Comparative Analysis of Residential Heating Systems

Final Report June 2009

PROPANE education & research COUNCIL

Prepared for
The Propane Education & Research Council

By Newport Partners LLC

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About the Authors

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

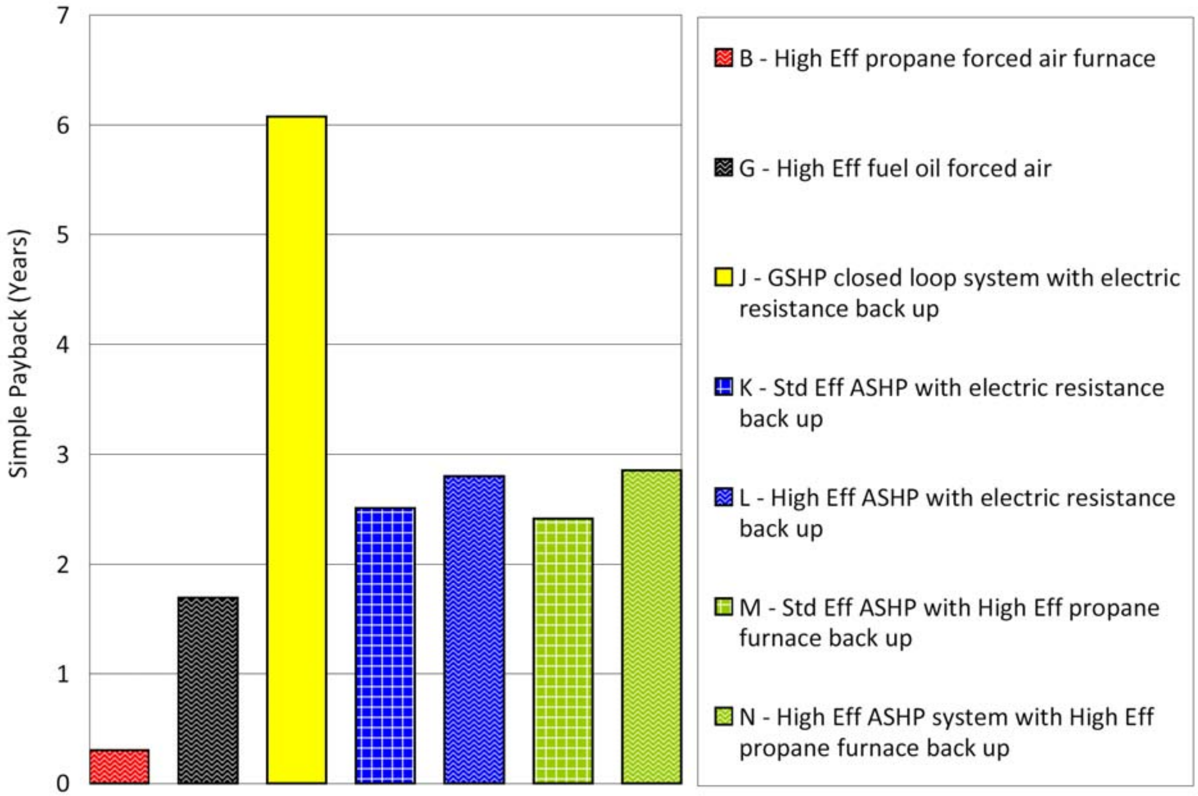
Builders, contractors, and homeowners today face a myriad of options for home heating systems. Traditional furnaces and boilers, high efficiency models, heat pumps (both air-source and ground-source), and even dual fuel systems are all options. Sorting out the best choice for a home requires consideration of system costs, efficiency levels, energy rates, comfort levels, the severity of the climate, and any applicable incentives including tax credits. Carbon emissions have evolved 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 111 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. 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.

At a time when energy prices are rising, new technologies are emerging in the residential market, and programs and regulations are developing to limit carbon emissions, this study provides unique insights into the performance of home heating systems. In analyzing 14 heating systems in 16 different locations across the U.S., the study allows comparisons of key metrics such as annual operating costs, CO2 emissions, and simple paybacks for higher first cost, more efficient systems. The heating systems assessed included mainstream system types such as furnaces, boilers, and air-source heat pumps, as well as less common options including dual fuel systems and ground-source heat pumps. The energy sources were electricity, fuel oil, and propane, and most of the systems were evaluated at a high efficiency and a standard efficiency level. Each of these systems was 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 change-outs. 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, and often a compromise, of several factors. For instance, the relatively low <u>first cost</u> (materials and installation) of a 95% high efficiency propane furnace must be weighed against slightly lower <u>operating costs</u> for air-source heat pumps (ASHPs) in some climates. Likewise, the attractive operating costs for ground-source heat pumps (GSHPs) must be weighed against a significant first cost premium compared to other high efficiency alternatives such as a dual fuel system (ASHP with 95% efficient propane furnace back-up) or a 95% efficient propane furnace.

A specific example of the relationship between cost and performance is highlighted in the graph below, which evaluates alternatives to replacing the old heating system in a Cold Climate existing home with a standard 78% efficient propane furnace. Several higher cost, but more efficient, alternative systems are projected to quickly (< 3 years) pay for their initial cost premium through utility bill savings. This analysis incorporates estimates of system costs based on unit capacity and other factors, and does not include tax credits or market incentives due to their varied and transient terms at the state, utility, and federal level.



Simple Payback of Various Heating Systems for Cold Climate Existing Homes, Assuming a 78 AFUE Propane Furnace as the Baseline System

While first cost and operating cost were often inversely related, the CO_2 emissions from heating system operation showed significantly lower emissions from high efficiency propane-based systems and dual fuel systems. Air-source heat pumps experienced much higher emission rates, especially in the coal-based Midwest, due to less efficient operation at colder temperatures. Combining these findings with the system replacement scenario shown above, excellent opportunities exist to simultaneously improve efficiency and carbon emissions in existing homes. The greatly reduced carbon emissions which result from some heating systems also indicates the potential for future decisions on technologies to more heavily weigh this factor in the interest of managing both emissions and energy consumption.

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 dual fuel systems are all options. Sorting out the best choices requires taking a close look at system costs, efficiency levels, energy rates, comfort levels, 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 efficiency and environmental advocates also have a keen interest in the energy/environmental performance of residential heating systems. Collectively, America’s 111 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 enhancements represent a unique and high impact opportunity.

This research project examined the performance of 14 heating systems in 16 different locations across the U.S. The 14 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, operating cost, emissions, and simple payback. “Operating cost” is defined as the cost for heating and cooling energy within this study, and does not include maintenance. 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.

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.

