Opportunities for Energy and Economic Savings by Replacing Electric Resistance Heat with Higher-Efficiency Heat Pumps

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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

About one-quarter of US homes use electric resistance heat, including electric furnaces (electric heating elements located in air-supply ducts) and baseboard electric heaters (heating elements in baseboards in each room), as their primary heating source. These systems can be inexpensive to install but are often expensive to run. Many of these homes also have central air-conditioning. Substantial energy can be saved at a moderate cost by installing a heat pump at the time the central air conditioner needs to be replaced. Even in homes without central air-conditioning, there are opportunities to save energy when an existing electric furnace needs to be replaced, or to install ductless electric heat pumps in homes with baseboard electric heaters. Ductless heat pumps are popular in Asia and Europe and are becoming more popular in the United States; they mount high on a wall and can provide heating and cooling to one or several rooms.

In order to better understand potential energy savings and consumer economics, we conducted an analysis on a detailed data set of nearly 2,000 US homes with electric resistance heating systems, available as part of the Energy Information Administration (EIA)'s *2009 Residential Energy Consumption Survey* (RECS). Using these data we looked at how much conversion to a heat pump would cost and save on a home-by-home basis.

Our analysis finds that converting from electric resistance heat to heat pumps can cut electricity use for home heating by a little over half on average. However the economics of conversion vary depending on whether the home has central air-conditioning, and on a range of other factors such as cost of conversion, current energy consumption, and the impact of climate on heat pump efficiency. Converting electric furnaces is often attractive from both an energy-saving and an economic point of view in the 88% of electric-furnace homes and 17% of electric-baseboard homes that already have central air-conditioning systems. Payback periods are also sometimes less than 10 years for converting electric furnaces without central air conditioners, when the electric furnace needs replacement. For homes with built-in electric systems but without central air-conditioning, payback periods will often be more than 10 years, although the addition of air-conditioning will be attractive to some owners. If all homes in buildings of one to four units, with electric resistance heat as their primary heating system, were to install heat pumps, residential electricity use in the United States would decline by about 2.1%.

These savings are based on estimates of typical conversion costs, but costs are likely to vary from home to home and region to region. Additional data collection on actual costs in particular regions would be useful. Furthermore, this analysis is based on current equipment and energy costs and current technologies. As costs and technologies change, this analysis should be revised.

The South appears to be a particularly promising region for conversion to heat pumps, as electric furnace saturation is high in the South, most homes have central air-conditioning, and relatively mild temperatures mean that heat pump efficiency is high. We recommend that program administrators in the South consider introducing new heat pump programs, starting with analysis of opportunities within their service area and proceeding to pilot programs if the results are promising. Once programs have been in operation for more than a year, an ex post analysis of billing and weather data should be conducted to determine

actual weather-normalized energy savings, and the results should be compared to the estimates in this study.

In the North efforts are likely to focus on ductless heat pumps because many homes with electric heat lack ducts. In addition several ductless systems are optimized for cold climates. We also suggest that efforts in the North should target market niches with better-than-average economics. These include the Northwest, where the relatively mild climate, high saturation of built-in units, and extensive network of experienced ductless heat pump contractors create an opportunity, and Vermont, which has high electric costs that make the economics more attractive and a growing contractor network.

In conclusion, this analysis finds that substantial energy and dollar savings are possible by converting electrically heated homes to heat pumps if they already have central air-conditioning but use electric resistance heat. Conversions generally make much less sense if there is not already central air-conditioning, unless owners want to add air-conditioning and are willing to pay for this amenity. Further localized analysis would be useful, perhaps leading to pilot programs in regions where this localized analysis shows favorable energy and economic savings.

Introduction

In the US residential sector, according to the *2009 Residential Energy Consumption Survey* (RECS) (EIA 2013), 34% of homes use electric heat as their primary heating source, comprising 25% that use electric resistance heat and 9% that use heat pumps.[1] At the individual-home level, electric resistance heating systems appear relatively efficient because a resistance element converts one unit of electricity to one unit of heat. However the conversion of energy to heat in the home does not tell the whole story. A generating plant powered by some other form of energy supplies the electricity delivered to the home. In much of the United States, natural gas powers new electric-generating plants. With new natural gas power plants, typically about two units of fuel must be burned at a power plant to produce about one unit of heat in a home.[2] Furthermore, if one includes losses in the home associated with the ducted distribution system used by electric furnaces, efficiency may drop by another 15–25%.[3] Thus the overall efficiency from primary fuel to delivered heat in a forced-air electric-heated home can be on the order of 40%.

Heat pumps are generally much more energy efficient than electric resistance heat, extracting heat from cold air to produce warm air, and exhausting air that is even colder than what is outdoors. A typical new heat pump in the United States is on average roughly twice as efficient as electric resistance heat. Heat pump efficiency varies with the rated efficiency of the heat pump and with the outside temperature. As we discuss later, the most efficient heat pumps can be three times more efficient than electric resistance heat, with efficiencies a little higher in locations with temperatures above the US average and somewhat lower in locations colder than the US average.

Electric furnaces (see figure 1) account for about two-thirds of residential electric resistance heating systems in the United States. Electric furnaces include a blower to move conditioned air through ducts and electric resistance coils to provide heat. These systems are inexpensive to manufacture and were popular with home builders in regions with low heating needs, particularly when electricity prices were much lower than they are today. Many homes with electric furnaces also have central air-conditioning (about 88%), so the blower in the electric furnace also circulates cooled air during the air-conditioning season.

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[1] The US Census Bureau reports similar but slightly different figures in its 2013 American Housing Survey. It reports that 38% of US housing units use electricity as their primary heating fuel, which includes 12% of housing units with heat pumps (Census Bureau 2014).

[2] Older power plants burned roughly three units of fuel for one unit of heat; renewable-energy systems use no fuel.

[3] See neea.org/docs/reports/residential-building-stock-assessment-single-family-characteristics-and-energy-use.pdf?sfvrsn=8 and ducts.lbl.gov.

