Comparative Energy Use of Residential Gas Furnaces and Electric Heat Pumps

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About the Author

Steven Nadel has been ACEEE's executive director since 2001. He has worked in the energy efficiency field for more than 30 years and has over 200 publications. His current research interests include utility-sector energy efficiency programs and policies, state and federal energy and climate change policy, and appliance and equipment efficiency standards. He joined ACEEE in 1989 and previously served as deputy director of the organization and director of ACEEE's Utilities and Buildings programs.

Prior to ACEEE, Steve planned and evaluated energy efficiency programs for New England Electric, a major electric utility; directed energy programs for the Massachusetts Audubon Society, Massachusetts' largest environmental organization; and ran energy programs for a community organization working on housing rehabilitation in the poorest neighborhoods of New Haven, Connecticut. Steve earned a master of science in energy management from the New York Institute of Technology and a master of arts in environmental studies and a bachelor of arts in government from Wesleyan University.

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Executive Summary

This paper explores the question of whether we should be encouraging or discouraging natural gas use in residential space-heating and water-heating applications based on relative source energy use. Our analysis looks primarily at the relative energy use for different regions and types of heating systems, but we also include a simplified economic analysis looking at the same regions and system types.

Our analysis finds that electric heat pumps generally use less energy in warm states and have moderately positive economics in these states if a heat pump can replace both the furnace and a central air conditioner. Moderately cold states (as far north as Pennsylvania and Massachusetts) can save energy if electricity comes from the highest-efficiency power plants, but from an economic point of view, life cycle costs for gas furnaces in existing homes will be lower than for heat pumps in these states. (We did not look at new construction where using electric heat and hot water can avoid the need to install gas service.) For cold states further development of cold-temperature electric heat pumps and gas-fired heat pumps will be useful from an energy point of view. Likewise, heat pump water heaters (HPWHs) can save more energy than non-condensing and condensing gas water heaters if power comes from efficient natural gas combined-cycle power plants or renewable-power plants. The life cycle costs of HPWHs and new gas water heaters are similar.

We base this analysis on current conditions. The analysis should be repeated in a few years, as a number of evolving trends will affect the results.

We recommend the following next steps:

- Further analysis at the state, local, and utility levels, as a more nuanced analysis at the utility or local level, based on specific rate schedules and climate zones, will more clearly indicate who might benefit from heat pumps and who will not
- Continued work to develop good cold-climate electric air-source heat pumps and gas-fired heat pumps
- Consideration of programs to encourage use of heat pumps in warm states, starting with further localized analysis and proceeding to pilot programs

More localized analysis is needed, but this analysis finds likely opportunities to save energy and money from electric heat pumps, particularly in warm states.

Introduction

In the US residential sector, electricity and natural gas account for the vast majority of site energy use. According to the latest Residential Energy Consumption Survey (RECS), natural gas accounts for about 46% of total site energy use and electricity for about 43%, while fuel oil and propane account for much of the remainder (EIA 2013).[1] Natural gas is used primarily for space and water heating. According to RECS, of the natural gas used in the residential sector 63% goes toward space heating and 26% toward water heating.

There has been a long-running debate between the natural gas and electricity industries about which fuel is more efficient. For example, the American Gas Association (AGA) has published a variety of analyses that tend to depict natural gas in a positive light (e.g., AGA 2015). The Electric Power Research Institute (EPRI) has published several analyses that portray electric applications in a favorable light (e.g., EPRI 2009), as has the National Rural Electric Cooperative Association (e.g., Dennis 2015).

In the past few years growing concerns about climate change have led to research on how the United States could achieve very large reductions in greenhouse gas emissions, i.e., reductions of 80% or more relative to recent annual emissions. For example, the California Council on Science and Technology found that to achieve even a 60% reduction of greenhouse gases in California would require four key strategies:

1. Aggressive efficiency measures for buildings, industry, and transportation to reduce the need for both electricity and fuel
2. Electrification of transportation and heat wherever technically feasible to avoid fossil fuel use as much as possible
3. Developing emission-free electricity production with some combination of renewable energy, nuclear power, and fossil fuels accompanied by underground storage of the carbon dioxide emissions, while at the same time nearly doubling electricity production
4. Finding supplies of low-carbon fuel to power transportation and heat use that cannot be electrified, such as for airplanes, heavy-duty trucks, and high-quality heat in industry (CCST 2011)

The second strategy includes converting many homes from natural gas to electric space and water heating.

Similarly, Howland et al. (2014), in the Acadia Center's *EnergyVision* report for New England, propose four strategies for achieving deep carbon reductions:

[1] *Site energy use* looks only at energy use at the customer level and does not include upstream energy losses such as in power generation, transmission, and distribution.

1. Electrify buildings and transportation
2. Modernize our electric power grid and adopt a new utility business model
3. Ensure a clean energy supply
4. Maximize energy efficiency

Likewise, in a report on deep decarbonization strategies for the United States, Williams et al. (2014) conclude that

> Deep decarbonization requires three fundamental changes in the US energy system: (1) highly efficient end use of energy in buildings, transportation, and industry; (2) decarbonization of electricity and other fuels; and (3) fuel switching of end uses to electricity and other low-carbon supplies.

However two of these studies are only for limited regions of the United States, and the third study is for the country overall; results from region to region may vary. In addition these studies did not look at the economics of converting from gas (or propane and fuel oil) to electric heat.

In order to begin to address these gaps, this paper presents an initial analysis that explores the question of whether we should be encouraging or discouraging natural gas use in some residential applications based on relative source energy use, with relative carbon emissions also a significant motivating factor.[2] We focus on space-heating energy, as the majority of residential natural gas goes to space heating. Near the end of this paper we briefly look at residential water heating. Our analysis examines primarily the relative energy use for different regions and types of heating systems, but in addition we include a simplified economic analysis, also for different regions and system types. The balance of this paper presents our methodology and findings. We find that based on current equipment and energy-supply technologies and efficiencies, fuel switching may reduce energy use and emissions and save money in some regions and for some system types, but not in other regions for other system types. Quite a few situations are on the cusp. For example, efficient heat pumps often use less energy in warm states and have moderately positive economics in these states, but only if a heat pump can replace both the furnace and a central air conditioner. As the electric generating mix changes in the future and both gas and electric equipment efficiency improves, results will likely evolve. We discuss some of these factors and end with some recommendations for initial program efforts and further research.

Methodology

For our initial analysis we compared the annual natural gas used by gas furnaces with the gas used at a power plant to power a heat pump for a year. In the long term natural gas will often be the marginal generation fuel because of its generally competitive cost and the ability of many natural gas plants to quickly ramp up their power generation in response to

[2] *Source energy use* includes energy used on-site plus transmission and distribution losses as well as the power burned in power plants in order to generate electricity.

variations in demand and supply on the grid. By avoiding inter-fuel comparisons, the analysis also remains much simpler.

However we note that from a carbon emissions point of view, to the extent that sources with lower emissions than natural gas are used on the margin, the comparison will be more favorable to electric heat pumps than what we show here. For example, California recently enacted a requirement that 50% of its electricity come from renewable sources by 2030, which will likely reduce its marginal heat rate to well below that of a natural gas plant. We include one scenario that addresses this situation. On the other hand, if a high-emissions source such as coal-fired power plants is on the margin, the comparison will be more favorable to gas furnaces than what we show here.[3]

At the house level we analyze the following systems:[4]

- 80% annual fuel utilization efficiency (AFUE) furnace (the current federal minimum efficiency standard)[5]
- 95% AFUE furnace (the most common high-efficiency furnace and the ENERGY STAR® level for the North)
- 97% AFUE furnace (the ENERGY STAR Most Efficient level)
- 8.2 heating seasonal performance factor (HSPF) heat pump (current federal standard for split systems)
- 8.5 HSPF heat pump (the ENERGY STAR level)[6]
- 10.3 HSPF heat pump (the ENERGY STAR Most Efficient level)[7]
- A cold-climate electric heat pump. This is a very preliminary analysis based on one field test that found a seasonal 2.8 coefficient of performance (COP) in Connecticut. More products and data are needed.

[3] We received varied input on the likelihood of this scenario. One commenter on a draft of this paper thought that coal would be on the margin in some regions, at least in the near term, noting that natural gas generation can have a lower marginal cost than coal and sometimes puts coal on the margin. On the other hand another commenter noted that with new air pollution regulations for nitrogen oxides (NO_x), mercury, and other hazardous pollutants, many of the marginal coal plants will be retired.

[4] There are also dual-fuel heat pumps and ground-source heat pumps on the market. Dual-fuel heat pumps operate in heat pump mode in mild weather but use a furnace in cold weather. Ground-source heat pumps use the relatively stable temperature of the ground to provide higher heat pump efficiencies, but at a significantly higher cost than conventional air-source heat pumps. To keep our project scope within the bounds of available resources, we did not examine these systems.

[5] Information on current federal standards can be found at energy.gov/eere/buildings/appliance-and-equipment-standards-program.

[6] Under a recent negotiated rulemaking agreement the federal minimum standard will rise to 8.8 HSPF in 2023. At that time the ENERGY STAR level will also rise, likely to a value above 9.0.

[7] The ENERGY STAR Most Efficient level requires an HSPF of 9.6, but as of January 2016 the average HSPF of the ENERGY STAR Most Efficient units listed on the Environmental Protection Agency (EPA)'s website was 10.3.

- A gas-fired heat pump. This is also a very preliminary analysis based on projections of 1.31–1.38 COP from one research project. More data, ultimately including field data, will be needed.