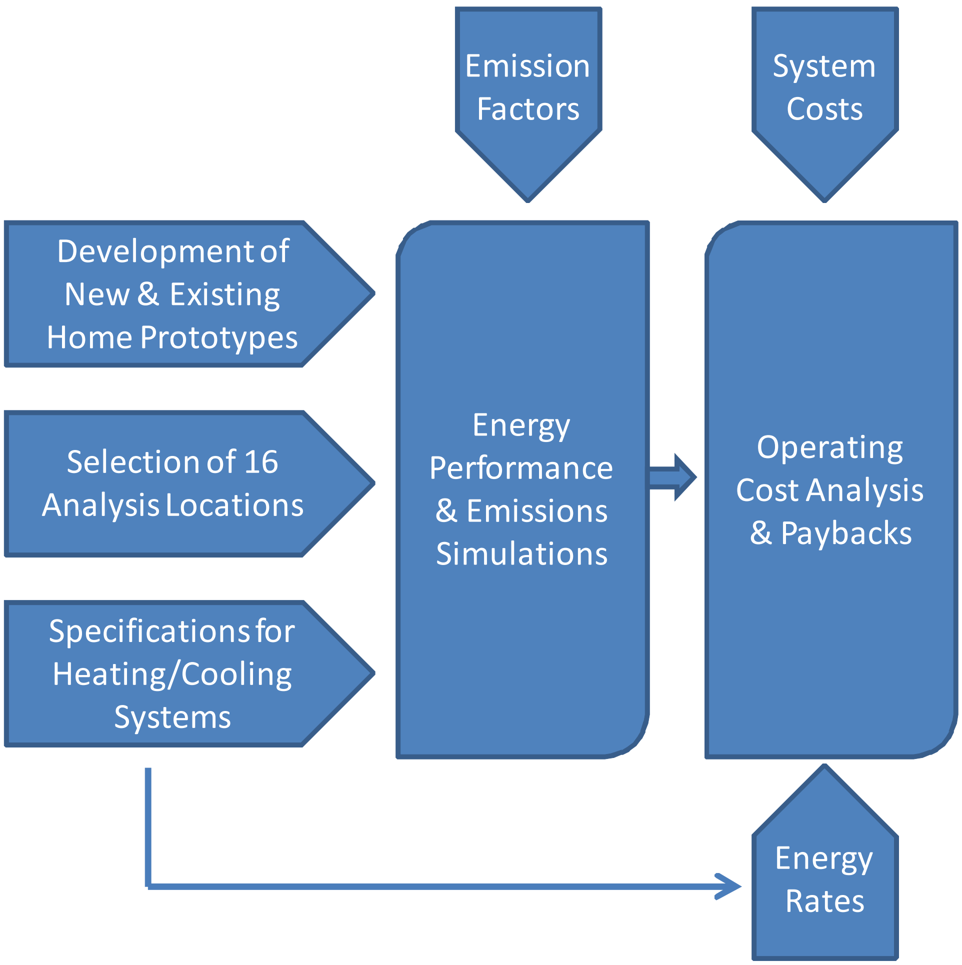

Figure 1: Analysis Methodology and Sequence of Analysis

As indicated in the figure, 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, 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 is the median date of construction for the existing U.S. housing stock.

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 2006 International Energy Conservation Code (IECC).

Figure 2 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	2,434 SF
Number of stories	1	1 or 2, depending on location
Foundation Type	Slab, crawlspace, and basement – depending on location	Slab, crawlspace, and 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

Figure 2: 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 16 analysis locations were selected from across the U.S. The locations span 5 of the Climate Zones typically used in U.S. building codes, including most of the U.S. except for the warmest regions where heating system performance is not nearly as significant in terms of energy use or cost. A map of the analysis locations is shown below in Figure 3.

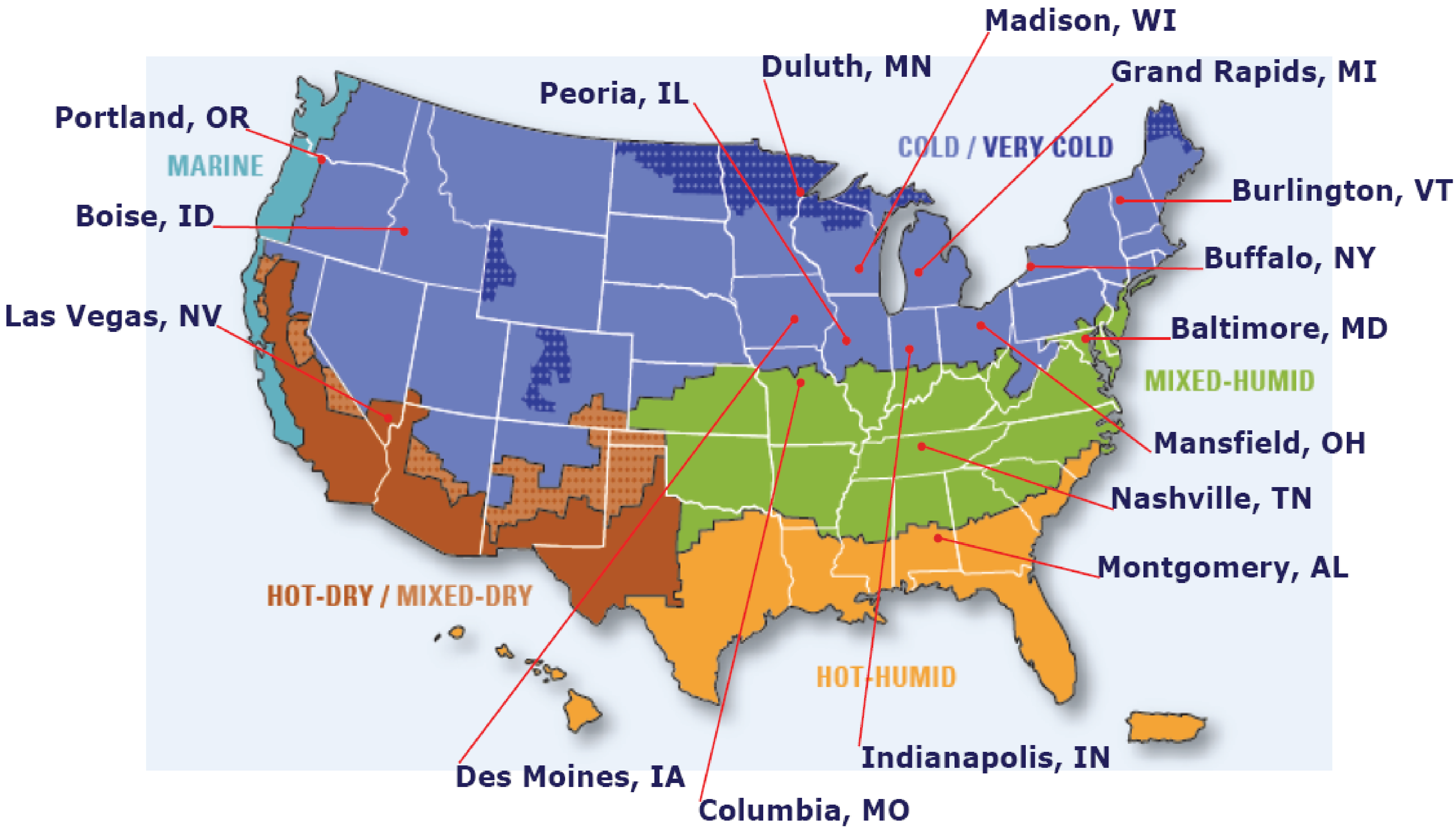

Figure 3: Analysis Locations

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 based on federally regulated minimum levels (e.g. a 78% AFUE propane furnace is the federal – and market – minimum). In the case of "high efficiency" equipment, system efficiency ratings were based on the thresholds set by the current federal tax credits for energy efficiency, which were recently updated with the passage of the American Recovery and Reinvestment Act of 2009. 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 however, 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[1]. So for this particular system, a high efficiency fuel-oil boiler, the efficiency rating used in the study was adjusted to reflect products available in the marketplace. The heating systems examined in the study along with their associated efficiency ratings are shown below in Figure 4.

Additionally, overall system design parameters were also developed for the analyses. The capacity of each heating system (e.g., a 48 kBtu/hour 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 should the furnace be than the exact heating design load) followed common industry guidance from groups such as the Air-Conditioning Contractors of America (ACCA) and the ENERGY STAR Homes program.