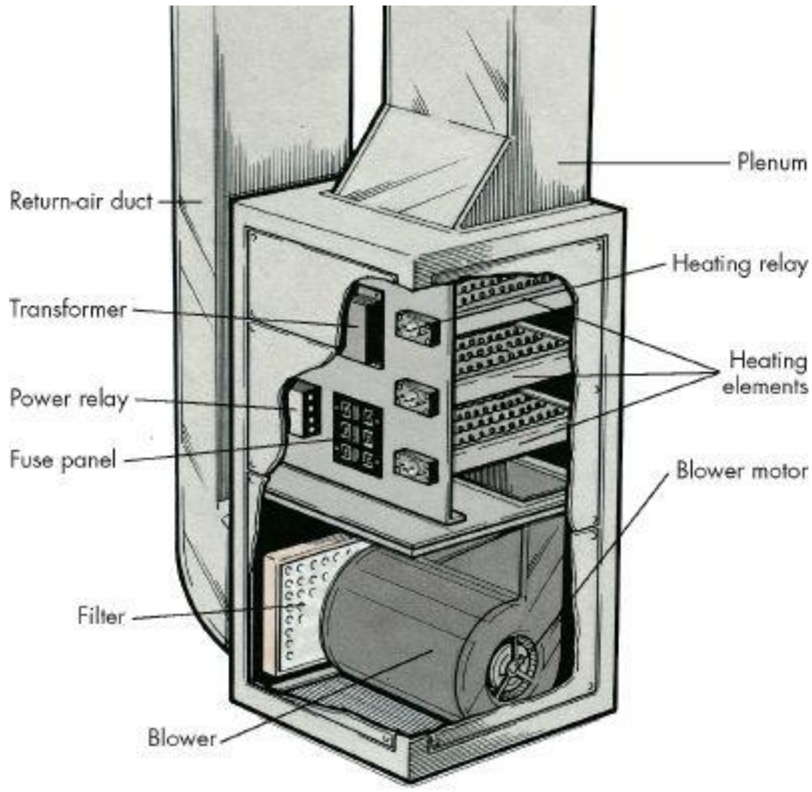

Figure 1. Schematic of electric furnace. *Source:* www.electricfurnaceguide.info/electric-furnace-work. Most electric furnaces also have cooling coils linked up with an air conditioner, but this diagram does not show such coils.

Built-in electric units account for about 20% of electric resistance heating systems according to RECS (EIA 2013). By far the most common type of built-in electric unit is baseboard electric heaters, which are generally located at the bottom of outside walls as figure 2 shows. The balance of homes with electric resistance heat include those with portable space heaters and "other" (EIA 2013).

Figure 2. Electric baseboard heater. *Source:* www.mesa-plumbing.com/heating-furnace-repair-installation-boulder-colorado/baseboard-heating-systems-boulder-colorado.

As noted above heat pumps can extract heat even from cold air. Heat pumps are simply two-way air conditioners. During the summer an air conditioner works by moving heat from the relatively cool indoors to the relatively warm outdoors. In winter the heat pump reverses this process, obtaining heat from the cold outdoors with the help of a refrigerant and a compressor, and discharging that heat inside the house. Figure 3 illustrates heating and cooling operations.

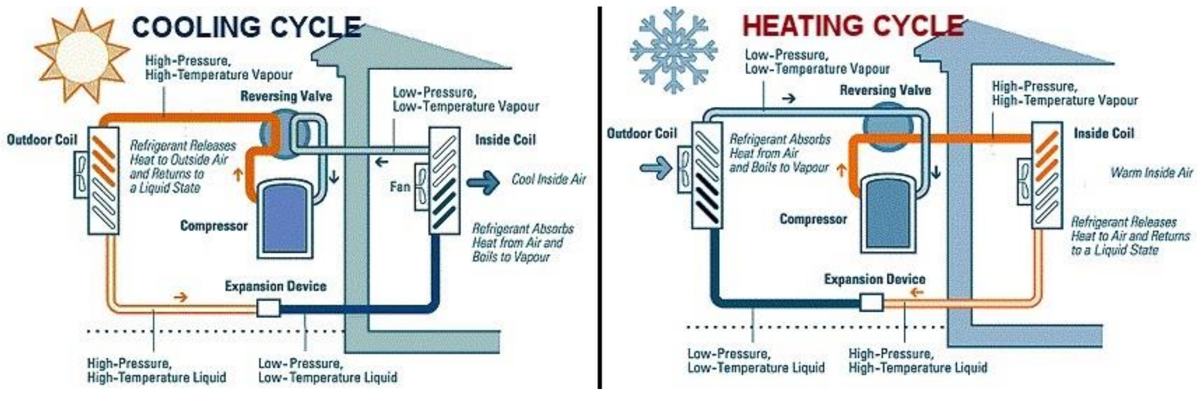

Figure 3. Schematic of heat pump operations during cooling and heating seasons. *Source:* www.woodharbinger.com/heat-pumps-the-undiscovered-energy-saver/.

As outdoor ambient temperatures drop, the ability of heat pump systems to supply heat to structures using vapor-compression technology also drops. At extremely cold temperatures, air-source heat pump systems may rely more on supplemental electric resistance heat, thereby reducing their overall seasonal efficiency. For example, Stevens et al. (2015) found opportunities for cold climate–optimized air-source heat pumps in coastal Alaska but not farther north.

Table 1 summarizes the saturation of different types of electric heating systems, including both nationally and in the South, where electric systems are more common. We include both data that reflect all housing units and a line that excludes apartments in buildings with five or more apartments in a building. In these large buildings it is likely that many of the units listed as having electric furnaces use either central systems with fan coils serving each apartment, or packaged terminal heat pumps.[4]

[4] The same might be true for some buildings with three or four apartments, but this might be offset by the fact that some buildings with five or more units have true electric furnaces. Note that EIA (2013) estimates that there are many fewer apartments with electric furnaces in buildings of three to four units (1.5 million) than in buildings with five or more units (4.9 million).

Table 1. Percentage of housing units in 2009 whose primary heating system was an electric furnace, a built-in electric heating unit (primarily electric baseboard), or an electric heat pump

		Percentage of units with type of heating equipment		
	Region	Electric furnace	Built-in electric	Electric heat pump
All housing units	US	16.8%	5.0%	8.6%
	South	32.5%	2.9%	17.8%
1–4 units per building	US	15.0%	3.6%	9.3%
	South	29.2%	2.0%	18.8%

Figures reflect percentages of all housing units or housing units in one- to four-unit buildings in their respective regions. *Source:* 2009 RECS (EIA 2013).

The saturation of electric furnaces and built-in electric units varies from state to state. Electric furnaces are particularly common in the Southeast, where heating demand is lower and use of ducted central air-conditioning is common. For example, among one- to four-unit buildings, more than 35% of housing units in Florida use electric furnaces as their primary heating system. This figure is more than 25% in Texas, Tennessee, and the three-state region made up of Arkansas, Louisiana, and Oklahoma. Figure 4 illustrates the saturation of electric furnaces by state or group of states, after excluding buildings with five or more apartments.