At the power plant level we looked at five different possible marginal heat rates:[8]

- 6,161 Btus (Higher heating value [HHV]/kWh (the rated efficiency of General Electric's best turbine; to achieve this level in the field may require some additional improvements)[9]
- 6,503 Btus/kWh (the best actual heat rate in 2014 as recorded in the database of the federal Energy Information Administration, or EIA)[10]
- 7,658 Btus/kWh (the average combined-cycle plant heat rate in 2014, per EIA)[11]
- 10,408 Btus/kWh (the average steam turbine heat rate in 2014).[12] While gas-fired steam turbines are not common, some coal turbines have been converted to gas, and some additional conversions may happen in the future. This is also something of a proxy for the energy use of a typical coal-fired steam turbine.
- 4,958 Btus/kWh (a scenario for the future, with 50% renewables and 50% high-efficiency natural gas). We use 3,412 Btus/kWh for renewables (the Btu value of a kWh of electricity) and 6,503 Btus/kWh for natural gas (per the best-performing natural gas plant in 2014 as discussed above). California has established a 50% renewable-energy standard for 2030, and some other states are likely to set strong renewable-energy requirements.[13]

The analysis is conducted for 16 states plus 2 regions of 2 states each. The most recent EIA RECS examined 12 of the most populous states individually (EIA 2013). We included all of these states in our analysis, namely, Arizona, California, Colorado, Florida, Georgia, Illinois, Massachusetts, Michigan, Missouri, New Jersey, New York, Pennsylvania, Tennessee,

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[8] All are based on higher heating value, meaning that they include the energy recovered by condensing any steam product of combustion.

[9] GE rates its 7H CC at about 5,550 British thermal units (Btus)/hour based on lower heating value (LHV): powergen.gepower.com/plan-build/products/gas-turbines/7ha-gas-turbine/product-spec.html?cycletype=Combined_Cycle_1x1. We increase this by 11% to estimate the higher heating value (HHV) efficiency: en.wikipedia.org/wiki/Combined_cycle.

[10] This represents the most efficient generating unit in 2014. This is Tennessee Valley Authority (TVA)'s new combined-cycle unit at its John Sevier plant and use the first GE 7E turbines. More data are available at www.eia.gov/electricity/data/eia923/.

[11] www.eia.gov/electricity/annual/html/epa_08_02.html.

[12] Ibid.

[13] Data compiled by the Natural Resources Defense Council (NRDC), using EPA projections from Clean Power Plan implementation, estimate that by 2030 power plants in 16 states will emit on average less than 1,000 pounds of CO_2 per megawatt-hour (MWh) of electricity, significantly less than natural gas emissions. While not all of these states will achieve the 50% renewable-energy standard, their average will be better than the natural gas values we use in this analysis. Source: "State 2030 grid carbon intensity from CPP," spreadsheet attached to email of February 1, 2016, from Pierre Delforge, NRDC. Furthermore, under situations of high renewable generation, during certain high solar and wind hours, the cost of renewable energy will be essentially free, as choices will need to be made on whether to use or dump this energy.

Texas, Virginia, and Wisconsin. In addition we examined the two-state pairs of Oregon/Washington and North/South Carolina.[14] Together these states cover a wide range of regions and climates throughout the United States. These analyses draw on average conditions in each state and do not necessarily apply to regions within each state that are significantly warmer or colder than the state average. Furthermore, by looking at entire states, we miss variations in energy prices between different utilities serving the same state.

The analysis makes use of average space-heating consumption data by state for gas-heated homes in the most recent RECS, which reports data from 2009. We assume that the average furnace captured in the RECS has an 80% AFUE and that more-efficient furnaces will use proportionally less.[15] We also assume that if a gas furnace is converted to a heat pump, it will need to supply the same number of Btus that are provided by the current gas system.[16]

We estimated the seasonal efficiency for heat pumps at different locations using a methodology developed by the Florida Solar Energy Center (FSEC), which estimates seasonal heat pump efficiency as a function of local winter design temperature (Fairey et al. 2004). Fairey et al. find that depending on winter temperatures, heat pump seasonal efficiency can be as much as 40% below the rated efficiency (e.g., in Minnesota) or as much as 20% above the rated efficiency (e.g., in Florida). Our analysis also includes allowances for electric transmission and distribution (T&D) losses of 6% and gas distribution losses of 2%.[17]

[14] For the other states RECS generally groups three or more states together. These are typically states with lower populations than the states examined individually or in pairs.

[15] In 2009 the installed stock of furnaces included a mix of old furnaces with AFUE below 80%, AFUE 80% units, and some condensing furnaces with AFUE of 90% or above. In some colder states the average in 2009 may have been above 80%. To the extent that this occurs our analysis is conservative, as we will have underestimated the gas use of AFUE 80% furnaces and, by extension, also underestimated the gas use of condensing furnaces.

[16] Furnaces contribute to heat losses from a house as heat from the house escapes through the flue. With induced-draft furnaces (i.e., most post-1992 furnaces), these losses are generally modest, and for condensing furnaces (with an AFUE of 90% or more), flue losses are smaller still. We do not consider this effect in our analysis. Furthermore, our furnace analysis does not include electricity to power the blower. A small amount of blower power is included in the HSPF ratings of heat pumps, but these ratings essentially assume very low friction in duct systems. In the field most duct systems have a lot of friction; hence the HSPF ratings include only a minority of typical blower power.

[17] Per EIA data. The 6% figure represents the average over the previous decade. See www.eia.gov/tools/faqs/faq.cfm?id=105&t=3. Other sources have estimated losses as high as 8%, but these appear to include theft and unaccounted-for power. For electric we include both transmission and distribution losses, as these losses occur downstream of the power plant. For natural gas we include only distribution-system losses, as pipeline losses will affect both gas transported to power plants and gas transported to distribution networks. Published estimates of distribution losses appear to range from 1% to 4%. The 1% estimate is from www.aga.org/full-fuel-cycle-energy-and-emission-factors-building-energy-consumption-20node3-update-jan-20node4; 3% is from www.scientificamerican.com/article/how-much-natural-gas-leaks/; 3.4% for 2014 is from www.eia.gov/naturalgas/annual/pdf/table_001.pdf; 4% is from pubs.naruc.org/pub/538EB66D-2354-D714-51CD-86E3D5DC7824. However the 3% and 4% estimates also include unaccounted-for gas, and the 3.4% estimate includes pipeline losses, which are incurred regardless of whether the gas goes to a power plant or to a local distribution system. Given these data points we estimate 2% distribution losses in our analysis.

Energy Use Comparisons

We give detailed tables from our analysis in Appendix A. In particular, in table A3 we provide the results of five comparisons:

1. Comparing an 80% AFUE furnace with an 8.2 HSPF heat pump (the current federal minimum standards)
2. Comparing a 95% AFUE furnace with an 8.5 HSPF heat pump (the current ENERGY STAR levels)
3. Comparing 95% and 97% AFUE furnaces with a 10.3 HSPF heat pump (i.e., comparing current high-efficiency products)
4. Comparing a 95% AFUE furnace with an electric cold-climate heat pump (with an HSPF in the field of approximately 10)
5. Comparing an electric cold-climate heat pump with a gas-fired heat pump (equivalent to about AFUE 135%)

Figures 1–5 below provide graphical summaries of each of these analyses. Where the electric heat pump uses less source energy, the bar goes above the zero line; where the gas option uses less source energy, the bar goes below the zero line. Note that according to 2009 RECS data the average US home uses a total of about 90 million Btus of energy per year.[18] The differences shown here are generally much smaller than 90 million Btus per year. Thus, while there are energy and carbon savings at stake, at the individual-household level they are not dramatic, hence attracting homeowners' attention may be difficult.

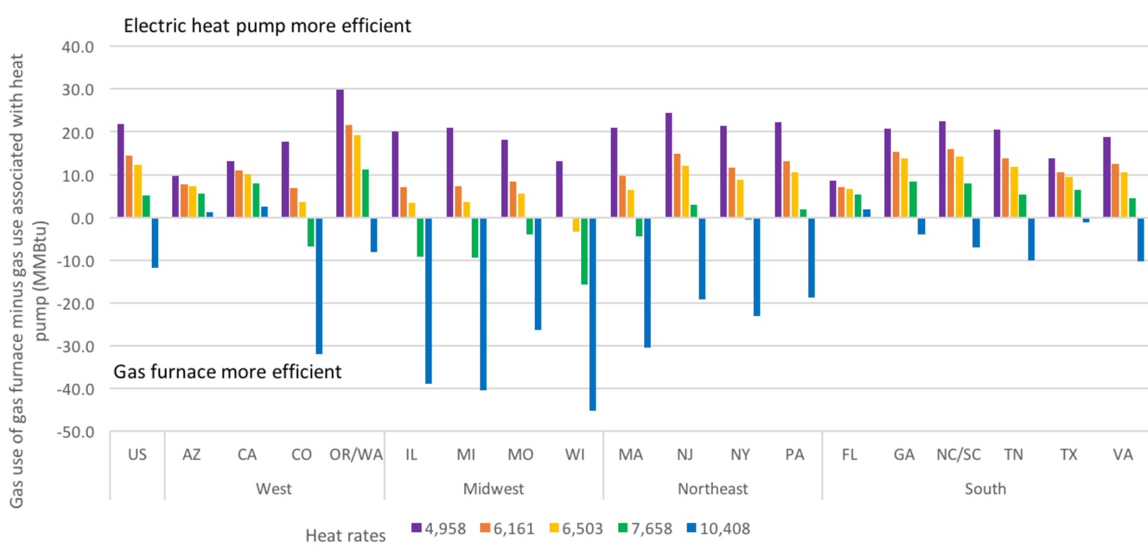

Figure 1. Comparison of an 80% AFUE furnace with an 8.2 HSPF electric heat pump

[18] This represents site energy use and does not include associated energy losses at the power plant and in the T&D system. Over time this figure is likely to decline due to tighter building codes and retrofits to existing homes. We do not factor declining loads into our analysis.

Relative to the numbers presented in figure 1, the comparison in figure 2 below shows gas furnace efficiency increasing by 16% ((95%-80%)/95%), while heat pump efficiency increases by only 4% ((8.5-8.2)/8.5).

