-air	13,776	N/A	17,396	N/A	N/A
H - High Eff heating oil hydronic with forced-air (hydronic with air handler coil)	15,360	N/A	19,410	N/A	N/A
I - High Eff heating oil hydronic system with in-floor heat	12,004	N/A	15,155	N/A	N/A
J - GSHP closed loop system with electric resistance backup	5,562	13,291	6,392	4,387	6,006
K - GSHP closed loop system with High Eff propane furnace backup	8,959	14,615	11,630	N/A	8,909
L - Std Eff ASHP with electric resistance backup	9,454	28,122	11,796	5,023	10,708
M - High Eff ASHP with electric resistance backup	8,925	26,864	11,097	4,671	9,942
N - Std Eff ASHP with High Eff propane furnace backup	9,333	13,893	9,323	3,282	6,286
O - High Eff ASHP system with High Eff propane furnace backup	9,211	13,593	9,190	3,138	6,113

Table B1: CO_2 Emissions by Region for Various Heating Systems (New Homes).

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The Propane Education & Research Council was authorized by the U.S. Congress with the passage of Public Law 104-284, the Propane Education and Research Act (PERA), signed into law on October 11, 1996. The mission of the Propane Education & Research Council is to promote the safe, efficient use of odorized propane gas as a preferred energy source.