On the other hand electric baseboard units and other built-in electric units are more widely distributed. They are most common in Pennsylvania and the Oregon/Washington region. (The Census Bureau also groups Alaska and Hawaii in this region, but our understanding is that use of electric baseboard heat is rare in these states.) The high saturation in the Northwest is due to the low power prices when many homes were built. In Pennsylvania the Gold Medallion Home program of the 1960s, which promoted all-electric homes, was particularly active. Figure 5 summarizes saturation of electric baseboard and other built-in electric units by state or group of states. These figures exclude buildings with five or more apartments.

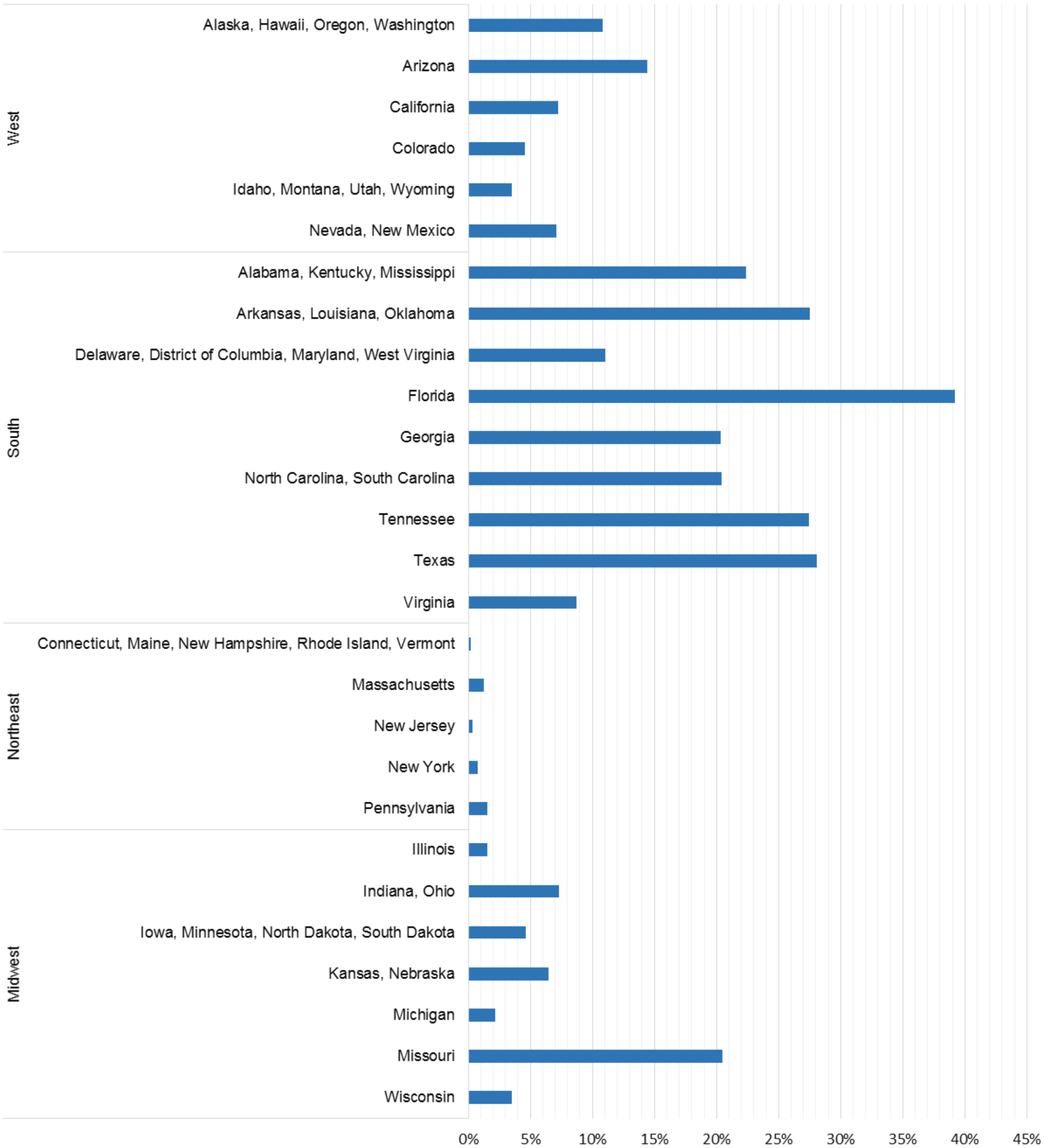

Figure 4. Percentage of homes using electric furnaces as their primary heating source, by state or group of states. These figures are for single-family homes and multifamily homes with two to four units per building. These values apply the weighting factors in the RECS study. *Source:* ACEEE analysis of the detailed 2009 RECS data files.