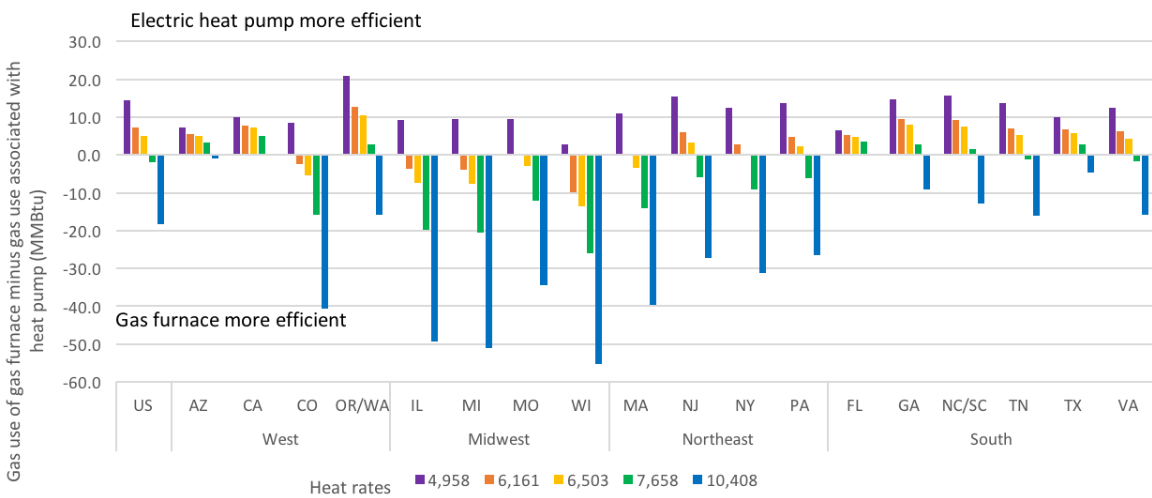

Figure 2. Comparison of a 95% AFUE furnace with an 8.5 HSPF electric heat pump

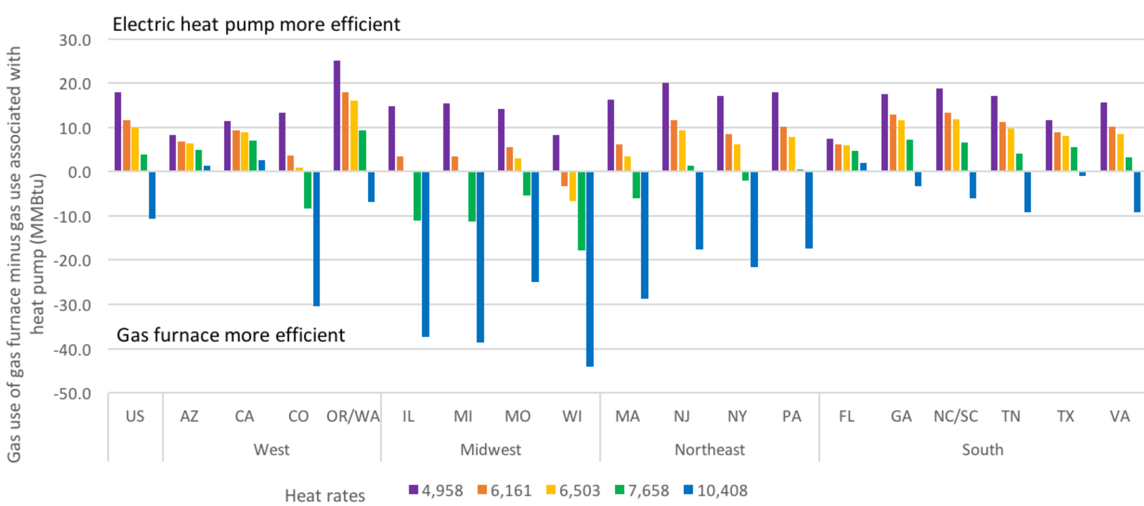

Figure 3. Comparison of a 95% AFUE furnace with a 10.3 HSPF electric heat pump

The comparison in figure 4 below shows data for a 95% AFUE furnace. As we show in table A3 in the appendix, the results for 97% AFUE are very similar. This graph and the one in figure 5 look only at colder climates, where the conventional heat pump did not do well from an energy savings point of view.

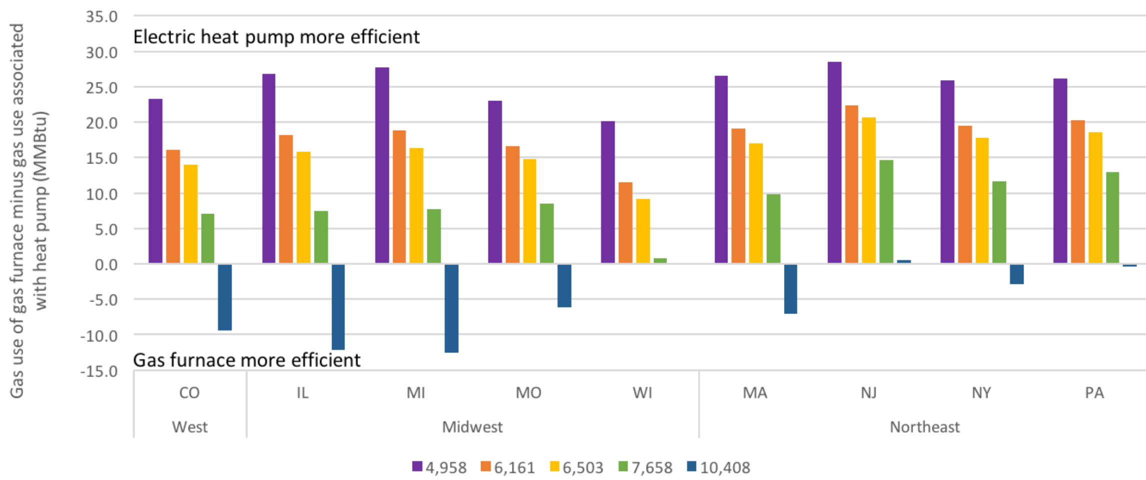

Figure 4. Comparison of a 95% AFUE furnace with a cold-climate electric heat pump

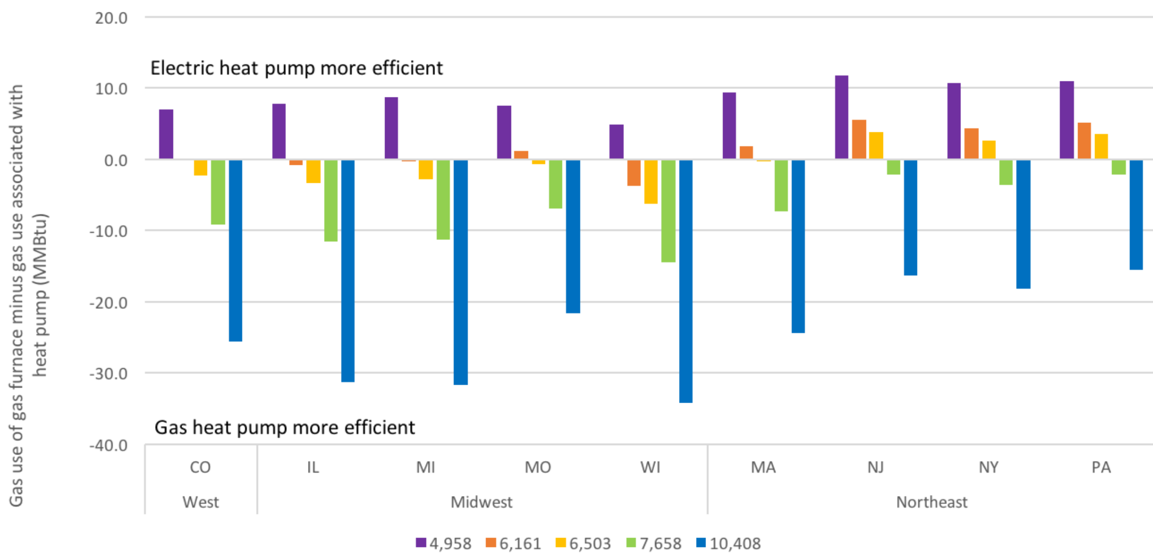

Figure 5. Comparison of a gas heat pump (~135% AFUE) with a cold-climate electric heat pump (in-field HSPF of ~10). This analysis is highly approximate, as the efficiency of the electric heat pump is based on a single field study in one city and extrapolated to other regions, and the efficiency of the gas heat pump is based on modeling. The design and average temperatures by state are also approximate.

Based on these comparisons, from an energy point of view:

- In warm states (Arizona, California, and Florida) electric heat pumps generally use less source energy on average regardless of power plant heat rate. This is because heat pumps are very efficient in warm climates.

- Georgia, New Jersey, Pennsylvania, Tennessee, Texas, Virginia, Oregon/Washington, and the Carolinas join this list when power comes from a standard combined-cycle plant versus a less efficient plant.[19]
- In Colorado, Illinois, Massachusetts, Michigan, Missouri, and New York, a 95% AFUE furnace uses less source energy than an ENERGY STAR heat pump in all but the high-renewable-energy case. However, in these states, the highest-efficiency electric heat pumps use less source energy than gas furnaces when the highest-efficiency power plants (heat rates of ~6,500 and below) or extensive renewable energy is used.
- In all states less energy is used by heat pumps in the 50%-renewable-energy scenario.
- Relative to a 95% AFUE furnace the cold-climate electric heat pump does well, using less energy at heat rates of 7,700 and below. However, for all but the high-renewables scenario (and, in some states, the best combined-cycle power plant), the gas-fired heat pump does better than the cold-climate electric heat pump in the cold states we examined. Data on cold-climate electric heat pumps and gas heat pumps are limited, so these findings are subject to significant uncertainty; more data are needed.

