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Analysis of Comparative Energy Use of Residential Furnaces and Heat Pumps

Steven Nadel

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An ACEEE White Paper

# Contents

[About the Author(s) ii](#_Toc403469918)

[Acknowledgments ii](#_Toc403469919)

[Abstract iii](#_Toc403469920)

[Formatting Reports and White Papers 1](#_Toc403469921)

[Headings 1](#_Toc403469922)

[Fonts **Error! Bookmark not defined.**](#_Toc403469925)

[Tables **Error! Bookmark not defined.**](#_Toc403469926)

[Figures **Error! Bookmark not defined.**](#_Toc403469927)

[Footnotes **Error! Bookmark not defined.**](#_Toc403469928)

[References 9](#_Toc403469929)

# About the Author(s)

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, CT. 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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# Abstract

[to be written later]

# 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) (EIA 2013), natural gas accounts for about 46% of total site energy use and electricity for about 43%. Natural gas is primarily used for space and water heating. According to RECS, of the natural gas used in the residential sector, 63% is for space heating and 26% for 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 put natural gas in a positive light (e.g., AGA 2015). [looking for a good pro-electric analysis to also cite]

In the past few years, growing concerns about climate change have led to research on how the US 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 (2011) found that to achieve even a 60% reduction of greenhouse gases in California will 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 fuel 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 supply transportation and heat use which cannot be electrified, such as for airplanes and heavy duty trucks, and high quality heat in industry.

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

Similarly, the Acadia Center (2014), in their *Energy Vision* report for New England, proposes four similar strategies for achieving deep carbon reductions:

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

However, these two studies are only for limited regions of the US; other regions may vary. Also, these studies did not look at the economics of converting from gas to electric heat.

In order to begin to address these gaps, this paper discusses a preliminary analysis that explores the question of whether we should be encouraging or discouraging natural gas use in some applications based on relative energy use and carbon emissions. We focus on space heating energy, since the majority of residential natural gas goes to space heating. Near the end we briefly look at water heating. Our analysis primarily looks at the relative energy use for different regions and types of heating systems, but we also include a simplified economic analysis, also for different regions and system types. The balance of this paper discusses our methodology and findings. We find that fuel switching may reduce energy use and emissions and save money in some regions and for some system types but not for other regions and system types, with many situations “on the cusp”. For example, efficient heat pumps often 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. We end with some recommendations for further research and for initial program efforts.

# Methodology

For this initial analysis, we compared the gas used by gas furnaces to the gas used at a power plant in order to power a heat pump. In the long-term, natural gas is likely to be the marginal generation fuel in many, if not most, regions, so this is a reasonable place to start. And by not getting into inter-fuel comparisons, the analysis can be much simpler.[[1]](#footnote-1)

At the house level the following systems are analyzed:

1. 80% AFUE furnace (current federal standard)
2. 95% AFUE furnace (most common high efficiency furnace – this is Energy Star for the north)
3. 97% AFUE furnace (Energy Star Most Efficient level)
4. 8.2 HSPF heat pump (current federal standard for split systems)
5. 8.5 HSPF heat pump (Energy Star level)
6. 9.6 HSPF heat pump (Energy Star Most-Efficient)
7. A cold climate electric heat pump (just a very preliminary analysis based on one field test – more products and data needed)
8. A gas-fired heat pump (also just a very preliminary analysis based on projections from one research project – more data, including ultimately field data, will be needed).

And at the power plant level we looked at four different heat rates:[[2]](#footnote-2)

1. 6161 Btu (HHV)/kWh (the rated efficiency of GE’s best turbine; to achieve this level in the field may need some additional improvements)[[3]](#footnote-3)
2. 6503 Btu/kWh (the best actual heat rate in 2014 from EIA’s database)[[4]](#footnote-4)
3. 7667 Btu/kWh (the average combined cycle plant heat rate in 2013 per EIA [2014 data not yet available][[5]](#footnote-5)
4. 10,354 Btu/Kwh (the average steam turbine heat rate in 2013).[[6]](#footnote-6) 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. Also, this is somewhat of a proxy for the energy use of a typical coal-fired steam turbine.