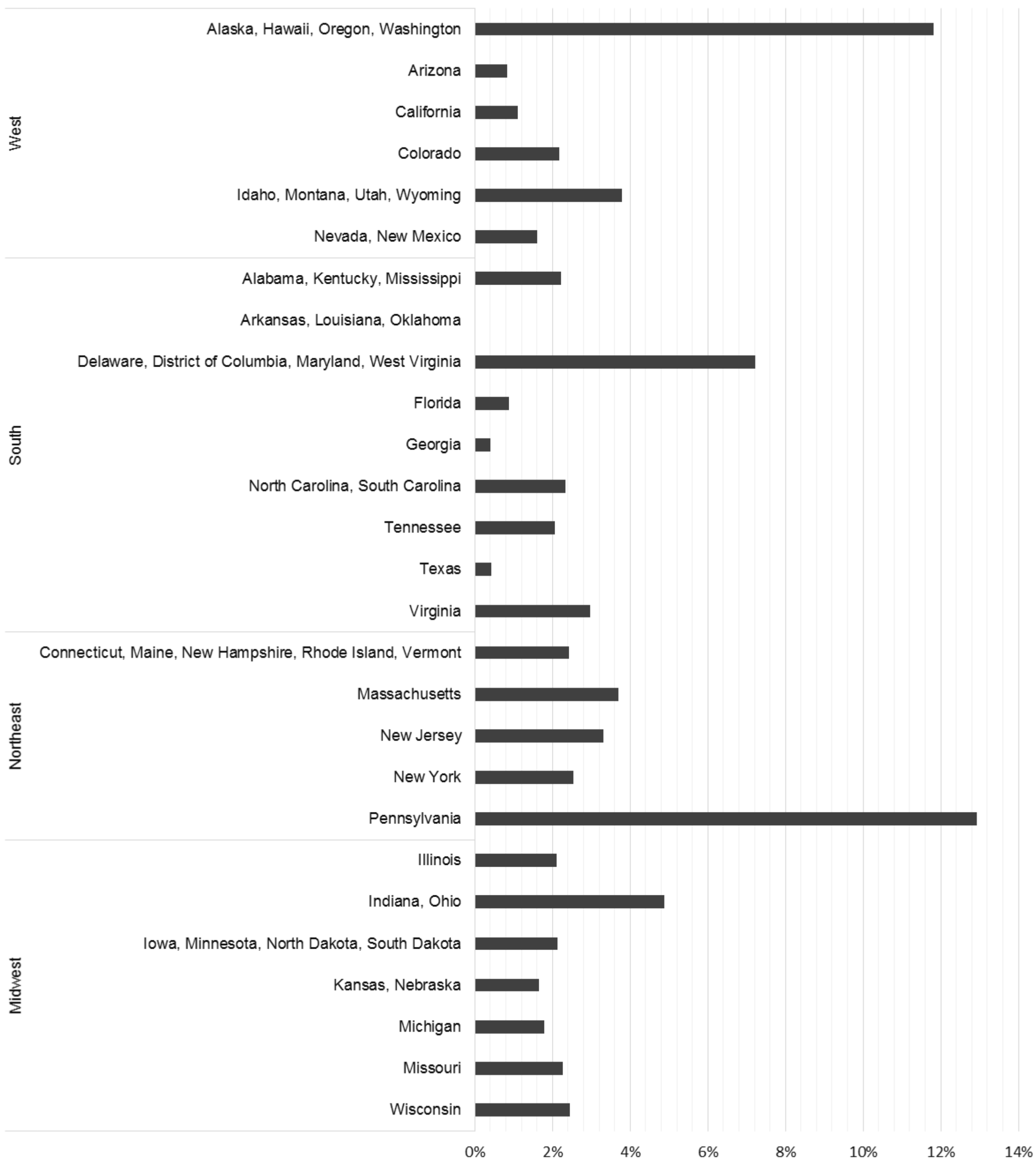

Figure 5. Percentage of homes using electric baseboard or other built-in electric heating units as their primary heating source, by state or group of states. These figures are for single-family homes and multifamily apartment buildings with two to four units per building. These values apply the weighting factors in the RECS study. *Source:* ACEEE analysis of the detailed 2009 RECS data files.

Fortunately, converting homes with electric furnaces to heat pumps is often fairly straightforward. As noted above, about 88% of homes with electric furnaces (excluding buildings with five or more apartments) also have central air-conditioning. When the existing central air conditioner must be replaced, it can be replaced by installing a heat pump and having the electric furnace removed. Heat pumps do cost more than a standard central air conditioner, but when the cost of a replacement electric furnace/air handler combination is included, the cost difference is modest.[5] (We discuss specific costs in the next section.) In a home with an electric furnace but no central air-conditioning, the furnace can still generally be replaced with a heat pump, but the upfront price difference between the heat pump and the electric furnace will be much greater than for a home that has a central air conditioner in need of replacement.

Turning to homes with electric baseboard heaters or other built-in electric systems, about 17% of homes in one- to four-unit buildings that have built-in electric systems and use electricity as their main fuel for space heating also have central air-conditioning systems. Converting these homes to a heat pump at the time when the central air conditioner needs replacement should not be difficult. However the other 83% of homes with built-in electric systems generally do not have ducts. In these cases converting from built-in electric systems to heat pumps is generally much more difficult. Research in the Northwest and Northeast has found that ductless heat pumps may be the best option in these homes.[6] Ductless heat pumps are popular in Asia and Europe and are becoming more common in the United States. They consist of an outdoor unit, generally mounted on an outside wall, and one or more indoor units, typically mounted high on interior walls (see figure 6). These systems are not cheap, so the economics of converting to heat pumps will be site specific.

Figure 6. A ductless heat pump. *Source:* www.qualityrcss.com/ductless-heat-pumps.

In the balance of this paper we discuss a detailed home-by-home analysis of a representative sample of nearly 2,000 homes throughout the United States with electric furnaces and built-in electric heating systems, taken as part of the 2009 RECS (EIA 2013). We compare current

[5] New air handlers are generally needed with new modern, high-efficiency air conditioners in order to achieve the rated performance of the new air conditioner. Even when a new air handler is not necessary, there will likely be a cost to replace a worn-out air handler a few years later.

[6] See neea.org/initiatives/residential/ductless-heat-pumps and Faesy et al. (2014).

energy use in each of these homes with their estimated energy use if they were to convert to heat pumps. We also examine conversion economics.

Methodology

RECS (EIA 2013) provides a wealth of information on the nuances of building energy consumption in the residential sector. The detailed RECS data files make available data on over 12,000 homes representing 113.6 million residential buildings all over the country. Among the variables included are the size of each home, type of heating and cooling equipment used, type of main-space heating fuel used, energy usage, energy bills, and types of appliances used in each home.

For this study we extracted from the RECS sample data on the 1,638 homes with electric furnaces as the primary source of heat and the 315 homes with electric baseboard as the primary source of heat. (These figures exclude buildings with five or more units.) We separated each of these categories into homes with and without central air-conditioning. For homes with ducts we examined the cost of installing ducted heat pumps when the existing central air conditioner or electric furnace needs to be replaced.[7] For homes with electric baseboard heat and without ducts, we analyzed the cost of installing ductless heat pumps. Smaller homes can use one ductless heat pump; larger homes will generally require two such heat pumps. In many cases these units will be *multi-head systems*, which can provide heating and cooling to several rooms separately using a single outdoor unit. For homes that currently use room air conditioners and not central air conditioners, our calculations include credits for the fact that a current room air conditioner will no longer need to be replaced and for the higher cooling efficiency of heat pumps relative to room air conditioners.[8]

Table 2 summarizes the estimated incremental costs of these various conversions. We provide the installed costs of specific types of equipment and the sources for these costs in Appendix A.