While our analysis does not focus on carbon emissions, our results provide some insights on relative carbon emissions. Where the heat pump uses less energy than the gas furnace, the heat pump is also likely to emit less direct and indirect carbon unless the heat pump is powered by coal-generated electricity. If a high proportion of electricity comes from renewable energy, this will decrease carbon emissions relative to emissions with a gas-generating plant. However, where the gas furnace uses less energy but electric power comes disproportionately from renewable energy, further analysis will be needed to determine relative carbon emissions.

Economic Analysis

We also analyzed the economics of the different options from the homeowner perspective.

METHODOLOGY

For this analysis we used estimates of installed costs from the most recent US Department of Energy (DOE) Technical Support Documents (TSDs) for furnaces and residential central air conditioners and heat pumps. Our analysis looks only at systems that are now widely available; presently there are not enough data to include cold-climate electric heat pumps and gas-fired heat pumps in the economic analysis. We looked at costs assuming that a house did not have central air-conditioning, but we also conducted a set of analyses for homes with central air-conditioning, assuming a heat pump could be installed instead of a central air conditioner at the time the central air conditioner needed to be replaced. In the 2009 RECS, 61% of US homes had central air-conditioning including 35% in the Northeast,

[19] The Northwest Power and Conservation Council (2012) provides a more detailed analysis for the Northwest.

66% in the Midwest, 82% in the South, and 44% in the West.[20] The RECS reports that 87% of homes built from 2000 to 2009 included central air-conditioning (EIA 2013).

Our analysis focuses on existing homes where gas service and ducts are already installed. For new construction the results might be very different, as several thousand dollars can be saved by not installing gas service. In addition, high-performance ductless heat pumps may be an option for new construction. These systems are generally more efficient than ducted heat pumps but incur higher capital costs. On the other hand, by avoiding the costs of ducts (and the space taken up by ducts), they may be cost competitive in some new homes.

We based energy costs in our analysis on data from EIA on average gas and electric costs by state in 2014. We then adjusted for the expected nationwide increase in energy costs during the operating life of this equipment. Specifically, based on EIA's *Annual Energy Outlook 2015* (AEO) (EIA 2015), we compared estimated residential gas and electric prices in 2025 and 2014 and applied this ratio to state-specific energy prices from 2014. In many states energy costs vary by season. Our analysis adjusted for seasonal effects on electricity and natural gas prices by developing a state-by-state factor comparing 2014 winter prices (January–March and November–December) with annual average prices. In most states winter natural gas and electricity prices are slightly lower than annual prices, but the adjustment was generally small. In many states the price of energy varies with the quantity used, and for some residential customers electricity price varies by time of use. This simple analysis does not address these two factors.[21]

We calculated the life cycle cost for each system type and location assuming an 18-year equipment life and a 5% real discount rate.[22] We then subtracted the life cycle cost of the gas system from the life cycle cost of the heat pump system to calculate the net life cycle cost for each comparison. Both furnaces and heat pumps have periodic maintenance costs, but we did not include these in this analysis. We considered including a scenario with higher natural gas prices, but because the percentage of electricity generated from natural gas is growing, higher natural gas prices will affect both gas furnaces and electric heat pumps. In the 2015 AEO, for example, EIA includes a high-fuel-price scenario that increases residential natural gas prices in 2025 by 7.35% and increases residential electricity prices by 6.64% (EIA 2015). This is not a large enough difference to significantly affect the results of our analysis.

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[20] Many of the major cities in the West are on the Pacific coast, where there is less need for air-conditioning than in the interior.

[21] For example, Pacific Gas & Electric (PG&E) gets very different results from those shown here when it applies its tiered electric rates and local climate (A. Pligavko, Energy Efficiency Strategy Group, PG&E, pers. comm., February 5, 2016).

[22] The 5% real rate is approximately the weighted average cost of utility capital considering both stock equity and bonds. Energy efficiency investments are commonly analyzed using the same discount rate as new generating plants and other energy system infrastructure, as energy efficiency reduces the need for this infrastructure. Currently utility capital cost is lower than 5% real (see pages.stern.nyu.edu/~adamodar/New_Home_Page/datacurrent.html), but 5% real represents a typical capital cost over the last decade.

We present further details of the analysis in table A4 in the appendix.

RESULTS

Based on our analysis, we find that electric heat pumps have higher equipment and installation costs than gas furnaces and that electricity is generally more expensive per Btu than natural gas. As a result, in all of the comparisons the gas furnace has a lower life cycle cost for homes without central air-conditioning. However, if a central air conditioner can be replaced with a heat pump, the high-efficiency heat pump has lower life cycle costs in climates from Virginia southward as well as in the Northwest. This is shown by an analysis that credits the avoided cost of a central air conditioner and also includes cooling-energy savings from replacing a central air conditioner meeting federal minimum efficiency standards—a seasonal energy efficiency ratio (SEER) of 13 in the North and a SEER of 14 in the South—with a higher-efficiency heat pump. Figure 6 presents these results.

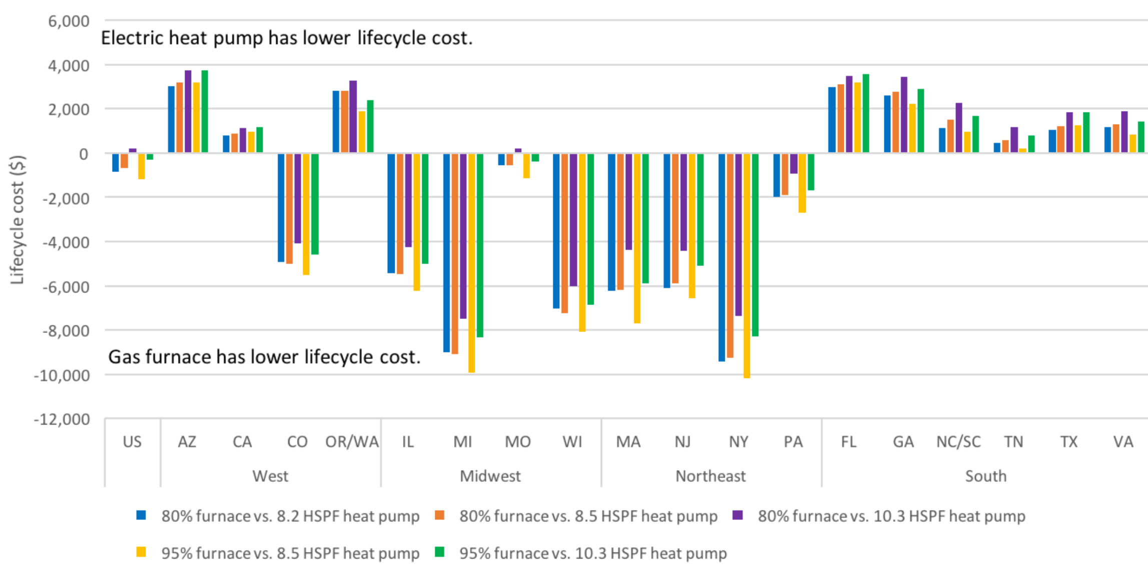

Figure 6. Life cycle cost comparison of several furnaces and heat pumps for cases in which a heat pump can replace a central air conditioner

However, where heat pumps are less expensive than gas furnaces on a life cycle cost basis, the life cycle cost savings are typically $500–3,500, or about $25–195 per year. These savings may appear modest to some homeowners and may not influence many of them unless there is a significant program or policy push.

As discussed above, our analysis is only for existing homes. The results may be more positive toward heat pumps for new homes, as most new homes have air-conditioning and the cost of supplying gas to the home can be avoided by installing heat pumps.[23]

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[23] We discuss gas versus electric water heating in the next section. However some consumers prefer additional gas-fueled appliances including stoves, clothes dryers, and fireplace amenities. The desire for other gas appliances must be factored into a decision on whether or not to install gas service in a new home.

We also find that small changes in the assumed values for many variables do not change the overall results. For example, when we used different values for gas and electric distribution losses or for winter electric and gas prices, the results barely changed. However at the local level there may be larger variation than we considered in some values such as energy use, energy prices, and installation costs. As a result we recommend that this analysis be considered indicative, and we encourage performing the analysis using actual local values. For the near future, efforts should focus on local analysis and not on divergent high-level variables.

A Note on Water Heating

Thus far all of this discussion has focused on space heating. However, because water heating is also a significant factor in home energy use, we also prepared a single national comparison of gas and electric water heaters from an energy and economic point of view. For this analysis, as with the space-heating analysis, we began with average natural gas use for water heating from the 2009 RECS, which shows a national average of 21.1 million Btus per year (EIA 2013).[24] We estimated that the average gas water heater in 2009 had an energy factor (EF) of 0.54 (the old federal standard), resulting in a water-heating demand of 11.4 million Btus. (The other 9.7 million Btus are lost up the stack or in heat loss from the water heater.) We then analyzed a heat pump water heater (HPWH) and a condensing gas water heater that would provide the same amount of hot water as the EF 0.54 non-condensing gas water heater. For this analysis we estimated that a new condensing gas water heater would have an EF of 0.77 (from Lekov et al. 2011), and an HPWH would have an EF of 1.92 or 2.5.[25] Our analysis also included an EF 0.62 water heater, which is the typical standard for non-condensing gas water heaters as of 2015. All of the water heaters we examined are storage water heaters, as tankless water heaters are much less common and would make the analysis more complicated. Because this is a simple analysis, we did not consider interactions between the HPWH and space-heating and air-conditioning energy use, nor did our analysis consider the fact that some warm air in a home will be lost up the flue of a non-condensing gas water heater; this is not an issue for HPWHs as they do not need a flue.[26]

At an EF of 1.92, the HPWH uses 1,736 kWh per year. Adding the same allowances for gas- and electric-system distribution losses as discussed above for space heating, and assuming the electricity to operate the heat pump comes from a natural gas–fired power plant, the

[24] According to data in RECS 2009, the average home with a gas water heater has about 2.7 residents, while the average home with an electric water heater has about 2.5 residents. The more residents, the more hot water is generally used. Our analysis is based on the water use of the average gas water heater customer.