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 ground source heat pumps (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 Btuh/ft*°F). The system characteristics and specifications were input into both the energy modeling software (REM/Rate v12.61) as well as the cost estimating phases of the project.

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

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 14 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 Burlington, VT. In these locations no central cooling system was included.

In existing homes, the assumptions on first cost for new equipment were different. 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 it be 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 fuel oil were only evaluated in those markets where this energy source is most common (the Northeast US).

Fuel Source	Heating System Type*	System Efficiency Ratings
Furnaces* (with central A/C)	• Standard Efficiency Propane • High Efficiency Propane • Standard Efficiency Fuel Oil • High Efficiency Fuel Oil	• 78 AFUE w/ 13 SEER A/C • 95 AFUE w/ 13 SEER A/C • 78 AFUE w/ 13 SEER A/C • 95 AFUE w/ 13 SEER A/C
Boilers* (with central A/C)	• High Efficiency Propane with Forced-Air (water/air heat HX) • High Efficiency Fuel Oil w/ Forced-air (water/air HX) • Standard Efficiency Propane Hydronic with Baseboard Radiant • High Efficiency Propane Hydronic with In-Floor Radiant • High Efficiency Fuel Oil Hydronic with In-Floor Radiant	• 95 AFUE w/ 13 SEER A/C • 86 AFUE w/ 13 SEER A/C • 80 AFUE w/ 13 SEER A/C • 95 AFUE w/ 13 SEER A/C • 86 AFUE w/ 13 SEER A/C
GSHPs	• GSHP Closed Loop System with Electric Resistance Back-up	• EER=14.1; COP=3.3
ASHPs	• Standard Efficiency ASHP with Electric Resistance Back-up • High Efficiency ASHP with Electric Resistance Back-up • Standard Efficiency ASHP w/ High Efficiency Propane Furnace Back-up • High Efficiency ASHP with High Efficiency Propane Furnace Back-up	• 13 SEER; HSPF 7.7 • 15 SEER; HSPF 8.5 • 13 SEER; HSPF 7.7; 95 AFUE • 15 SEER; HSPF 8.5; 95 AFUE

*Heating-only systems (boilers and furnaces) were combined with a standard central cooling system in all locations except Burlington, VT and Duluth, MN for the purpose of cost estimating systems in new homes and assessing overall system operating costs

Figure 4: Heating Systems and Efficiency Ratings

Emissions Factors

Beyond energy performance, another very important performance metric of residential heating systems is their environmental footprint in terms of carbon emissions. The CO2 emissions which are associated with the operation of each heating system in each location were analyzed as part of this project. This analysis was conducted through the use of "emissions factors" integrated into the REM/Rate software from U.S. EPA's Emissions & Generation Resource Integrated Database (eGRID). These emission factors provide a multiplier to estimate the emissions which result from the production of a unit of electricity. The emissions factors within REM/Rate are given down to the state level. So for a given state, the emissions factor takes into account 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 will result in lower emissions than a unit of electricity in a state heavily reliant on coal-generated electricity.

System Costs

Equipment and installation 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 kBtu/hr)
- 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 for GSHP systems, including drilling costs, pump costs, and tubing costs

Most of these cost estimates were available through R.S. Means 2009 Mechanical Cost Data and R.S. Means 2008 Residential Cost Data. For these data points, location factors were also applied 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 directly contacting several dozen contractors and collecting cost data.

For the 14 systems analyzed, the average first cost of each system across all 16 locations for new homes is shown in Figure 5 below.

System*	Average First Costs of System
A – Standard efficiency propane forced-air furnace w/ 13 SEER A/C	$8,848
B - High efficiency propane forced-air furnace w/ 13 SEER A/C	$9,108
C - High efficiency propane boiler with forced-air (water/air HX) w/ 13 SEER A/C	$14,769
D - Standard eff. propane boiler system with baseboard radiation w/ 13 SEER A/C	$14,165
E - High efficiency propane boiler system with in-floor radiant heat w/ 13 SEER A/C	$23,877
F – Standard efficiency fuel oil forced-air furnace w/ 13 SEER A/C	$8,985
G - High efficiency fuel oil forced-air furnace w/ 13 SEER A/C	$11,245
H - High efficiency fuel oil boiler with forced-air (water/air HX) w/ 13 SEER A/C	$12,065
I - High efficiency fuel oil boiler system with in-floor radiant heat w/ 13 SEER A/C	$20,189
J - GSHP closed loop system with electric resistance back-up	$22,378
K - Standard efficiency ASHP with electric resistance back-up	$9,482
L - High efficiency ASHP with electric resistance back-up	$10,337
M - Standard efficiency ASHP with high efficiency propane furnace back-up	$10,573
N - High efficiency ASHP with high efficiency propane furnace back-up	$11,428

*Average system costs across all 16 locations are shown. Note that for the 2 coldest locations, furnace and boiler systems did *not* include a central cooling system.

Figure 5: Average First Cost for Heating/Cooling Systems of New Homes

For the systems listed above, all of the system costs include heating plus cooling functions. 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 (Burlington, VT 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 14 locations.

Highlights of the first cost estimates for the 14 systems include the following points:

- Standard efficiency fossil-fired (propane and fuel oil) furnaces are the least expensive systems
- The marginal first cost for upgrading from a standard efficiency to high efficiency unit was lowest for propane furnaces, at less than 5%

- The marginal first cost for upgrading from an air-source heat pump to an air-source heat pump with a high efficiency propane furnace back-up (System K vs M; System L vs N) was modest, at about 11%
- 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 had to incorporate forced-air duct work for central cooling in all but 2 locations.
- The higher first cost of ground-source heat pumps is driven mostly by the cost of the ground loop drilling and materials.

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 operating 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 analysis, the most recent EIA data available for deriving annual estimates of residential rates for heating oil, propane, and electricity was data averaged over 2008. 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). Additional information on the Energy Rate Methodology is included in Appendix A.

The results of this analysis – which are the energy rates used in the analysis – are shown in Figure 6 below. Fuel oil prices are only provided for those locations (Burlington, VT and Buffalo, NY) where these systems were analyzed.

City	**State**	**Residential Propane Price ($/gal)**	**Residential Heating Oil Price ($/gal)**	**Residential Electricity Price ($/kWh)**
Burlington	VT	3.02	3.61	0.15
Baltimore	MD	2.92	N/A	0.14
Buffalo	NY	2.75	3.54	0.19
Des Moines	IA	1.87	N/A	0.10
Peoria	IL	2.15	N/A	0.11
Indianapolis	IN	2.31	N/A	0.09
Grand Rapids	MI	2.30	N/A	0.11
Duluth	MN	2.04	N/A	0.10
Columbia	MO	2.04	N/A	0.08
Mansfield	OH	2.44	N/A	0.10

City	State	Residential Propane Price ($/gal)	Residential Heating Oil Price ($/gal)	Residential Electricity Price ($/kWh)
Nashville	TN	2.15	N/A	0.09
Madison	WI	2.13	N/A	0.12
Montgomery	AL	2.54	N/A	0.10
Boise	ID	2.30	N/A	0.07
Las Vegas	NV	2.57	N/A	0.12
Portland	OR	2.57	N/A	0.09
Average		**$2.38**	**$3.57**	**$0.11**

Figure 6: 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 sometimes not set up to do so. Even in cases where a system is capable of providing hot water and is set up to do so, the efficiency and energy-savings benefit of this operation depends heavily on the actual hot water demand in the home, which varies widely. Lastly, 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 was modest. For this reason “operating 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, which will match how a building performs in the real world, is not as exact. The actual energy performance of a home will vary (sometimes quite significantly) with several factors including occupancy behavior, actual weather conditions, changes to the building, changes in energy rates, the quality of the system installation, and system maintenance. Due to the number of variables involved, the results shown below 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 several data points of interest, there is extensive data generated by this study. This section extracts key findings and trends from this data set, organized into Operating Costs, Paybacks, and Emissions. Many of the findings concentrate either on the Cold Climate or the Midwest region, as these areas contain the most data points in the analysis and represent most of the country's heating-dominated areas.