The analysis is conducted for 16 states plus two 2-state regions. These are the states and two-state regions with data in the 2009 RECS (EIA 2013).[[7]](#footnote-7) The states are Arizona, California, Colorado, Florida, Georgia, Illinois, Massachusetts, Michigan, Missouri, New Jersey, New York, Pennsylvania, Tennessee, Texas, Virginia and Wisconsin. In addition, we examined two 2-state pairs – Oregon/Washington and North/South Carolina. Together these states cover a wide range of regions and climates throughout the US. These analyses are based 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.

The analysis makes use of average space heating consumption data by state for gas-heated homes in the 2009 RECS. We assume that the average furnace captured in RECS has an 80% Annual Fuel Utilization Efficiency (AFUE) and that more efficient furnaces will use proportionately less.[[8]](#footnote-8) We also assume that if they convert to a heat pump, they will need the same number of BTU’s as they get from their current gas system.[[9]](#footnote-9) We estimated the seasonal efficiency for heat pumps at different locations using a methodology developed by the Florida Solar Energy Center (FSEC) that 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 T&D losses of 5.5%[[10]](#footnote-10) and gas distribution losses of 2%.[[11]](#footnote-11) Additional specifics are provided in the Appendix.

# Energy Use Comparisons

Detailed tables from our analysis can be found in the Appendix. 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 a 8.5 HSPF heat pump (the current Energy Star levels)
3. Comparing a 95% and 97% AFUE furnace with a 9.6 HSPF heat pump (comparing current high-efficiency products).
4. Comparing a 95% AFUE furnace with an electric cold climate heat pump.
5. Comparing an electric cold climate heat pump with a gas-fired heat pump.

Below we provide graphical summaries of each of these analyses. Where the electric heat pump uses less energy the bar goes above the zero-line. Where the gas option uses less energy, the bar goes below the zero line. Please note that according to RECS 2009 the average US home uses about 90 million Btu per year for space heating. The differences shown here are generally much smaller and thus while there are energy and carbon savings at stake, at the individual household level, they are not dramatic and hence getting homeowner attention may be difficult.

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

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

Figure 3. Comparison of a 95% AFUE furnace with a 9.6 HSPF electric heat pump.

Figure 4. Comparison of a 95% AFUE furnace with a cold climate electric heat pump.[[12]](#footnote-12)

Figure 5. Comparison of gas heat pump with a cold climate electric heat pump.

Note: This analysis is highly approximate as the efficiency of the electric heat pump data 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. Also, the design and average temperatures by state are approximate.

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

* In warm states (Arizona, California and Florida) electric heat pumps use less energy on average, regardless of power plant heat rate. Georgia, New Jersey, Pennsylvania, Tennessee, Texas, Virginia, Oregon/Washington and the Carolinas join this list when power comes from a standard combined-cycle plant. And in Colorado, Illinois, Massachusetts, Michigan, Missouri, New York and Wisconsin, heat pumps use less energy than furnaces only when the highest-efficiency power plants (heat rates of ~6500 and lower) are used. These results are pretty much the same for each of the conventional equipment comparisons, with only minor differences between the three comparisons (e.g. in the coldest states, relative to a 95% AFUE furnace, its takes a 6161 heat rate for an electric heat pump to outperform a gas furnace).
* Relative to a 95% AFUE furnace, the cold climate electric heat pump does well, using less energy at heat rates of 7700 and lower. But for all but the very lowest (best) power plant heat rate, the gas-fired heat pump does better than the cold climate electric heat pump. Data on cold climate electric heat pumps and gas heat pumps are limited, so these findings are subject to large uncertainty – more data are needed.