[25] For the 1.92 EF, see Ealey and Domitrovic (2015), presenting results of an EPRI field test in New York State. A 2012 EPRI field study in a variety of climates found lower seasonal EFs (Bush 2012). Some new HPWHs are rated at HSPFs above 3 (e.g., see www.geappliances.com/ge/heat-pump-hot-water-heater.htm. Because field tests of older HPWHs indicate that field performance is often below laboratory performance (see footnote above), we roughly estimate that these newer HPWHs will have field EFs of around 2.5.

[26] If the HPWH is located in the living space it will scavenge some heat from the living space. On the other hand, during the cooling season an HPWH will provide some cooling, reducing air-conditioning energy use. For HPWHs located in basements and garages, these effects are likely to be small. Our assumed EF value for HPWHs is based on an average application from field studies, assuming more basement and garage installations but also some installations in living spaces.

HPWH uses less energy than the new non-condensing gas water heater at heat rates of about 10,170 and below. For the condensing gas water heater, the break point is about 8,200 Btus/kWh. In other words, for either type of gas water heater the heat pump uses less energy if the electric power comes from a combined-cycle plant. An EF 2.5 HPWH does better, using less gas than a condensing gas water heater at heat rates of about 10,600 and below. We provide details of this analysis in table A5 in the appendix.

We also examined the economics of this conversion, using estimated national average electricity and natural gas prices for 2025 from EIA (2015) and installed costs for gas and electric water heaters from the most recent DOE analysis (Lekov et al. 2011). These costs assume that electric service and gas service are already in the home. Under these assumptions we found that the non-condensing gas water heater is less expensive to install (by about $400) than the EF 1.92 HPWH, and the non-condensing gas water heater and the HPWH cost about the same to operate. As a result the non-condensing gas water heater is about $400 more expensive to purchase and operate over the life of the water heater than the EF 1.92 HPWH (present net value, assuming a 5% real discount rate). On the other hand the EF 2.5 HPWH is less expensive to install than a condensing gas water heater and has slightly lower operating costs. Thus the EF 2.5 HPWH has lower life cycle costs than the condensing water heater (about $300 less). Again, we have included details in table A5 in the appendix.

This is a national analysis based on many assumptions. Local and household specifics may be different, and all assumptions are subject to substantial uncertainty. For example, not all houses can install HPWHs, and the economics of both HPWHs and condensing gas water heaters generally improve for households with above-average hot water use.[27] Still, this illustrative analysis tends to show that there is no large life cycle cost difference between efficient gas water heaters and electric HPWHs; gas is slightly less expensive at the EF 0.62/1.92 level, while electric is slightly less expensive at the EF 0.77/2.5 level. The differences in life cycle cost are modest enough that it will generally be difficult to convince owners of gas water heaters to switch to electric without using incentives.

This analysis looks only at existing homes that already have gas water heaters. However, because the economics of HPWHs and gas water heaters are similar for existing homes, the economics will often favor HPWHs for new construction in cases where use of both heat pumps for space heating and HPWHs avoids the cost of installing gas service in a new home.

Summary and Conclusions

Which is better from an energy and economic point of view, a natural gas furnace or an electric heat pump? The answer is that it depends. The results vary by state (due to differences in climate, building stock, and energy prices), furnace and heat pump efficiency, and power plant heat rate. Our analysis suggests that electric heat pumps use less energy in warm states and have moderately positive economics in these states if a heat pump can

[27] Some utilities, particularly some electric cooperatives, are using electric water heaters, both electric-resistance heaters and HPWHs, as load management devices, shutting them off or turning them down during peak periods and/or controlling them so that they operate primarily at night. Our analysis was not detailed enough to consider these issues.

replace both the furnace and a central air conditioner. Moderately cold states (as far north as Pennsylvania and Massachusetts) may save energy if electricity comes from the highest-efficiency power plants, but from an economic point of view, life cycle costs for gas furnaces will be lower than for heat pumps in these moderately cold states.

In cold states, further development of cold-temperature electric heat pumps and gas-fired heat pumps will be useful from an energy point of view. We did not have enough data to analyze the economics of these new technologies. Additionally, while we did not explicitly analyze combined space/water heating systems, these are another promising system type that may merit further development.[28]

Likewise, HPWHs can save energy relative to non-condensing and condensing gas water heaters if power comes from efficient natural gas combined-cycle power plants or renewable-power plants. The life cycle costs of heat pump and new gas water heaters are similar.

Our results are based on current conditions. The analysis should be repeated in a few years, as several trends favor heat pumps, including improving heat pump efficiencies (e.g., the federal minimum efficiency standard will increase to 8.8 HSPF as of 2023, and the ENERGY STAR standard will also increase); development of more cold-climate heat pumps (noted above); possible declines in the cost of HPWHs; increased penetration of low-carbon renewable-energy generation; and the fact that natural gas prices are relatively low at present relative to prior years. Other factors that will affect a future analysis are pending federal furnace standards (which could raise the minimum AFUE to 92% or even 95% in the North), development of gas heat pumps (also noted above), and improvements in home efficiency (for both new construction and existing homes) that will lower average space-heating and -cooling energy use per home.

We have three recommendations for next steps:

1. Further analysis would be useful, particularly at the state, local, and utility levels, using more-specific data on local conditions and different categories of customers. Our results are based on state averages, and a more nuanced analysis at the utility or local level and based on specific rate schedules and climate zones will more clearly indicate who might benefit from heat pumps and who will not. It might be useful if someone, perhaps DOE, developed an analytic engine that local utilities and energy analysts could use after they entered local data.
2. Continued development of good cold-climate electric air-source heat pumps and gas-fired heat pumps. Good cold-climate ductless heat pumps are available, but currently very few systems are designed for use with ducts.[29] For both cold-climate and gas-fired heat pumps, work is needed to examine system economics. These

[28] DOE is working on all three efforts (see energy.gov/eere/buildings/listings/heating-ventilation-and-air-conditioning-projects), and EPRI has a program to develop advanced cold-climate heat pumps (see aceee.org/sites/default/files/pdf/conferences/mt/2016/Domitrovic_MT16_SessionC4_3.22.16.pdf).

[29] For a list of current systems see www.neep.org/initiatives/high-efficiency-products/emerging-technologies/ashp/cold-climate-air-source-heat-pump.

systems save energy, but will probably make economic sense only if the cost is not too much higher than that of current electric heat pumps.[30]

3. The case for converting gas furnaces to electric heat pumps is strongest in warm states, where use of air-conditioning is routine, heat pump performance is not significantly degraded by cold outdoor temperatures, and a heat pump can be purchased for only moderate additional cost relative to a central air conditioner. In these states it might be useful to consider programs to encourage use of heat pumps, starting with further localized analysis and proceeding to pilot programs.

In conclusion, more localized analysis is needed, but this analysis finds likely opportunities to save energy and money from electric heat pumps, particularly in warm states.

[30] For areas without natural gas service, heat pumps may make particular sense, as fuel oil and propane typically cost more per Btu than natural gas.

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Appendix A. Detailed Analysis