Operating Costs

Operating costs represent the cost to provide heating and cooling to the prototype house. Operating costs in the study are presented on an annual basis. Figure 7 below lists the annual operating costs for the heating/cooling systems in the Cold Climate.   This data is derived from the analysis for all study locations (9) located in the Cold zone in the Figure 3 map.

System	**Annual Operating Cost**
A – Standard efficiency propane forced-air furnace w/ 13 SEER A/C	$2,619
B - High efficiency propane forced-air furnace w/ 13 SEER A/C	$2,160
C - High efficiency propane boiler with forced-air (water/air HX) w/ 13 SEER A/C	$2,166
D - Standard eff. propane boiler system with baseboard radiation w/ 13 SEER A/C	$2,037
E - High efficiency propane boiler system with in-floor radiant heat w/ 13 SEER A/C	$1,747
F – Standard efficiency fuel oil forced-air furnace w/ 13 SEER A/C	$2,956
G - High efficiency fuel oil forced-air furnace w/ 13 SEER A/C	$2,219
H - High efficiency fuel oil boiler with forced-air (water/air HX) w/ 13 SEER A/C	$2,427
I - High efficiency fuel oil boiler system with in-floor radiant heat w/ 13 SEER A/C	$2,134
J - GSHP closed loop system with electric resistance back-up	$938
K - Standard efficiency ASHP with electric resistance back-up	$1,821
L - High efficiency ASHP with electric resistance back-up	$1,720
M - Standard efficiency ASHP with high efficiency propane furnace back-up	$1,739
N - High efficiency ASHP with high efficiency propane furnace back-up	$1,690

Average Cold Climate Utility Prices: Propane: $2.36/gal; Electricity: $0.11/kWh; Fuel Oil: $3.57/gal

Figure 7: New Home Annual Heating and Cooling System Operating Costs, Cold Climate

Most of the systems are bunched within roughly a $500 band between ~$1700 and $2200 (except for GSHPs at less than $1000 and a few fuel oil systems and one propane system above $2200). While a $500 difference in annual operating costs is significant (~ $42/month difference), for systems grouped this closely changes in energy prices can flip-flop cheaper systems with more expensive ones. This point is particularly relevant if pending carbon emissions regulations eventually drive up residential electricity rates. Also note that the table relates heating plus cooling costs, so heat-pump systems with higher-than-standard cooling efficiencies, such as System L, will fare better than the 13 SEER cooling systems which are coupled with all boilers and furnaces.

The lowest operating cost system is the ground-source heat pump system. This system achieves high rated performance by utilizing thermal energy from the earth, although the ground loop which makes this possible also results in a higher first cost for the system. The tradeoffs between performance and first cost are examined in the section below.

Simple Paybacks

Simple paybacks can be used as a tool to evaluate how long it will take to "pay back" a higher first cost for 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 as new and existing homes, a large number of payback analysis scenarios can be conducted within this study. A selection of payback analyses, which concentrate on common scenarios in new construction and for existing homes, are 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% propane furnace with 13 SEER central A/C?

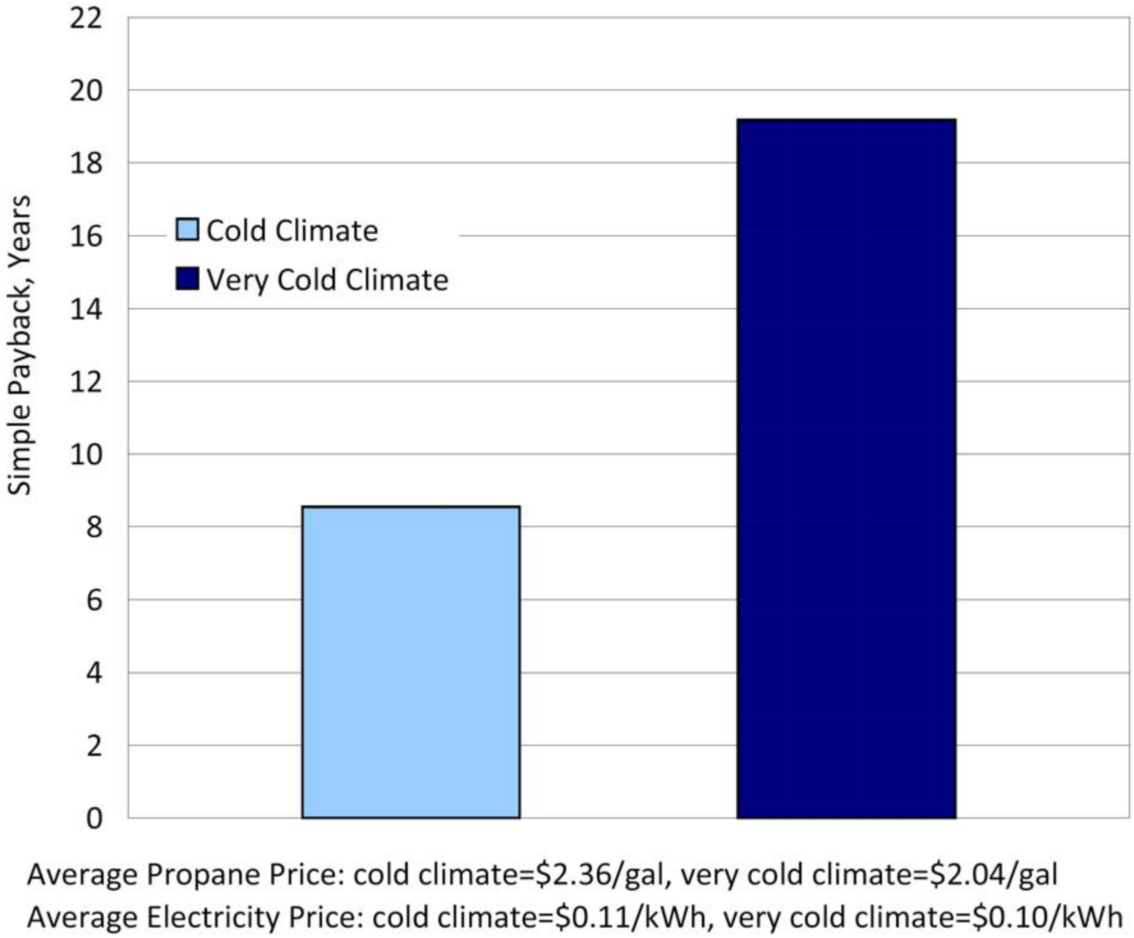

Figure 8: Payback Period for a GSHP System in a New Home Compared
to a High Efficiency Propane Furnace System

The payback scenario in Figure 8 shows that although GSHP systems will generally produce lower heating and cooling bills to condition a home (Figure 7), the significantly higher up-front cost can take over 8 years to recover in the form of energy savings in a Cold Climate. The payback for a GSHP system is considerably longer in the Very Cold climate, due in part to the fact that the first cost for the propane furnace in this climate did not include any cost for a central cooling system, as discussed above.