# Economic Analysis

Next, we conducted a preliminary economic analysis from the homeowner point of view comparing the different options. For this analysis we used estimates of installed costs from the most recent US Department of Energy (DOE) Technical Support Documents for furnaces and residential central air conditioners and heat pumps. This analysis only looks at systems that are now widely available – there is presently 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 did a set of analyses for homes with central air conditioning and assuming a heat pump could be installed instead of a central air conditioner at the time the central air conditioner needs to be replaced. As of 2009, 61% of US homes had central air conditioning, including 35% in the northeast, 66% in the Midwest, 82% in the south and 44% in the west (EIA 2013).

Energy costs were based on average gas and electric costs by state in 2014 from EIA and then adjusted for the expected nationwide increase in energy costs during the operating life of this equipment. Specifically, based on EIA’s 2015 Annual Energy Outlook (EIA 2015), we compared estimated residential gas and electric prices in 2025 and 2014 and applied this ratio to the state-specific energy prices from 2014. In some states energy costs vary by season, a factor not addressed in this simple preliminary analysis. We calculated the lifecycle cost for each system type and location assuming an 18-year equipment life and a 5% real discount rate. We then subtracted the lifecycle cost of the gas system from the lifecycle cost of the heat pump system to calculate the net lifecycle cost for each comparison. Further details of the analysis are presented in Table A4 in the appendix.

Based on our analysis, we find that heat pumps are more expensive than furnaces and electricity is generally more expensive per Btu than natural gas, so for all of the comparisons, the furnace has a lower life-cycle cost for homes without central air conditioning. But 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 on south as well as in the northwest. This latter analysis includes cooling energy savings from replacing a central air conditioner meeting federal minimum efficiency standards (SEER 13 in the north, SEER 14 in the south) with a higher efficiency heat pump. This analysis is shown in Figure 6 below.

Figure 6. Lifecycle cost comparison of several furnaces and heat pumps in cases where a heat pump can replace a central air conditioner.

Thus, from an economic point of view, gas furnaces have lower life-cycle costs for space heating only. But if a home has central air conditioning, replacing the air conditioner with a heat pump can reduce life-cycle costs from about Virginia on south, and in the northwest. However, where heat pumps are less expensive on a lifecycle cost basis than gas furnaces, the lifecycle-cost savings are typically $1000-3000, which works out to about $55-$165 per year. These savings are modest and may not influence many homeowners unless there is a significant program or policy push.

# A Briefer Note on Water Heating

Thus far, all of the discussion has been on space heating. But since water heating is also a significant 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 – national average of 21.1 million Btu per year (EIA 2013). We then analyzed an heat pump water heater and a condensing gas water heater that would provide the same amount of hot water as a non-condensing gas water, assuming the average gas water heater in 2009 had an Energy Factor (EF) of 0.54 (the old federal standard), a new non-condensing gas water heater would have an EF of .62 (the new federal standard), a new condensing gas water heater would have an EF of .77 (from Lekov et al. 2011) and the heat pump water heater has an EF of 1.92.[[13]](#footnote-13) The heat pump water heater uses 2712 kWh per year. Adding in the same allowances for gas and electric 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 electric heat pump uses less energy than the new non-condensing gas water heater at heat rates of about 6500 and below (i.e., for new high-efficiency combined cycle plants) but the condensing gas water heater uses less gas than the heat pump, even if the electricity comes from the best combined cycle power plant now offered for sale. Details of this analysis can be found 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 there is already electric and gas service in the home. Under these assumptions, we found that the non-condensing gas water heater is less expensive to install (by about $400) and operate (about $140 less per year). As a result, the non-condensing gas water heater is about $1700 less expensive to purchase and operate over the life of the water heater (net present value, assuming a 5% real discount rate). The condensing gas water heater has the lowest operating costs of all three systems but is the most expensive to install. Overall, the condensing gas water heater has lifecycle costs about $275 more than the non-condensing gas water heater but about $1400 less than the heat pump water heater. Again, details can be found 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, non all houses can install heat pump water heaters and the economics of both heat pump water heaters and condensing gas water heaters tends to be better for households with above-average hot water use. Still, this illustrative analysis tends to show that where there is gas service in a home, switching to an electric heat pump water heater is unlikely to make sense given current system costs and projected energy prices.