Table 2. Estimated conversion costs

Conversion	Incremental cost	Rationale
Electric furnace with central AC to ducted HP (HSPF 8.5)	$711	Based on difference in cost between HP and central AC
Electric baseboard with central AC to ducted HP	$861	Same as above plus $150 for the incremental cost of an HP thermostat and running a wire from the thermostat to the backup heating coils
Electric furnace without central AC to ducted HP	$2,778	Cost of HP minus cost of electric furnace

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[7] We did not examine the economics of installing a heat pump while the existing system is still functioning, concentrating instead on time of replacement, when economics are likely to be more favorable.

[8] In these calculations we assume the same amount of cooling with the heat pump as the household obtained in 2009 with its room air conditioner. In actuality a home with a heat pump is likely to be cooled more, but this extra cooling has value to the residents. For purposes of our analysis, we assume these effects offset each other.

Conversion	Incremental cost	Rationale
Electric baseboard without central AC to ductless HP (homes with five rooms or fewer)	$3,874	One ductless heat pump
Same as above but more than five rooms	$6,973	Two ductless heat pumps
Credit for room AC	–$419	For homes with room AC but not central AC, we credit the net-present-value cost of one replacement room AC unit.

We calculated the benefits of conversion based on the actual 2009 space-heating energy use and space-heating electricity costs of each home in our sample. We used 2009 cost and usage figures because that is the year for which data are provided in the RECS sample. (The next RECS, with 2015 data, is now scheduled for release in 2017.) We estimated energy savings by calculating the heating seasonal performance factor (HSPF), a metric to measure seasonal heat pump efficiency, for each house. For ducted heat pumps we assumed new heat pumps would meet the ENERGY STAR® requirement of a *rated* HSPF of 8.5 (i.e., HSPF as tested under standard conditions in a test laboratory), which is a little above the federal minimum efficiency standard of an 8.2 rated HSPF. In the most recent available data ENERGY STAR held a 37% market share for heat pumps (EPA 2014), but we estimate that ENERGY STAR will be more common for electric furnace conversions because homeowners who convert are interested in saving energy, and also because in some cases their utilities will be encouraging ENERGY STAR units. Furthermore, as of 2023 the federal minimum will increase to an 8.8 rated HSPF.[9]

Field HSPF is performance in a particular climate averaged over a full year; temperatures are different than in laboratory conditions. We estimated the field HSPF for ducted systems based on a formula developed by Fairey et al. (2004) that estimates seasonal field HSPF as a function of winter outdoor design temperature. (The colder the design temperature, the lower the seasonal HSPF.) This formula includes use of backup electric strip heat during cold periods when the heat pump cannot provide enough heat.

For ductless heat pumps we looked at measured field performance for a sample of ductless heat pumps as analyzed by Ecotope (2014).

Our calculations for both ducted and ductless heat pumps assume that the heat pump is properly installed. Improper installation can adversely affect heat pump performance (Domanski, Henderson, and Payne 2014). Additionally, our calculations assume that the shift to a heat pump does not affect use of secondary heating sources such as wood and portable space heaters. We provide details on these calculations in Appendix A.

[9] See www.regulations.gov/#!documentDetail;D=EERE-2014-BT-STD-0048-0076.

Results: Replacing Electric Furnaces

In our analysis we calculated the average seasonal efficiency of a new heat pump for each home in our database. The heat pump we modeled met the ENERGY STAR efficiency level for heat pumps, an HSPF of 8.5. A substantial majority of electric furnaces are located in the South, where heat pump performance can be greater than equipment ratings. As a result the average adjusted HSPF was 8.57 based on the 1,638 homes with electric furnaces in our sample and the weighting factor that RECS assigns to each home. (Each home in the RECS sample represents many other homes, and the weight assigned to each home in the sample is equal to the number of homes in the US housing population that it represents.) We found that replacing electric furnaces with heat pumps would on average reduce space-heating electricity use by 57%, assuming the same level of heating as with the electric furnace. Average annual savings per home are 1,541 kilowatt-hours (kWh) based on 2009 weather conditions. (On a national-average basis, 2009 was just slightly warmer than the 30-year average as measured using heating degree days, or HDDs.)[10] These energy savings are worth an average of $164 per home, using the same costs for electric space heating as these homes paid in 2009.

The amount of electric savings tends to increase as HDDs increase for home locations, up to about 5,000 HDDs as figure 7 shows. As HDDs increase, so does space-heating energy use and hence savings. However, at cold temperatures, heat pump efficiency declines at the same time as the need for space heating increases, and at very cold temperatures electric resistance backup coils are activated, reducing the savings.

[10] HDDs measure the need for heating over the course of a year. The colder the climate, the higher the number of HDDs. In Atlanta the 30-year average is 2,694 HDDs (at Hartsfield–Jackson airport); in Chicago it is 5,960 (at Midway airport). In 2009 the national average was 4,493 HDDs. The 30-year national average is 4,524. National-average data are taken from www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb0107.

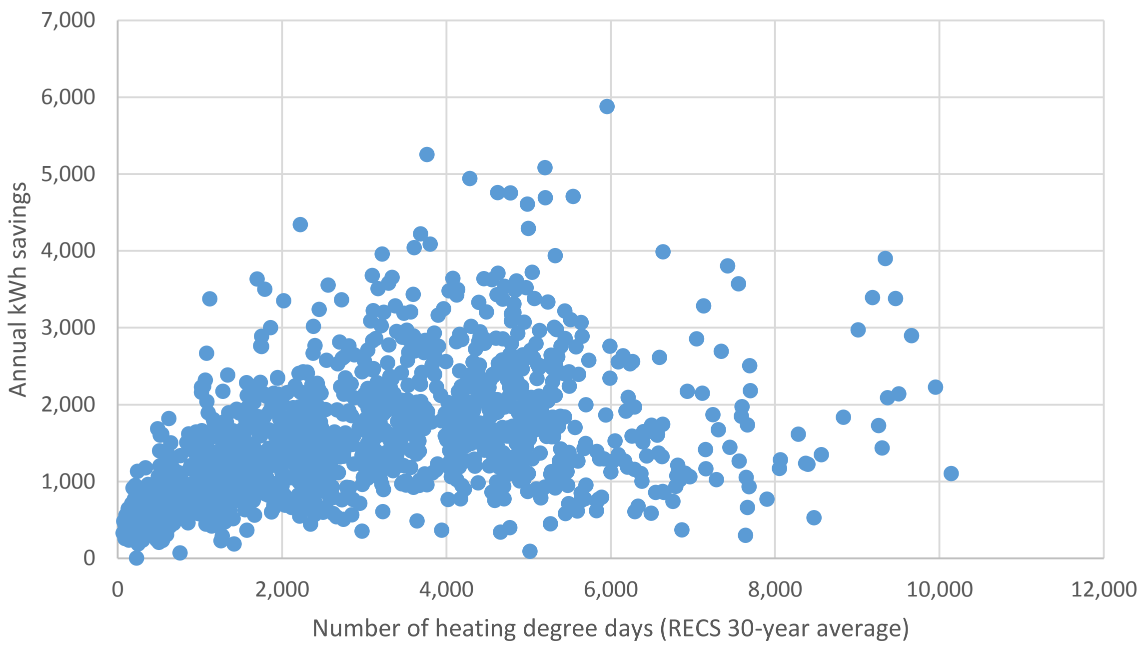

Figure 7. Annual kWh savings in RECS sample homes from converting an electric furnace to a heat pump as a function of HDD