Scenario B: For an existing home in the Cold climate where the homeowner needs to replace the old heating system, what is the payback for more efficient systems relative to a standard 78% propane furnace change-out?

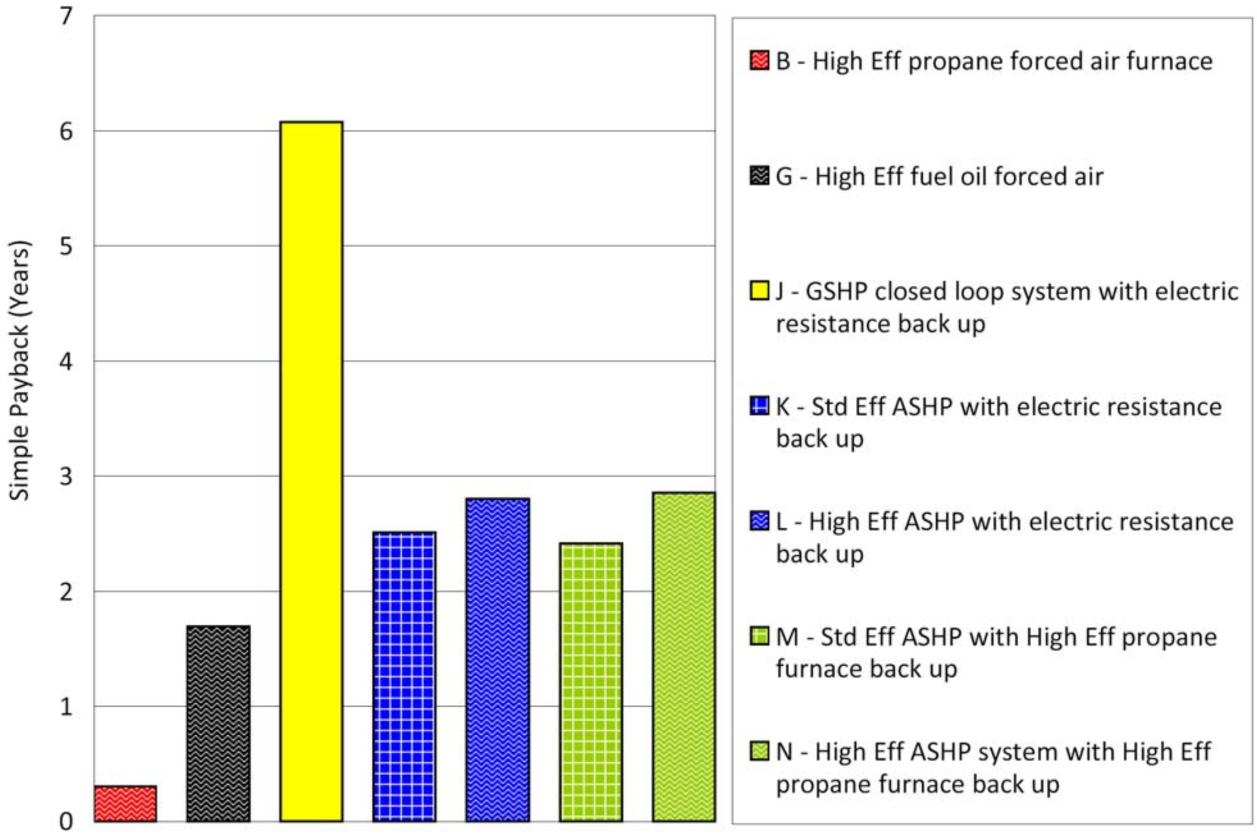

Figure 9: Simple Payback of Various Heating Systems for Cold Climate Existing Homes, Assuming a 78 AFUE Propane Furnace as the Baseline System

The scenario above assumes that the home already has forced-air duct work in place, and evaluates a range of different forced-air systems as possible replacements for the home. Figure 9 clearly shows that investing in a high efficiency propane furnace will quickly (< 1/2 year) result in heating energy savings which are greater than the added cost for the 95% efficient furnace. The GSHP system will provide significant heating energy savings relative to a 78% propane furnace (refer to Figure 7); however the sizable up-front system costs take 6+ years to recover through reduced heating bills. Air-source heat pump systems and dual fuel systems coupling ASHPs with back-up furnaces are estimated to have paybacks in the 2-3 year range, while a high efficiency fuel-oil system would be less than 2 years.

Scenario C: For an existing home in the Cold Climate where the homeowner is strongly interested in high efficiency systems and needs to replace the old heating system, what is the payback for alternative heating systems assuming the default replacement system will be a 95% efficient propane furnace?

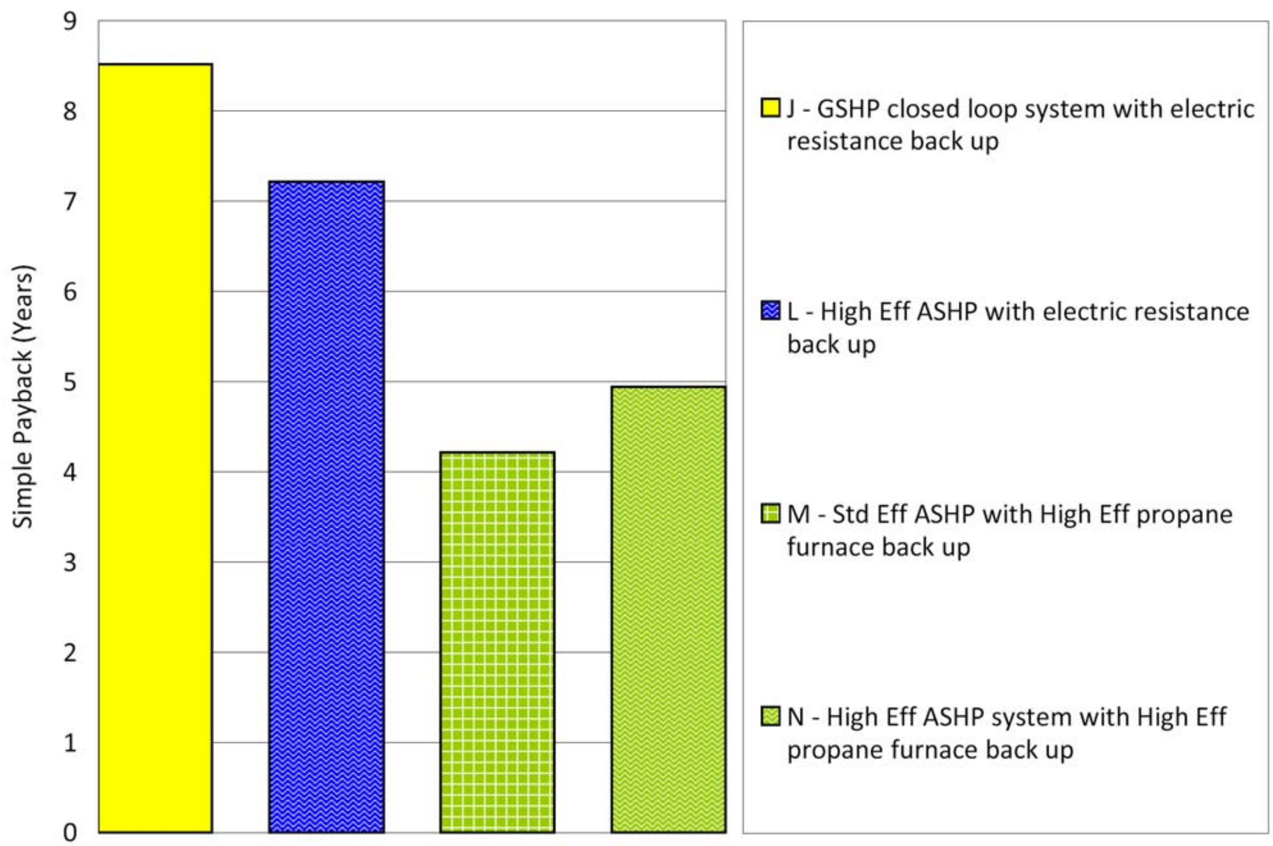

Figure 10: Simple Payback of Various Heating Systems for Cold Climate Existing Homes, Assuming a 95 AFUE Propane Furnace as the Baseline System