Table A1. Analysis of furnaces and conventional heat pumps

	US	West				Midwest				Northeast				South					
		AZ	CA	CO	OR/WA	IL	MI	MO	WI	MA	NJ	NY	PA	FL	GA	NC/SC	TN	TX	VA
Furnace																			
Avg. annual mBtu for natural gas furnace	51.4	17.1	22.6	61.6	63.1	72.5	75.0	57.7	64.9	66.5	63.0	60.7	58.4	14.4	42.3	48.3	47.5	27.0	44.5
Add gas system distribution losses	52.4	17.4	23.1	62.8	64.4	74.0	76.5	58.9	66.2	67.8	64.3	61.9	59.6	14.7	43.1	49.3	48.5	27.5	45.4
Estimated mBtu for 95% AFUE furnace	43.3	14.4	19.0	51.9	53.1	61.1	63.2	48.6	54.7	56.0	53.1	51.1	49.2	12.1	35.6	40.7	40.0	22.7	37.5
Add gas system distribution losses	44.1	14.7	19.4	52.9	54.2	62.3	64.4	49.6	55.7	57.1	54.1	52.1	50.2	12.4	36.3	41.5	40.8	23.2	38.2
Estimated mBtu for 97% AFUE furnace	42.4	14.1	18.6	50.8	52.0	59.8	61.9	47.6	53.5	54.8	52.0	50.1	48.2	11.9	34.9	39.8	39.2	22.3	36.7
Add gas system distribution losses	43.2	14.4	19.0	51.8	53.1	61.0	63.1	48.5	54.6	55.9	53.0	51.1	49.1	12.1	35.6	40.6	40.0	22.7	37.4
Heat pump																			
99% winter design temperature	18	37	40	3	24	2	2	6	-6	6	14	10	13	42	26	23	19	29	18
HSPF adjustment factor for HSPF 8.2 unit	0.1391	-0.1339	-0.1841	0.2998	0.0613	0.3088	0.3088	0.2715	0.3731	0.2715	0.1867	0.2308	0.1980	-0.2186	0.0336	0.0748	0.1266	-0.0095	0.1391
Adjusted HSPF for nominal 8.2 unit	7.06	9.30	9.71	5.74	7.70	5.67	5.67	5.97	5.14	5.97	6.67	6.31	6.58	9.99	7.92	7.59	7.16	8.28	7.06
kWh per year with HSPF 8.2 unit	5,825	1,471	1,862	8,583	6,558	10,233	10,586	7,728	10,099	8,906	7,557	7,699	7,104	1,153	4,270	5,093	5,306	2,609	5,043
Add electric system distribution losses	6,174	1,560	1,974	9,098	6,951	10,847	11,221	8,191	10,705	9,440	8,010	8,161	7,531	1,222	4,527	5,399	5,625	2,766	5,345
mBtu gas consumed as function of heat rate																			
4,958	30.6	7.7	9.8	45.1	34.5	53.8	55.6	40.6	53.1	46.8	39.7	40.5	37.3	6.1	22.4	26.8	27.9	13.7	26.5
6,161	38.0	9.6	12.2	56.0	42.8	66.8	69.1	50.5	65.9	58.2	49.3	50.3	46.4	7.5	27.9	33.3	34.6	17.0	32.9
6,503	40.2	10.1	12.8	59.2	45.2	70.5	73.0	53.3	69.6	61.4	52.1	53.1	49.0	7.9	29.4	35.1	36.6	18.0	34.8
6,711	41.4	10.5	13.2	61.1	46.7	72.8	75.3	55.0	71.8	63.4	53.8	54.8	50.5	8.2	30.4	36.2	37.7	18.6	35.9
7,658	47.3	11.9	15.1	69.7	53.2	83.1	85.9	62.7	82.0	72.3	61.3	62.5	57.7	9.4	34.7	41.3	43.1	21.2	40.9
10,408	64.3	16.2	20.5	94.7	72.3	112.9	116.8	85.3	111.4	98.3	83.4	84.9	78.4	12.7	47.1	56.2	58.5	28.8	55.6
HSPF adjustment factor for HSPF 8.5 unit	0.1467	-0.1422	-0.1954	0.3159	0.0644	0.3254	0.3254	0.2862	0.3926	0.2862	0.1969	0.2434	0.2089	-0.2320	0.0352	0.0787	0.1335	-0.0104	0.1467
Adjusted HSPF for nominal 8.5 unit	7.25	9.71	10.16	5.81	7.95	5.73	5.73	6.07	5.16	6.07	6.83	6.43	6.72	10.47	8.20	7.83	7.36	8.59	7.25
kWh per year with HSPF 8.5 unit	5,669	1,409	1,779	8,475	6,348	10,114	10,463	7,608	10,056	8,769	7,383	7,551	6,947	1,100	4,126	4,934	5,160	2,515	4,908
Add electric system distribution losses	6,009	1,494	1,886	8,984	6,729	10,721	11,091	8,065	10,659	9,295	7,826	8,004	7,364	1,166	4,374	5,230	5,469	2,666	5,203
mBtu gas consumed as function of heat rate																			
4,958	29.8	7.4	9.4	44.5	33.4	53.2	55.0	40.0	52.8	46.1	38.8	39.7	36.5	5.8	21.7	25.9	27.1	13.2	25.8
6,161	37.0	9.2	11.6	55.3	41.5	66.0	68.3	49.7	65.7	57.3	48.2	49.3	45.4	7.2	26.9	32.2	33.7	16.4	32.1
6,503	39.1	9.7	12.3	58.4	43.8	69.7	72.1	52.4	69.3	60.4	50.9	52.0	47.9	7.6	28.4	34.0	35.6	17.3	33.8
6,711	40.3	10.0	12.7	60.3	45.2	71.9	74.4	54.1	71.5	62.4	52.5	53.7	49.4	7.8	29.4	35.1	36.7	17.9	34.9
7,658	46.0	11.4	14.4	68.8	51.5	82.1	84.9	61.8	81.6	71.2	59.9	61.3	56.4	8.9	33.5	40.1	41.9	20.4	39.8
10,408	62.5	15.5	19.6	93.5	70.0	111.6	115.4	83.9	110.9	96.7	81.5	83.3	76.6	12.1	45.5	54.4	56.9	27.7	54.1
HSPF adjustment factor for HSPF 10.3 unit	0.1974	-0.0915	-0.1447	0.3666	0.1152	0.3761	0.3761	0.3369	0.4433	0.3369	0.2476	0.2941	0.2596	-0.1813	0.0859	0.1294	0.1842	0.0403	0.1974
Adjusted HSPF for nominal 10.3 unit	8.27	11.24	11.79	6.52	9.11	6.43	6.43	6.83	5.73	6.83	7.75	7.27	7.63	12.17	9.42	8.97	8.40	9.89	8.27
kWh per year with HSPF 10.3 unit	4,974	1,217	1,533	7,554	5,539	9,025	9,336	6,759	9,054	7,790	6,503	6,679	6,126	947	3,594	4,309	4,523	2,185	4,306
Add electric system distribution losses	5,272	1,290	1,625	8,007	5,871	9,567	9,896	7,164	9,598	8,257	6,894	7,080	6,494	1,004	3,810	4,568	4,794	2,316	4,565
mBtu gas consumed as function of heat rate																			
4,958	26.1	6.4	8.1	39.7	29.1	47.4	49.1	35.5	47.6	40.9	34.2	35.1	32.2	5.0	18.9	22.6	23.8	11.5	22.6
6,161	32.5	7.9	10.0	49.3	36.2	58.9	61.0	44.1	59.1	50.9	42.5	43.6	40.0	6.2	23.5	28.1	29.5	14.3	28.1
6,503	34.3	8.4	10.6	52.1	38.2	62.2	64.4	46.6	62.4	53.7	44.8	46.0	42.2	6.5	24.8	29.7	31.2	15.1	29.7
6,711	35.4	8.7	10.9	53.7	39.4	64.2	66.4	48.1	64.4	55.4	46.3	47.5	43.6	6.7	25.6	30.7	32.2	15.5	30.6
7,658	40.4	9.9	12.4	61.3	45.0	73.3	75.8	54.9	73.5	63.2	52.8	54.2	49.7	7.7	29.2	35.0	36.7	17.7	35.0
10,408	54.9	13.4	16.9	83.3	61.1	99.6	103.0	74.6	99.9	85.9	71.7	73.7	67.6	10.4	39.7	47.5	49.9	24.1	47.5

Notes to table A1:

- Gas use by state for homes with gas space heating, as provided in the 2009 RECS (EIA 2013). To estimate total gas use we added 2% distribution losses (discussed in text).
- We estimated gas use for 95% and 97% AFUE furnaces by multiplying gas use for 80% AFUE by 80/95 or 80/97.
- We estimated heat pump seasonal efficiency for 8.2 HSPF units with the following formula from Fairey et al. (2004):
  - Seasonal HSPF = 8.2 * (1 – adjustment factor)
  - Adjustment factor = 0.1392 – 0.00846 * Design T – 0.0001074 * (Design T)^2 + 0.0228 * 8.2
  - Design T is the 99% design temperature and is based on representative values for each state, as we show in table A1.
- We based heat pump seasonal efficiency for 8.5 and 10.3 HSPF units on a slightly different adjustment factor, also from Fairey et al. (2004). For 8.5 HSPF and above:
  - Adjustment factor = 0.1041 – 0.008862 * Design T - 0.0001153 * (Design T)^2 + 0.02817 * 8.5
- To heat pump electricity use we added 6% for distribution system losses, as we explain in the text.
- We based natural gas use to supply this electricity on a power plant heat rate of 6,161, 6,503, 6,711, 7,658, or 10,408 Btus/kWh, as we explain in the text.

Table A2. Illustrative analyses for cold-climate air-source heat pumps and gas-fired heat pumps (cold states only)

	West	Midwest				Northeast			
	CO	IL	MI	MO	WI	MA	NJ	NY	PA
Cold climate heat pump									
Seasonal HSPF	8.73	8.60	8.60	9.14	7.67	9.14	10.37	9.73	10.20
kWh per year with cold-climate heat pump	5,646	6,745	6,978	5,051	6,767	5,822	4,860	4,992	4,578
Add electric system distribution losses	5,984	7,150	7,396	5,354	7,173	6,171	5,152	5,291	4,853
mBtu gas consumed as function of heat rate									
4,958	29.7	35.4	36.7	26.5	35.6	30.6	25.5	26.2	24.1
6,161	36.9	44.0	45.6	33.0	44.2	38.0	31.7	32.6	29.9
6,503	38.9	46.5	48.1	34.8	46.6	40.1	33.5	34.4	31.6
6,711	40.2	48.0	49.6	35.9	48.1	41.4	34.6	35.5	32.6
7,658	45.8	54.8	56.6	41.0	54.9	47.3	39.5	40.5	37.2
10,408	62.3	74.4	77.0	55.7	74.7	64.2	53.6	55.1	50.5
Gas-fired heat pump									
Average winter temperature	34	35	30	37	17	31	38	26	31
Average COP	1.37	1.37	1.35	1.38	1.31	1.36	1.38	1.34	1.36
Avg. annual mBtu for gas-fired heat pump	36.0	42.3	44.4	33.4	39.6	39.1	36.5	36.2	34.4
Add gas system distribution losses	36.7	43.2	45.3	34.1	40.4	39.9	37.3	37.0	35.0

Notes to table A2:

- We conducted an illustrative analysis for cold-climate air-source heat pumps based on a study for DOE that tested one unit and found a seasonal COP of about 2.8 in New Haven, Connecticut, over two heating seasons (Johnson 2013). 2.8 COP * 3.412 = 9.55 HSPF. New Haven has a 99% design temp of 7° F, so a 10.3 HSPF non-cold climate unit there would have a 7.14 adjusted HSPF; thus the cold-climate unit is 33.8% higher. We used this factor for each city as an order-of-magnitude estimate. The DOE field study looked at a Hallowell International Acadia cold-climate heat pump, a product no longer available as the manufacturer has gone out of business. Mitsubishi produces cold-climate heat pumps, most of which are ductless, but a few can be used in ducted applications (see www.mitsubishicomfort.com/sites/default/files/manual/m-series_hyper-heat_brochure.pdf?fid=1010). These can be linked to an indoor air handler (see www.mitsubishicomfort.com/press/press-releases/mvz-multi-position-air-handler-rounds-out-diamond-comfort-systemtm-for-efficient-whole-home-cooling-heating.
- We also conducted an illustrative analysis for gas-fired heat pumps based on Gas Technology Institute (GTI) projections from its research project with A. O. Smith; see Garrabrant (2014). GTI estimates seasonal COP based on average winter temperature. For each state we used a simple average of monthly temperatures for November–March, taken from www.weatherbase.com/weather/state.php3?c=US.