# 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” – varying by state (due to differences in climate, building stock and energy prices), furnace and heat pump efficiency, and power plant heat rate. This analysis tends to show that electric heat pumps 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 furnaces will be lower than for heat pumps in these moderately-cold states. 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. We did not have enough data to analyze the economics of these new technologies. Likewise, heat pump water heaters can save energy relative to non-condensing gas water heaters if power comes from efficient natural gas combined cycle power plants, but the economics of conversions are not good.

In terms of next steps, we have three recommendations:

1. Further analysis would be useful, particularly at the state-level using more specific data on different categories of customers. Our analysis is based on state averages and a more nuanced analysis will more clearly identify winners and losers.
2. Continued work to develop good cold-climate electric air-source heat pumps and gas-fired heat pumps. There are good cold climate *ductless* heat pumps available, but currently there are very few systems designed for use with ducts.[[14]](#footnote-14) For both cold-climate and gas-fired heat pumps, work is needed to examine system economics – these systems save energy, but will probably only make economic sense if the cost is not too much higher than current electric heat pumps.
3. The case for converting gas furnaces to electric heat pumps is strongest in warm states, where use of air conditioning is routine, 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 perhaps proceeding to pilot programs.

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# Appendix

Table A1. Analysis of Furnaces and Conventional Heat Pumps



Notes for Table A1:

* Gas use by state if for homes with gas space heating, as provided in the 2009 RECS (EIA 2013).
* To estimate total gas use we add 2% distribution losses (discussed in text).
* Gas use for 95% and 97% AFUE furnaces estimated by taking gas use for 80% AFUE and multiplying by 80/95 or 80/97.
* Heat pump seasonal efficiency for 8.2 HSPF units estimated 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 shown in Table A1.
* Heat pump seasonal efficiency for 8.5 and 9.6 HSPF units are based on a slightly different adjustment factor from Fairey et al. 2004. For 8.5 HSPF:
  + Adjustment factor = 0.1041 - 0.008862\*Design T - 0.0001153\*(Design T)2+0.02817\*8.5
* To heat pump electricity use we add 5.5% for distribution system losses as explained in the text.
* Natural gas use to supply this electricity is based on a power plant heat rate of 6161, 6503, 6711, 7667 or 10,354 Btu/kWh as explained in the text.

Table A2. Illustrative Analyses for Cold Climate Air-Source Heat Pumps and Gas-Fired Heat Pumps (only analyzed cold states)



Notes:

* 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, CT over 2 heating seasons (Johnson 2013). 2.8 COP \* 3.412 = 9.55 HSPF. New Haven has a 99% design temp of 7 F, and so a 9.6 HSPF unit there would have a 6.65 adjusted HSPF. Thus the cold T unit is 43.6% higher. We use 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 since the manufacturer went out of business. Mitsubishi produces cold climate heat pumps, most of which are ducted but a few can be used in ducted applications -- <http://www.mitsubishicomfort.com/sites/default/files/manual/m-series_hyper-heat_brochure.pdf?fid=1010> . Can be linked to an indoor air handler -- <http://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 for a research project they have with AO Smith. See Garrabrant (2014). They estimate seasonal COP based on average winter temperature. For each state we used a simple average of monthly temperatures for Nov-March from <http://www.weatherbase.com/weather/state.php3?c=US> .

Table A3. Furnace and Heat Pump Comparisons by State.

Difference in natural gas use (units are million Btu). In these comparisons, boxes shaded yellow are where gas uses less energy, while unshaded boxes show where electric heat pumps use less energy.



Table A4. Economic Analysis for Space Conditioning.