In Figure 10 above, the payback for high efficiency systems such as a GSHP (System J), a high efficiency ASHP (System L), or a high efficiency dual fuel system (System N) is roughly in the 5 to 8 year range. This is due to fairly comparable operating cost performance between the high efficiency propane furnace and Systems L and N, so the ability to make up for added first cost is somewhat limited. And in the case of the GSHP system, its relatively lower operating costs are offset by the higher initial investment which is required, which extends the payback. The best payback opportunity is offered by the dual fuel system utilizing a standard efficiency ASHP (System M).

Scenario D: For an existing home in the Cold Climate where the homeowner needs to replace the old fuel oil heating system, what is the payback for more efficient systems relative to a standard 78% fuel oil furnace change-out?

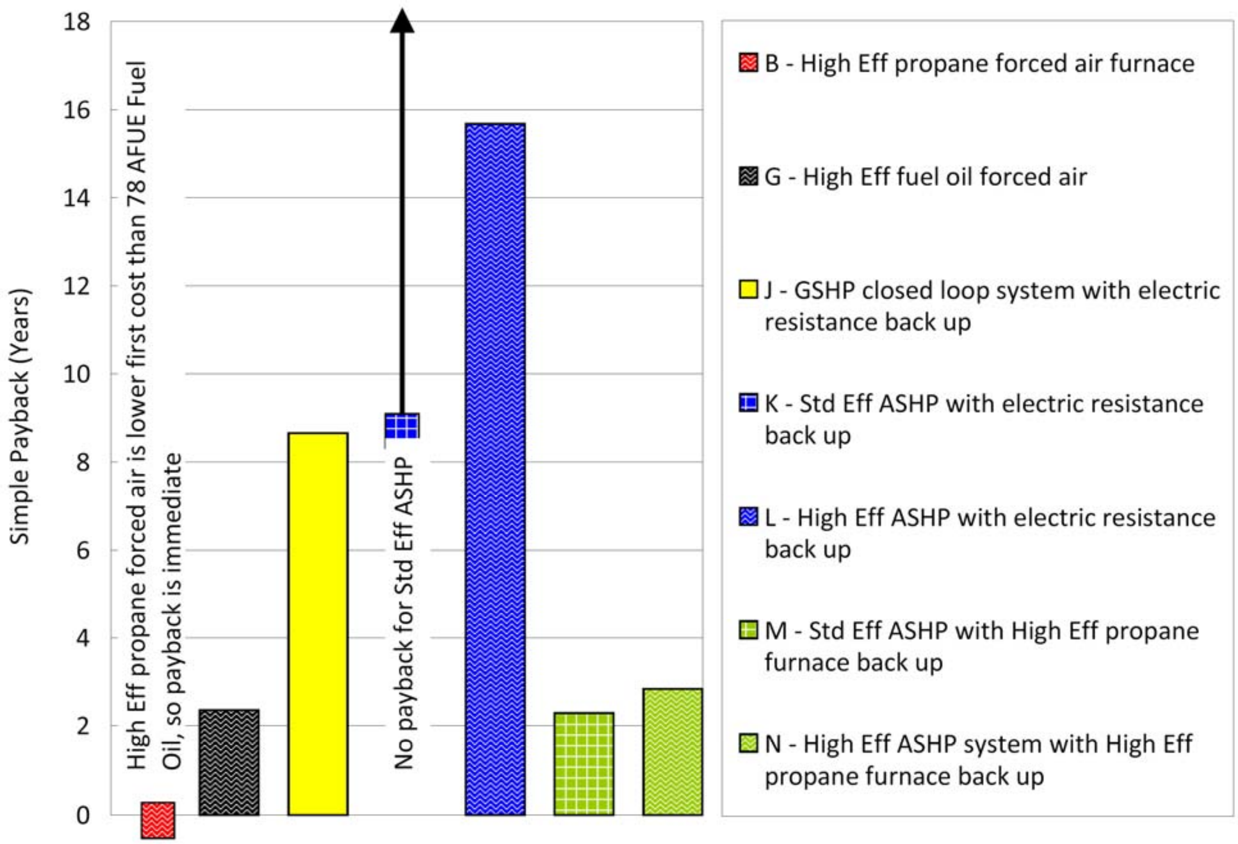

Figure 11: Payback of Various Heating Systems for Cold Climate Existing Homes, Assuming a 78 AFUE Fuel Oil Furnace as the Baseline System

The scenario explores the options when considering the replacement of an old fuel oil heating system. The chart in Figure 11 is based on the data for the 2 Cold Climate locations in the study which involved fuel oil: Burlington, VT and Buffalo, NY.

Notably, a high efficiency propane system actually has an immediate payback because it has a lower first cost *and* lower operating costs. Fuel-switching costs are not incorporated in system First Costs, to the extent that they apply.

A high efficiency fuel oil furnace would pay back in about 2 years compared to the standard efficiency fuel oil furnace. Also evident on the graph – the standard efficiency ASHP actually has an infinite payback compared to the baseline system because it is more expensive to operate and more expensive in terms of first cost. Note that the average electricity price in these 2 locations is \$0.17/kWh.

Dual fuel systems, similar to the other two scenarios above, are not the fastest payback option but do present a viable option with a payback in the 2-3 year range.

In each of the scenarios above, ultimately individual homeowners need to make decisions about how they should best invest their money. It should 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. While tax credits and incentives are not included in the payback analysis above (see page 11 for this discussion), interested readers can review available offers at the Database of State Incentives for Renewables & Efficiency (DSIRE) www.dsireusa.org.

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, fuel oil, or other fossil sources for combustion, release green house gasses (GHGs) such as CO2 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 in fact 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.