Table A3 below shows differences in natural gas use by state in millions of Btus. In these comparisons, the shaded cells indicate where gas uses less energy, while unshaded cells show where electric heat pumps use less energy.

Table A3. Furnace and heat pump comparisons by state

	US	West				Midwest				Northeast				South					
		AZ	CA	CO	OR/WA	IL	MI	MO	WI	MA	NJ	NY	PA	FL	GA	NC/SC	TN	TX	VA
80% furnace vs. 8.2 HSPF heat pump																			
4,958	21.8	9.7	13.3	17.7	29.9	20.2	20.9	18.2	13.1	21.0	24.5	21.5	22.2	8.6	20.7	22.5	20.6	13.8	18.9
6,161	14.4	7.8	10.9	6.8	21.5	7.1	7.4	8.4	0.2	9.7	14.9	11.6	13.2	7.2	15.3	16.0	13.8	10.5	12.5
6,503	12.3	7.3	10.2	3.7	19.2	3.4	3.5	5.6	-3.4	6.4	12.2	8.8	10.6	6.7	13.7	14.2	11.9	9.6	10.6
7,658	5.1	5.5	7.9	-6.8	11.1	-9.1	-9.4	-3.9	-15.8	-4.5	2.9	-0.6	1.9	5.3	8.5	7.9	5.4	6.4	4.5
10,408	-11.8	1.2	2.5	-31.9	-8.0	-38.9	-40.3	-26.4	-45.2	-30.4	-19.1	-23.0	-18.8	2.0	-4.0	-6.9	-10.1	-1.2	-10.2
95% furnace vs. 8.5 HSPF heat pump																			
4,958	14.4	7.3	10.1	8.4	20.8	9.1	9.4	9.6	2.9	11.0	15.3	12.5	13.7	6.6	14.6	15.6	13.7	10.0	12.4
6,161	7.1	5.5	7.8	-2.4	12.7	-3.8	-3.9	-0.1	-9.9	-0.1	5.9	2.8	4.8	5.2	9.4	9.3	7.1	6.8	6.2
6,503	5.1	5.0	7.1	-5.5	10.4	-7.4	-7.7	-2.9	-13.6	-3.3	3.2	0.1	2.3	4.8	7.9	7.5	5.2	5.9	4.4
7,658	-1.9	3.3	5.0	-15.9	2.7	-19.8	-20.5	-12.2	-25.9	-14.1	-5.8	-9.2	-6.2	3.4	2.8	1.4	-1.1	2.8	-1.6
10,408	-18.4	-0.9	-0.2	-40.6	-15.8	-49.3	-51.0	-34.4	-55.2	-39.6	-27.3	-31.2	-26.5	0.2	-9.2	-13.0	-16.1	-4.6	-15.9
95% furnace vs. 10.3 HSPF heat pump																			
4,958	18.0	8.3	11.4	13.2	25.1	14.8	15.4	14.0	8.2	16.2	19.9	17.0	18.0	7.4	17.4	18.8	17.0	11.7	15.6
6,161	11.7	6.7	9.4	3.6	18.0	3.3	3.5	5.4	-3.4	6.3	11.6	8.5	10.2	6.2	12.9	13.3	11.3	8.9	10.1
6,503	9.9	6.3	8.8	0.8	16.0	0.1	0.1	3.0	-6.7	3.4	9.3	6.1	7.9	5.8	11.6	11.8	9.6	8.1	8.5
7,658	3.8	4.8	7.0	-8.4	9.2	-11.0	-11.4	-5.3	-17.8	-6.1	1.3	-2.1	0.4	4.7	7.2	6.5	4.1	5.5	3.3
10,408	-10.7	1.3	2.5	-30.4	-6.9	-37.3	-38.6	-25.0	-44.1	-28.8	-17.6	-21.5	-17.4	1.9	-3.3	-6.1	-9.1	-0.9	-9.3
97% furnace vs. 10.3 HSPF heat pump																			
4,958	17.1	8.0	11.0	12.1	24.0	13.6	14.0	13.0	7.0	15.0	18.8	16.0	16.9	7.1	16.7	18.0	16.2	11.2	14.8
6,161	10.8	6.4	9.0	2.5	16.9	2.1	2.1	4.4	-4.5	5.1	10.5	7.4	9.1	5.9	12.1	12.5	10.4	8.4	9.3
6,503	9.0	6.0	8.4	-0.3	14.9	-1.2	-1.3	1.9	-7.8	2.2	8.2	5.0	6.9	5.6	10.8	10.9	8.8	7.7	7.8
7,658	2.9	4.5	6.6	-9.5	8.1	-12.3	-12.7	-6.3	-18.9	-7.3	0.2	-3.2	-0.6	4.4	6.4	5.7	3.2	5.0	2.5
10,408	-11.6	1.0	2.1	-31.5	-8.0	-38.6	-39.9	-26.0	-45.3	-30.0	-18.7	-22.6	-18.5	1.7	-4.1	-6.9	-9.9	-1.4	-10.1
95% furnace vs. cold-climate heat pump (tentative and illustrative)																			
4,958				23.2		26.8	27.8	23.0	20.2	26.5	28.6	25.9	26.1						
6,161				16.0		18.2	18.9	16.6	11.6	19.1	22.4	19.5	20.3						
6,503				14.0		15.8	16.3	14.7	9.1	17.0	20.6	17.7	18.6						
7,658				7.1		7.5	7.8	8.6	0.8	9.9	14.7	11.6	13.0						
10,408				-9.4		-12.1	-12.6	-6.2		-7.1	0.5	-2.9	-0.3						
Gas-fired heat pump vs. cold-climate electric (tentative and illustrative)																			
4,958				7.0		7.7	8.7	7.6	4.9	9.3	11.7	10.7	11.0						
6,161				-0.2		-0.9	-0.2	1.1	-3.8	1.9	5.5	4.4	5.1						
6,503				-2.2		-3.3	-2.8	-0.7	-6.2	-0.2	3.7	2.6	3.5						
7,658				-9.1		-11.6	-11.3	-6.9	-14.5	-7.4	-2.2	-3.6	-2.1						
10,408				-25.6		-31.2	-31.6	-21.6	-34.2	-24.3	-16.4	-18.1	-15.5						