About 88% of the electric furnace homes in our sample have central air-conditioning. For these homes we assumed that the heat pump would be installed when the existing central air conditioner is replaced. We estimated that at that time a heat pump could be installed for $711 more than the price of a new central air conditioner and air handler, including backup electric heating coils, as discussed in Appendix A. Under these assumptions nearly half of homes had a simple payback period of three to five years. The average simple payback period for a heat pump is 5.75 years due to some outliers with long payback periods. The median payback period is 4.7 years. All of these figures include use of the RECS weights. Figure 8 shows the distribution of payback periods for these homes.

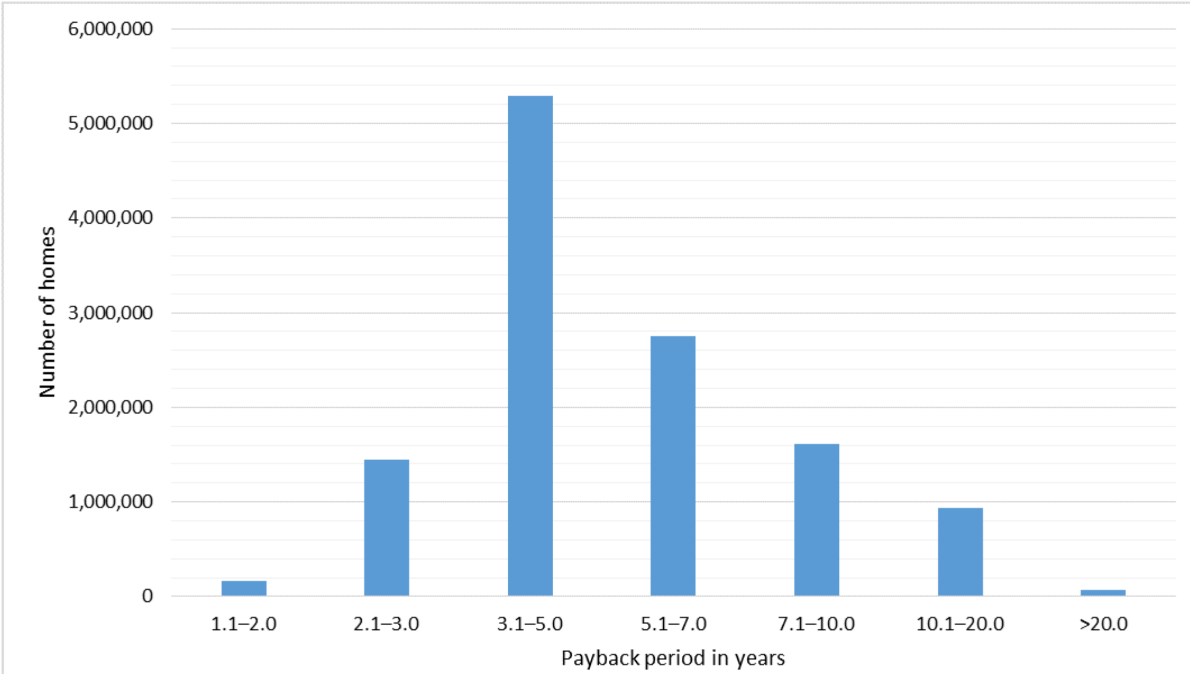

Figure 8. Distribution of simple payback periods for heat pump conversions for homes with electric furnaces and central air-conditioning. These figures are for single-family homes and multifamily buildings with two to four units per building. This distribution applies the weighting factors in the RECS sample.

Figure 9 displays the energy and dollar savings per year from replacing electric furnaces with heat pumps in air-conditioned homes, by state or group of states.