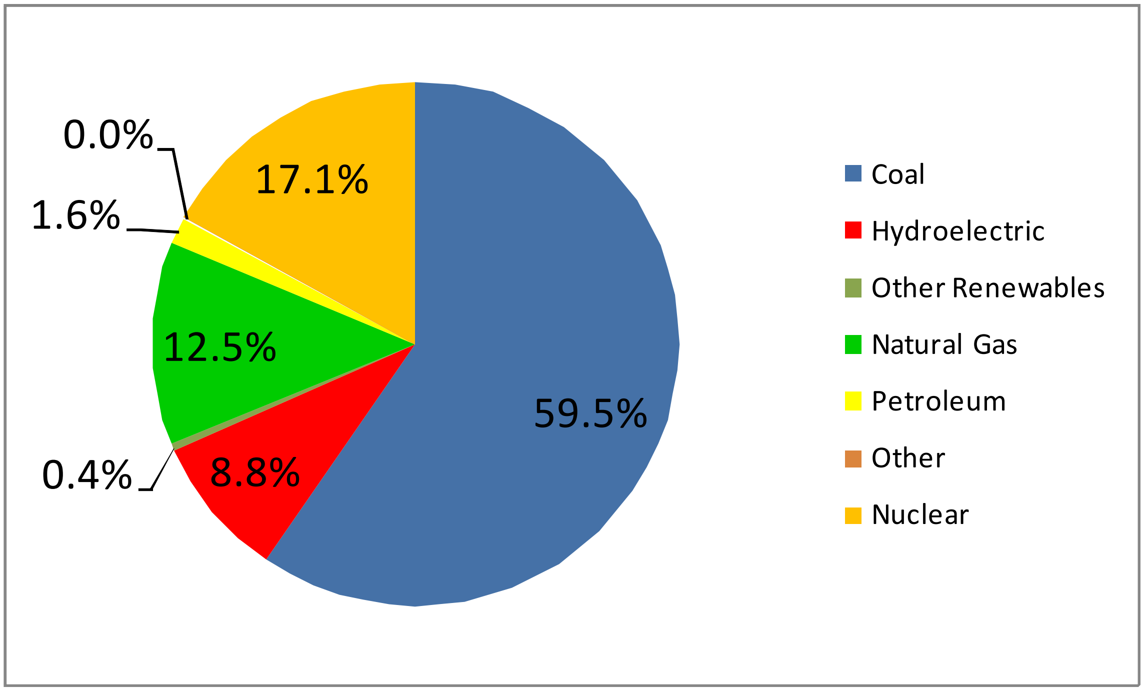

Figure 12: Electric Power Industry Electricity Generation by Energy Source, 2007
Source: U.S. Energy Information Administration, Electric Power Annual 2007

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 below illustrates the CO2 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 B. As described above, the modeling software used for the energy analysis also 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 emission factor which reflects the quantity of GHGs that result from the generation of electricity in the state.

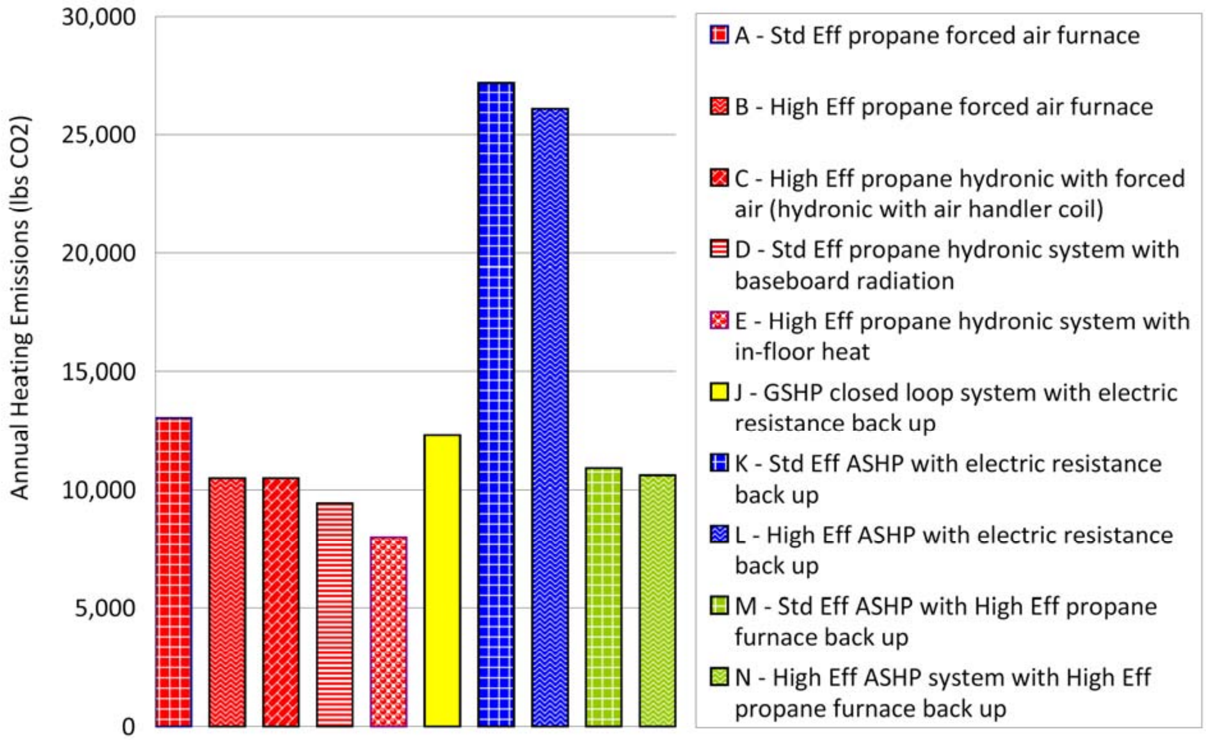

Figure 13: CO2 Emissions for Heating Systems for New Home Analysis for the Midwest Region

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 K) has more than double the CO2 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 far less efficient and uses more electricity, which in turn means greater carbon emissions.

To put these abstract quantities of "pounds of CO2" into somewhat more understandable terms[2], the difference each year in carbon emissions between the standard propane furnace and the standard ASHP is roughly equal to:

- the GHG emissions of a passenger vehicle for an entire year, or

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

- the carbon sequestered by 1.5 acres of pine forest in a year.

It should also be noted that these are only <u>annual</u> numbers, so for each year of operation the propane furnace would result in additional emissions benefits. So a homeowner in the Midwest could essentially offset the carbon emissions from one of their passenger cars for its entire life by opting to use a propane furnace instead of a standard air-source heat pump.

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 the high efficiency boiler (95%) and lower distribution system losses compared to forced-air duct (furnace) systems
- the ground-source heat pump system (System J) has lower emissions compared to ASHPs due to more efficient operation, but greater emissions than most propane-based systems due to greater consumption of electricity
- the dual-fuel systems, which combine an ASHP with a high-efficiency propane back-up furnace (Systems M and N), avoid the problem of inefficient resistance heating by turning off the heat pump during cold 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 dual fuel system emissions are similar to those of a 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). 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.

<u>The Cost to Save a Ton of CO2</u>
As the global community migrates towards carbon emission caps, trading schemes, and emission allowances, the metric of "$ per ton CO2 saved" is becoming a valuation tool for assessing carbon savings opportunities.

Looking at an example of two alternatives, one can estimate the cost of the carbon emissions reductions which result from using a dual fuel heating system (System M) compared to a high efficiency ASHP system (System L) in the Midwest.

System	First Cost (based on Midwest locations)	Heating Energy Costs over Product Life Span (Midwest)	CO_2 Emissions from Heating over Product Life Span - Midwest Location (tons)	\$ per Ton CO_2 Avoided
L – High efficiency ASHP with electric resistance back-up	\$10,041	\$21,512	185.3	
M – Standard efficiency ASHP with high efficiency propane furnace back-up	\$10,356	\$21,264	78.4	
Difference	\$315	-\$248	106.9	**~ \$1/ton CO_2**

Figure 14: \$/Ton CO_2 Comparing High Efficiency ASHP and Standard ASHP/High Efficiency Propane Furnace Back-up System

The dual-fuel system carries a higher first cost but also slightly lower annual heating energy costs (based on the study's data for Midwest locations). This system also offers significantly lower carbon emissions over the life of the system (14.25 years in this analysis). Combining the two cost differences with the emissions reduction, the "cost" of the dual fuel system's carbon savings over the life of the system is roughly \$1 per ton of avoided CO_2 emissions, relative to the high efficiency ASHP system.