Table A4. Economic analysis for space conditioning

	US	West				Midwest				Northeast			South						
		AZ	CA	CO	OR/WA	IL	MI	MO	WI	MA	NJ	NY	PA	FL	GA	NC/SC	TN	TX	VA
2014 gas rate	10.97	17.20	11.51	8.89	11.16	9.59	9.33	10.83	10.52	14.50	9.69	12.54	11.77	19.02	14.45	12.27	10.13	11.16	12.07
2014 electric rate	0.125	0.120	0.163	0.122	0.096	0.114	0.145	0.106	0.139	0.174	0.158	0.201	0.133	0.120	0.116	0.117	0.103	0.118	0.112
2025 gas rate	13.28	20.82	13.93	10.76	13.50	11.61	11.30	13.11	12.74	17.55	11.73	15.18	14.25	23.03	17.49	14.85	12.26	13.51	14.61
Winter/average ratio	0.910	0.938	0.971	0.899	0.971	0.884	0.941	0.888	0.964	0.986	0.946	0.912	0.926	0.911	0.863	0.900	0.916	0.889	0.915
2025 winter gas rate	12.09	19.53	13.53	9.67	13.11	10.26	10.62	11.64	12.28	17.30	11.10	13.85	13.20	20.97	15.09	13.36	11.23	12.02	13.37
2025 electric rate	0.141	0.135	0.184	0.138	0.108	0.129	0.164	0.120	0.157	0.197	0.179	0.227	0.151	0.135	0.131	0.132	0.117	0.134	0.127
Winter/average ratio	0.975	0.920	1.014	0.952	0.979	0.998	0.966	0.895	0.950	1.023	0.986	1.006	0.978	0.989	0.940	0.974	0.974	0.982	0.947
2025 winter electric rate	0.138	0.125	0.187	0.131	0.106	0.129	0.158	0.107	0.149	0.201	0.176	0.228	0.148	0.134	0.123	0.129	0.114	0.131	0.120
Annual heating cost (2025 energy prices, 2013 $)																			
80% furnace	621	334	306	596	828	744	797	672	797	1,151	699	841	771	302	638	645	534	324	595
95% furnace	523	281	257	502	697	626	671	566	671	969	589	708	649	254	537	544	449	273	501
97% furnace	512	275	252	491	682	613	657	554	657	949	577	693	636	249	526	532	440	268	491
8.2 HP	803	183	348	1,125	696	1,318	1,677	828	1,507	1,793	1,331	1,756	1,048	154	525	656	604	342	604
8.5 HP	781	176	332	1,111	674	1,303	1,658	815	1,500	1,765	1,300	1,722	1,025	147	507	636	587	330	588
10.3 HP	685	152	286	990	588	1,162	1,479	724	1,351	1,568	1,145	1,524	904	127	442	555	515	287	516
Purchase cost including installation (2013 $)																			
80% furnace	2,218	2,218	2,218	2,218	2,218	2,218	2,218	2,218	2,218	2,218	2,218	2,218	2,218	2,218	2,218	2,218	2,218	2,218	2,218
95% furnace	2,847	2,847	2,847	2,847	2,847	2,847	2,847	2,847	2,847	2,847	2,847	2,847	2,847	2,847	2,847	2,847	2,847	2,847	2,847
97% furnace	2,975	2,975	2,975	2,975	2,975	2,975	2,975	2,975	2,975	2,975	2,975	2,975	2,975	2,975	2,975	2,975	2,975	2,975	2,975
8.2 HP	5,242	5,242	5,242	5,242	5,242	5,242	5,242	5,242	5,242	5,242	5,242	5,242	5,242	5,242	5,242	5,242	5,242	5,242	5,242
8.5 HP	5,393	5,393	5,393	5,393	5,393	5,393	5,393	5,393	5,393	5,393	5,393	5,393	5,393	5,393	5,393	5,393	5,393	5,393	5,393
10.3 HP	5,969	5,969	5,969	5,969	5,969	5,969	5,969	5,969	5,969	5,969	5,969	5,969	5,969	5,969	5,969	5,969	5,969	5,969	5,969
SEER 14 central AC	4,299	4,299	4,299	4,299	4,299	4,299	4,299	4,299	4,299	4,299	4,299	4,299	4,299	4,299	4,299	4,299	4,299	4,299	4,299
SEER 13 central AC	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115
Lifecycle cost (18-year life, 5% real discount rate)																			
80% furnace	9,482	6,121	5,792	9,182	11,891	10,912	11,533	10,072	11,535	15,668	10,392	12,047	11,228	5,748	9,679	9,763	8,456	6,011	9,170
95% furnace	8,964	6,134	5,857	8,711	10,993	10,169	10,691	9,461	10,693	14,173	9,730	11,124	10,434	5,819	9,130	9,201	8,100	6,041	8,702
97% furnace	8,966	6,194	5,923	8,718	10,953	10,146	10,657	9,452	10,659	14,068	9,717	11,081	10,406	5,886	9,129	9,198	8,120	6,103	8,709
8.2 HP	14,624	7,385	9,307	18,395	13,380	20,648	24,851	14,919	22,857	26,198	20,796	25,772	17,495	7,047	11,379	12,912	12,299	9,243	12,302
8.5 HP	14,524	7,446	9,277	18,381	13,271	20,620	24,774	14,920	22,932	26,026	20,589	25,527	17,375	7,115	11,323	12,824	12,255	9,250	12,264
10.3 HP	13,981	7,742	9,316	17,545	12,842	19,556	23,263	14,433	21,761	24,298	19,354	23,778	16,534	7,451	11,134	12,459	11,984	9,320	11,998
Lifecycle cost if heat pump replaces central AC unit																			
8.2 HP	10,325	3,086	5,008	14,096	9,081	16,349	20,552	10,620	18,558	21,899	16,497	21,473	13,196	2,748	7,080	8,613	8,000	4,944	8,003
8.5 HP	10,225	3,147	4,978	14,266	9,156	16,505	20,659	10,805	18,817	21,911	16,474	21,412	13,260	2,816	7,024	8,525	7,956	4,951	7,965
10.3 HP	9,682	3,443	5,017	13,430	8,727	15,441	19,148	10,318	17,646	20,183	15,239	19,663	12,419	3,152	6,835	8,160	7,685	5,021	7,699
Air conditioning																			
Avg. kWh/year for central AC 2009	1,980	5,205	1,288	503	557	1,022	371	1,797	296	319	1,094	548	875	4,557	3,056	2,293	2,295	4,256	2,290
Avg. kWh/year for central AC SEER 13	1,523	4,004	991	387	428	786	285	1,382	228	245	842	422	673	3,505	2,351	1,764	1,765	3,274	1,762
Avg. kWh/year for central AC SEER 14	1,414	3,718	920	359	398	730	265	1,284	211	228	781	391	625	3,255	2,183	1,638	1,639	3,040	1,636
Avg. kWh/year for central AC SEER 14.5	1,366	3,590	888	347	384	705	256	1,239	204	220	754	378	603	3,143	2,108	1,581	1,583	2,935	1,579
Avg. kWh/year for central AC SEER 17	1,165	3,062	758	296	328	601	218	1,057	174	188	644	322	515	2,681	1,798	1,349	1,350	2,504	1,347
Additional LCC savings for cooling																			
HSPF 8.5/SEER 14.5	81	203	68	64	56	123	57	200	43	58	182	116	123	178	115	282	77	164	83
HSPF 10.3/SEER 17	412	1039	350	147	128	279	129	455	98	133	414	263	279	910	589	642	395	838	427
Comparisons with replacing central AC																			
80% furnace vs. 8.2 HSPF heat pump	-843	3,034	785	-4,915	2,810	-5,437	-9,019	-548	-7,023	-6,231	-6,105	-9,426	-1,967	2,999	2,600	1,150	456	1,066	1,167
80% furnace vs. 8.5 HSPF heat pump	-663	3,177	883	-5,020	2,792	-5,470	-9,070	-534	-7,239	-6,184	-5,900	-9,250	-1,909	3,109	2,771	1,520	577	1,224	1,288
80% furnace vs. 10.3 HSPF heat pump	213	3,717	1,125	-4,102	3,292	-4,250	-7,486	209	-6,013	-4,382	-4,434	-7,354	-912	3,505	3,433	2,245	1,166	1,828	1,899
95% furnace vs. 8.5 HSPF heat pump	-1,181	3,190	947	-5,490	1,894	-6,214	-9,911	-1,145	-8,081	-7,679	-6,562	-10,173	-2,703	3,181	2,222	958	221	1,254	820
95% furnace vs. 10.3 HSPF heat pump	-305	3,730	1,189	-4,572	2,393	-4,994	-8,328	-402	-6,855	-5,877	-5,096	-8,276	-1,705	3,576	2,884	1,683	810	1,858	1,430

Notes to table A4:

- Negative numbers mean gas has lower LCC; these cells are shaded.
- We took electricity costs from the February 2015 EIA *Electric Power Monthly*: www.eia.gov/electricity/monthly/current_year/february2015.pdf. Natural gas costs are from www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PRS_DMcf_a.htm.
- We estimated costs for 2025 from 2014 costs by state and projected national costs for 2025 and 2014, as we explain in the text.
- Adjustment for winter electricity and gas prices is as explained in the text and compares costs by state in January–March 2014 and November–December 2014 to average costs by state over the entire year.
- The installed cost of different systems comes from DOE TSDs as follows:
    - For furnaces we took costs from the DOE February 2015 TSD (www.regulations.gov/#!documentDetail;D=EERE-2014-BT-STD-0031-0027), pp. 8–16. For 97% AFUE we interpolated the cost of a 97% AFUE unit from the 95% and 98% costs in the DOE TSD.
    - For heat pumps we took costs from the DOE August 2015 TSD (www.regulations.gov/#!documentDetail;D=EERE-2014-BT-STD-0048-0029), pp. 8–33. We used the baseline for 8.2 HSPF, TSL 2 for 8.5 HSPF, and TSL 7 for 10.3 HSPF. For central air conditioners we used the current minimum standard—SEER 13 in the North and SEER 14 in the South. For the United States we used SEER 14, as this applies to the majority of air conditioner sales. Costs come from pp. 8–32 in the DOE August 2015 TSD (using the baseline for SEER 13 and TSL 3 for SEER 14).
- Average kWh per year for air-conditioning comes from the 2009 RECS (EIA 2013). We assume these data are for SEER 10 units and adjusted consumption downward based on the SEER of the new unit (SEER 13 for a basic new unit in the North, SEER 14 for a basic new unit in the South, SEER 14.5 for the HSPF 8.5 heat pump [both are ENERGY STAR levels], and SEER 17 for the HSPF 10.3 unit [based on slide 29 in DOE's October 26–27, 2015, presentation to CAC and HP ASRAC Working Group]). This can be found at www.regulations.gov/#!documentDetail;D=EERE-2014-BT-STD-0048-0052.

Table A5. National-level comparison of gas and electric heat pump water heaters

Factor	Values		Notes
Average gas water heater	21.1		mmBtu; from 2009 RECS (EIA 2013)
Better gas water heater	.62 EF	.77 EF	Base case is EF .54 as explained in text.
	18.3	14.8	mmBtu
With 2% distribution losses	18.7	15.1	mmBtu
Electric HPWH equivalent	1.92 EF	2.5 EF	Base case is EF .54 gas water heater.
	1,736	1,333	kWh
With 6% distribution losses	1,840	1,413	
HPWH gas use by heat rate			
4,958	9.1	7.0	
6,161	11.3	8.7	
6,503	12.0	9.2	
7,658	14.1	10.8	
10,408	19.1	14.7	
Break-even heat rate	10,170	13,243	Same energy used as for .62 EF + losses
	8,189	10,663	Same energy used as for .77 EF + losses
2025 prices, US			From EIA 2015
Gas	$ 13.28		per mmBtu
Electric	$ 0.141		per kWh
Average annual operating costs			
Gas (.62 EF)	$ 244		
Gas (.77 EF)	$ 196		
Electric (1.92 EF)	$ 245		
Electric (2.5 EF)	$ 188		
Difference	$ 1	Gas lower	For .62 EF gas and 1.92 EF electric
	$ (8)	Elec lower	For .77 EF gas and 2.5 EF electric
Installed cost			From Lekov et al. 2011
Gas (.62 EF)	$ 1,171		
Gas (.77 EF)	$ 1,893		
Electric (1.92 EF)	$ 1,574		
Electric (2.5 EF)	$ 1,674		Absent good data, added $100 to line above.
Difference	$ 403	Gas lower	For .62 EF gas and 1.92 EF electric
	$ (219)	Elec lower	For .77 EF gas and 2.5 EF electric
Life-cycle cost			
Gas (.62 EF)	$ 3,460		
Gas (.77 EF)	$ 3,736		
Electric (1.92 EF)	$ 3,873		
Electric (2.5 EF)	$ 3,440		
Difference	$ 413	Gas lower	For .62 EF gas and 1.92 EF electric
	$ (296)	Elec lower	For .77 EF gas and 2.5 EF electric