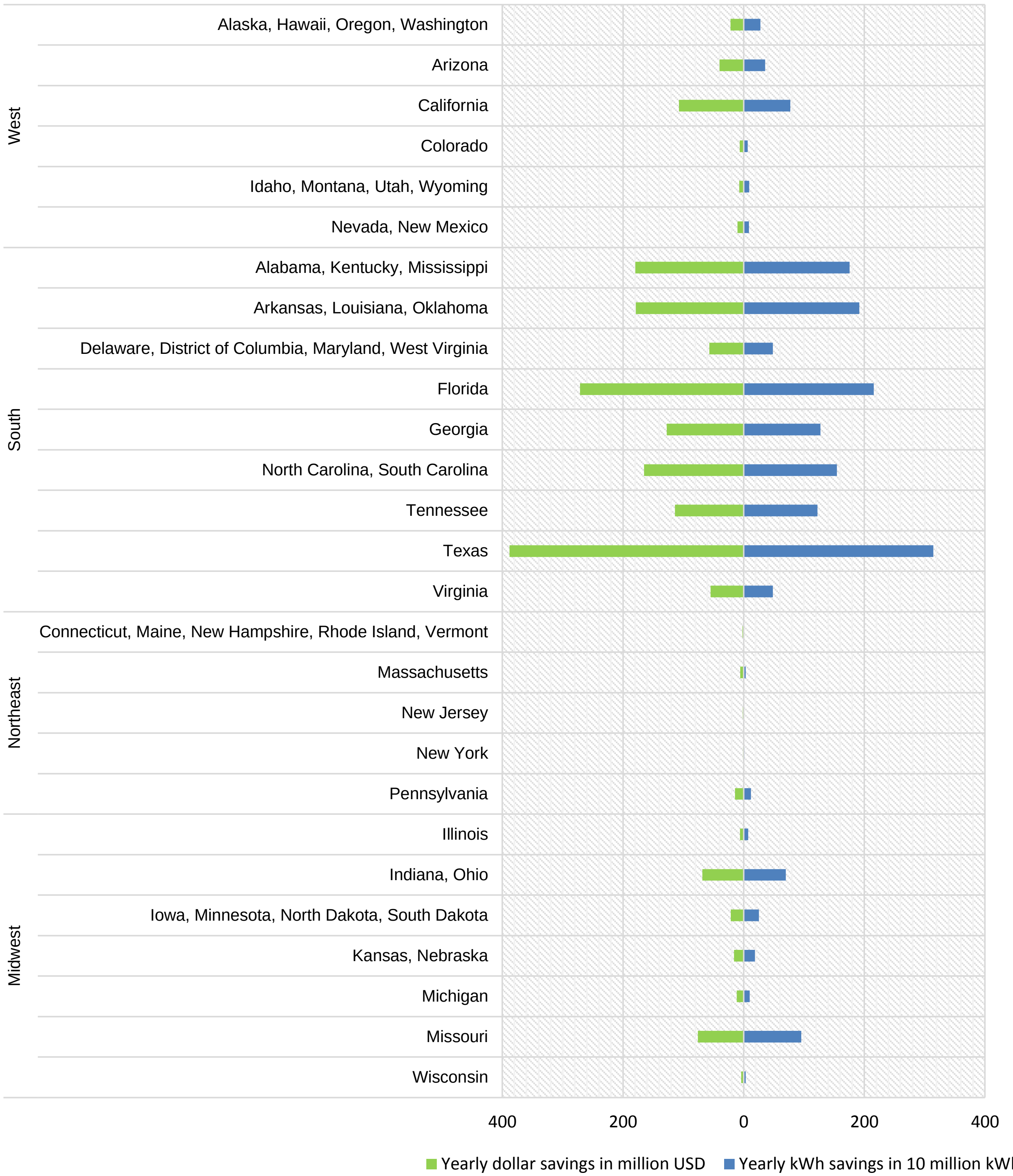

Figure 9. Estimated total annual kWh and dollar savings by state or group of states from converting electric furnaces to ducted heat pumps in homes that already have central air-conditioning. These figures are for single-family homes and multifamily buildings with two to four units per building, and apply the weighting factors in the RECS study. *Source:* ACEEE analysis of the detailed 2009 RECS data files.

Turning now to the 12% of electric furnace homes without a central air conditioner, as discussed above in the Methodology section, we estimated that a heat pump will cost $2,778 more to install than an electric furnace. In those homes that have room air conditioners we credit the cost of one replacement room air conditioner. Figure 10 plots the distribution of simple payback periods for the homes in the RECS sample with electric furnaces but without central air-conditioning, using the weights in the RECS sample to extrapolate to all homes with electric furnaces and without central air-conditioning. While conversions in some homes require a simple payback period of 10 years or less, the most common simple payback period is between 10 and 20 years, with a substantial number of homes having a simple payback period of over 20 years. Across all homes the conversion requires an average simple payback period of about 18 years, with a median of 14.9 years. These average and median payback periods are similar to the life of a heat pump. On the other hand, by converting to a heat pump the owner gains central air-conditioning, which might motivate some owners to make this investment. We report average savings for each state and region in Appendix B.

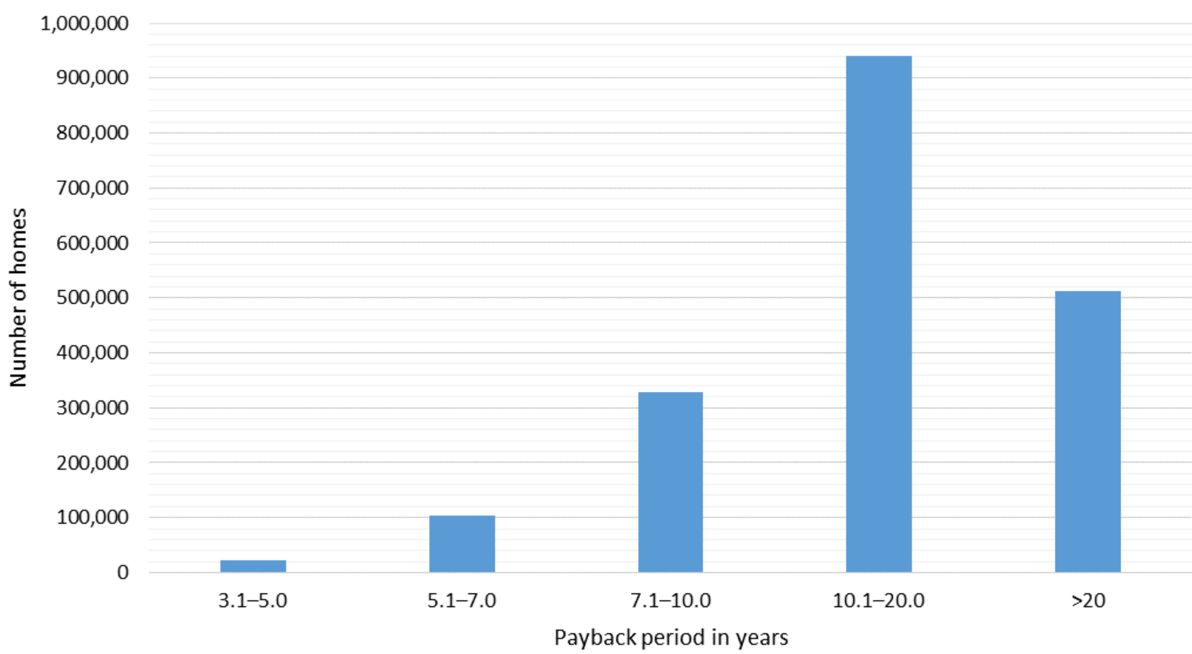

Figure 10. Distribution of simple payback periods for heat pump conversions for homes with electric furnaces but no central air-conditioning. These figures are for single-family homes and multifamily buildings with two to four units per building. This distribution applies the weighting factors in the RECS sample.