Notes for Table A4:

* Electricity costs are from the Feb. 2015 EIA Electricity Monthly -- <http://www.eia.gov/electricity/monthly/current_year/february2015.pdf> . Natural gas costs from <http://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PRS_DMcf_a.htm> .
* 2025 costs estimated from 2014 costs by state and projected national costs for 2025 and 2014 as explained in the text.
* The installed cost of different systems comes from DOE Technical Support Documents as follows:
  + For furnaces, costs from DOE Feb. 2015 TSD (<http://www.regulations.gov/#!documentDetail;D=EERE-2014-BT-STD-0031-0027> ), p. 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, costs from DOE August, 2015 TSD (<http://www.regulations.gov/#!documentDetail;D=EERE-2014-BT-STD-0048-0029> ), p. 8-33. We used the baseline for 8.2 HSPF, TSL 2 for 8.5 HSPF, and TSL 7 for 9.6 HSPF. For central air conditioners, we used the current minimum standard – SEER 13 in the north and SEER 14 in the south. For the US we use SEER 14 as this applies to majority of AC sales. Costs come from p. 8-32 in the DOE August, 2015 TSD (baseline for SEER 13, 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 17 for the HSPF 9.6 unit [based on slide 29 in DOE Oct. 26/27, 2015 presentation to CAC and HP ASRAC Working Group[[15]](#footnote-15)]).

Table A5. National-Level Comparison of Gas and Electric Heat Pump Water Heaters.



1. Of course, other scenarios can also be considered. From a carbon emissions point of view, to the extent sources with lower emissions than natural gas are used on the margin, the comparison will be more favorable to electric heat pumps than shown here. On the other hand, if high emissions sources such as coal-fired power plants are on the margin, the comparison will be more favorable to gas furnaces than shown here. [↑](#footnote-ref-1)
2. All are based on higher heating value, meaning that they include the energy recovered by condensing any steam product of combustion. [↑](#footnote-ref-2)
3. GE rates their 7H CC at about 5550 Btu/hour based on lower heating value (LHV) -- <https://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 -- <https://en.wikipedia.org/wiki/Combined_cycle> . [↑](#footnote-ref-3)
4. Most efficient plant in 2014 (preliminary data from EIA). This is TVA's new combined cycle unit at their John Sevier plant and use the first GE 7E turbines. [↑](#footnote-ref-4)
5. Source: <http://www.eia.gov/electricity/annual/html/epa_08_02.html> . [↑](#footnote-ref-5)
6. *Ibid*. [↑](#footnote-ref-6)
7. For all of the other states, RECS groups three or more states together. These are generally states with lower population than states they examined individually or in pairs. [↑](#footnote-ref-7)
8. 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% and above. In some colder states the average in 2009 may have been above 80%. To the extent 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. [↑](#footnote-ref-8)
9. Neither our furnace nor our heat pump analysis includes the electricity used to power the blower. [↑](#footnote-ref-9)
10. Per EIA data. 5% in 2013, 6% average over previous decade. We use 5.5%. See <http://www.eia.gov/tools/faqs/faq.cfm?id=105&t=3> . [↑](#footnote-ref-10)
11. 3-4% lost and unaccounted for. We assume 2% are losses and rest are unaccounted for. <http://www.scientificamerican.com/article/how-much-natural-gas-leaks/> (mentions 3%); <http://www.naruc.org/international/Documents/Technical_losses_in_natural_gas_transportation_distribution_storage_Paul_Metro.pdf> (mentions 4%). [↑](#footnote-ref-11)
12. For this comparison we show for 95% AFUE. As shown in Table A3 in the appendix, the results for 97% AFUE are very similar. For this graph and the next one we only looked at colder climates where the conventional heat pump did not do well from an energy-savings point of view. [↑](#footnote-ref-12)
13. Easley and Domitrovic 2015. Results of an EPRI field test in New York State. A 2012 EPRI field study in a variety of climates found lower seasonal EF’s (Bush 2012). [↑](#footnote-ref-13)
14. For a list of current systems, see <http://www.neep.org/initiatives/high-efficiency-products/emerging-technologies/ashp/cold-climate-air-source-heat-pump> . [↑](#footnote-ref-14)
15. This can be found at: <http://www.regulations.gov/#!documentDetail;D=EERE-2014-BT-STD-0048-0052> . [↑](#footnote-ref-15)