To put this figure in general context, a recent analysis of carbon reduction opportunities found that wind power costs about \$38/ton of CO_2 saved and solar power at \$30/ton CO_2[3]. The various systems assessed in the current study would result in a multitude of outcomes depending on first cost, operating cost, and emissions. Also note that the analysis methodology for the wind power and solar costs noted above varies from the simple example calculation made here. The solar and wind data are merely presented to illustrate that emissions reductions from lower emitting residential heating systems can be a viable opportunity, especially in a coal-intensive region like the Midwest where utilizing high-efficiency propane equipment or dual fuel systems results in significant reductions.

[3] "Reducing US Greenhouse Gas Emissions: How Much at What Cost?" US Greenhouse Gas Abatement Mapping Initiative Executive Report", 2007.

Conclusions

Considering the extent of information generated in this analysis a number of conclusions are found involving heating system performance. In reviewing operating cost, payback, and emissions analyses of the system, systems which appear strong in one respect are not the best 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 three of these factors. Occupant comfort is also another critical consideration, although that issue was not included in this analysis.

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

- Operating costs for the systems (Figure 7) show the majority of systems within a range of annual costs between ~$1700 and $2200. The grouping of systems in this range can be considered fairly close, and would easily switch positions with shifts in utility rates for propane and/or electricity. Fuel oil systems generally trend above this range, while the GSHP system was lower than all other systems. The lower GSHP system operating costs must be balanced against higher first cost for this system.
- 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 matched these characteristics and compared favorably against lower first cost options as well as lower operating cost options. Dual fuel systems combining an air-source heat pump with a high efficiency propane furnace for back-up heat were a viable option in several scenarios as well.
- Greenhouse gas emissions, quantified in terms of CO_2 within this study, result from the operation of heating systems regardless of fuel source. Emissions data from heating systems in the Midwest showed a relatively heavy carbon impact from air-source heat pump systems, while propane systems and dual fuel systems resulted in much lower (~ ½) quantities of CO_2 emissions.

Looking ahead, several important variables in this study are likely to evolve in the next several years. These include potential impacts on residential electricity prices resulting from carbon emissions regulations, volatility in propane and fuel oil pricing, and a greater emphasis on the GHG emissions of homes. On this last issue, heating systems with apparently equal efficiencies or even equal operating costs may increasingly be viewed as unequal if their carbon footprint is significantly different.

Appendices

Appendix A: Energy Rates Methodology

The most recent utility pricing data available through U.S. DOE's Energy Information Administration (EIA) was referenced to develop energy prices for each of the 16 analysis locations. Because recent state level data was not always available, it was sometimes necessary to derive state utility price estimates from regional data. Explanations for the derivation of energy prices are presented below.

Heating Oil

Heating oil prices are tracked by the EIA on both the PADD level and the state level for PADDs 1 and 2. PADDs (Petroleum Administration for Defense Districts) are geographic divisions whose petroleum sales, production, and pricing are tracked and reported by the EIA at state and/or district levels. There are 7 total PADD districts: 1A, 1B, 1C, 2, 3, 4, and 5. States are assigned to the PADDs as shown below in Figure 15.

PADD	States
1A	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont
1B	Delaware, District of Columbia, Maryland, New Jersey, New York, Pennsylvania
1C	North Carolina, Virginia, West Virginia
2	Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, Oklahoma, South Dakota, Tennessee, Wisconsin
3	Alabama, Arkansas, Louisiana, Mississippi, New Mexico, Texas
4	Colorado, Idaho, Montana, Utah, Wyoming
5	Alaska, Arizona, California, Hawaii, Nevada, Oregon, Washington

Figure 15: States by PADD Designation

Heating oil prices are reported for PADDs 1A, 1B, 1C, and 2 as well as most of their individual states on a monthly basis. This study requires heating oil prices for Vermont in PADD 1A and New York in PADD 1B. Monthly price data for New York and Vermont was collected and averaged from January, 2008 – December, 2008 to provide the most recent annual average state residential price data.

Electricity

Electricity prices are collected by the EIA on a monthly basis for all states. Monthly price data for each state location within the study was collected and averaged from January, 2008 – December, 2008 to provide the most recent annual average state residential price data.

Propane

Propane prices are available from the EIA in two data sets. The first data set provides weekly heating season prices by PADD and by state for PADD 1A, 1B, 1C, and 2. The second data set provides monthly prices by PADD only. To estimate monthly prices at the state level, weekly heating season prices were used to develop state to PADD price ratios. These ratios were derived from 2008 data. State to PADD price ratios were then applied to monthly PADD prices to provide state level monthly estimates for propane pricing. The 12 months of data for 2008 were then averaged to obtain the most recent annual average state residential price data. Where ratios could not be calculated due to missing data (e.g. PADD 3, 4, and 5), the PADD average was used as a proxy for the state level estimate.

City	State	PADD	Residential Propane Price ($/gal)	Residential Heating Oil Price ($/gal)	Residential Electricity Price ($/kWh)
Burlington	VT	1A	3.02	3.61	0.15
Baltimore	MD	1B	2.92	n/a	0.14
Buffalo	NY	1B	2.75	3.54	0.19
Des Moines	IA	2	1.87	n/a	0.10
Peoria	IL	2	2.15	n/a	0.11
Indianapolis	IN	2	2.31	n/a	0.09
Grand Rapids	MI	2	2.30	n/a	0.11
Duluth	MN	2	2.04	n/a	0.10
Columbia	MO	2	2.04	n/a	0.08
Mansfield	OH	2	2.44	n/a	0.10
Nashville	TN	2	2.15	n/a	0.09
Madison	WI	2	2.13	n/a	0.12
Montgomery	AL	3	2.54	n/a	0.10
Boise	ID	4	2.30	n/a	0.07
Las Vegas	NV	5	2.57	n/a	0.12
Portland	OR	5	2.57	n/a	0.09

Figure 16: Utility Prices Determined for Use in Analysis

Appendix B: Annual CO2 Emissions Resulting from Heating Energy

System	Midwest	Mid-Atlantic	Northeast	Southeast	Northwest	West
A - Std Eff propane forced air furnace	13,042	11,019	13,235	6,073	7,526	5,915
B - High Eff propane forced air furnace	10,477	8,896	10,865	4,880	6,130	4,666
C - High Eff propane hydronic with forced air (hydronic with air handler coil)	10,477	8,896	10,865	4,883	6,136	4,692
D - Std Eff propane hydronic system with baseboard radiation	9,436	8,176	10,320	4,469	5,785	4,311
E - High Eff propane hydronic system with in-floor heat	7,983	6,908	8,690	3,776	4,870	3,624
F - Std Eff fuel oil forced air	N/A	16,035	17,645	N/A	N/A	N/A
G - High Eff fuel oil forced air	N/A	13,238	11,590	N/A	N/A	N/A
H - High Eff fuel oil hydronic with forced air (hydronic with air handler coil)	N/A	14,555	12,803	N/A	N/A	N/A
I - High Eff fuel oil hydronic system with in floor heat	N/A	11,363	12,800	N/A	N/A	N/A
J - GSHP closed loop system with electric resistance back up	12,294	6,424	57	3,973	1,297	4,366
K - Std Eff ASHP with electric resistance back up	27,211	12,160	125	6,924	2,023	7,035
L - High Eff ASHP with electric resistance back up	26,094	11,382	120	6,401	1,866	6,420
M - Std Eff ASHP with High Eff propane furnace back up	10,902	7,873	7,642	4,080	3,519	4,498
N - High Eff ASHP system with High Eff propane furnace back up	10,599	7,652	7,642	3,987	3,403	4,315

Figure 17: CO2 Emissions by Region for Various Heating Systems (New Homes)

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