As noted previously each home in the RECS sample represents many other homes, with the weight assigned to each home in the RECS sample equal to the number of homes in the US housing population that it represents. By applying these weights we can extrapolate our results to the entire country. Using our findings from individual homes and their weights, we estimate that replacing all 14.2 million existing electric furnaces nationwide with heat pumps would reduce US electricity use by 21.8 billion kWh per year (based on 30-year average HDD) and would save $2.33 billion per year (based on 2009 electricity prices).[11] These figures do not include any central air-conditioning savings, as we assume that a new central air conditioner and a new heat pump will have the same cooling performance. These 21.8 billion kWh represent 1.6% of total residential electricity use in 2009 as reported by EIA.[12] As we discuss below conversions are not cost effective in all homes, so the cost-effective potential savings are somewhat lower. Almost all of the savings come from homes with both electric furnaces and air-conditioning because most homes with electric furnaces also have central air-conditioning. Replacements in these homes would yield 18.1 billion kWh in electricity savings and $1.96 billion in dollar savings. The upfront investment for these 14.2 million homes with electric furnaces would range from about $711 to $2,778; across all the homes in our sample with electric furnaces, the upfront investment totals $13.6 billion.

Results: Replacing Built-In Electric Heating Systems

For our analysis of homes with built-in electric heating systems, we modeled two types of heat pumps—ducted heat pumps for homes with central air-conditioning that already have ducts, and ductless units for homes without central air-conditioning and ducts. Relative to homes with electric furnaces homes with built-in systems tend to be located in climates that are colder on average. As a result the average HSPF for heat pumps in these homes would be about 7.59 for the ducted systems and 10.35 for the ductless systems, substantially better than for electric resistance heat (with an HSPF of 3.4) but below the 8.5 and 10–12 rated HSPF of the ENERGY STAR or high-efficiency equipment we modeled for ducted and ductless units, respectively.[13] We outline the methodologies for calculating the HSPF values of ducted and ductless systems in Appendix A.

There are 315 homes in our sample with electric baseboard or other built-in electric heating systems. The 17% of these homes that have central air-conditioning are relatively easy to convert to heat pumps at the time the central air conditioner needs replacing. As discussed in the Methodology section the incremental cost of a heat pump relative to a central air conditioner in these situations is $861 on average.

Homes without central air conditioners can be converted to heat pumps using ductless systems. For homes of five rooms or fewer we estimated that one heat pump with several indoor units could do the job. For homes with six or more rooms we assumed we would need two ductless systems. As discussed in the Methodology section we used costs of $3,874 for a single system and $6,973 for two systems. In those homes with room air conditioners we credited the cost of one replacement room air conditioner.

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[11] The 21.8 billion figure does not include buildings with five or more apartments.

[12] US residences used 1,365 billion kWh in 2009. See www.eia.gov/totalenergy/data/monthly/#electricity.

[13] However the HSPF of 3.4 does not account for the fact that electric baseboard heaters can be controlled room by room or for the fact that electric baseboard heating does not result in air and energy losses in duct systems. If both of these effects are 15% (typical values), the electric baseboard system can be said to have an effective HSPF of about 4.5, still below that of heat pumps.

On average converting built-in systems to heat pumps would reduce electricity use in these homes by 66%, saving an average of 2,829 kWh and $296 per home annually (based on 2009 weather and energy prices). Relative to the electric furnace conversions discussed in the previous section, energy savings in kWh and dollar terms are higher due to the higher efficiency of ductless systems and the colder average climate for homes with built-in systems. Energy savings on average increase as HDD increase, as figure 11 shows. Savings tend to drop off above approximately 7,000 HDD.

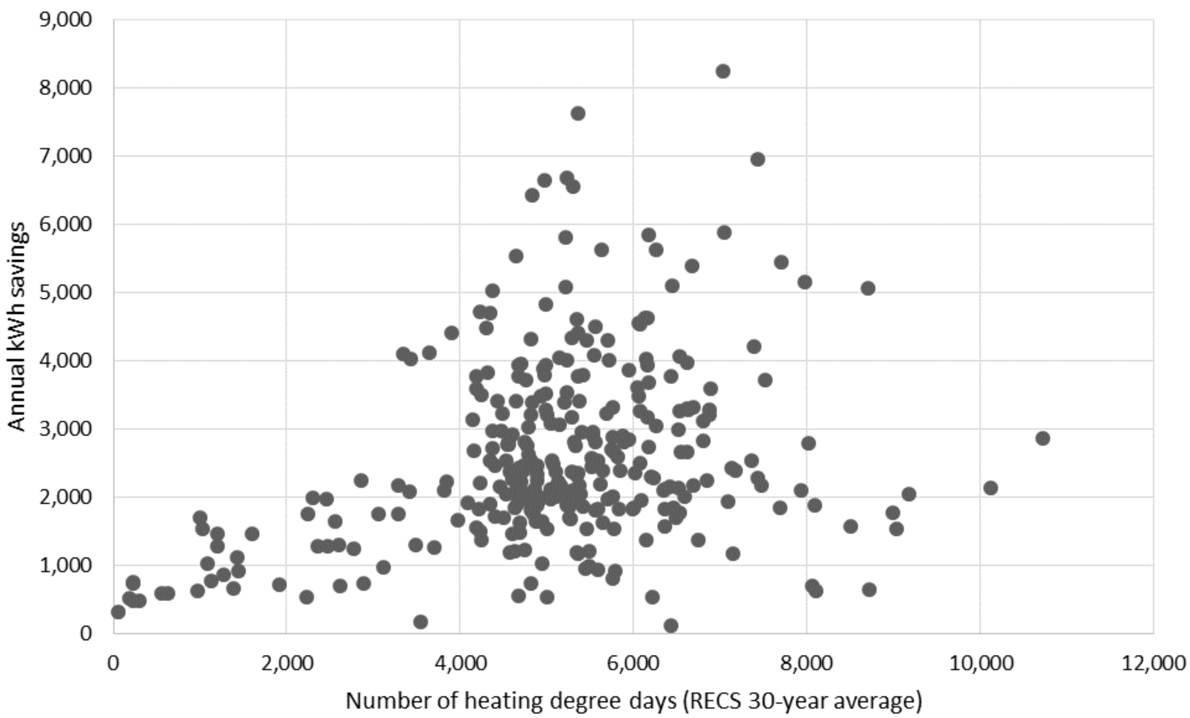

Figure 11. Annual kWh savings in RECS sample homes from converting built-in electric heating systems to heat pumps, as a function of HDD

As noted above EIA has assigned a weight to each home in our sample, allowing national extrapolations. Using our findings from individual homes and their weights, we estimated that replacing all 3.4 million built-in electric heating systems with heat pumps nationwide would reduce US electricity use by 9.7 billion kWh per year (based on 30-year average HDD) and would save $1 billion per year (based on 2009 electricity prices).[14] These electricity savings represent 0.5% of US residential electricity sales in 2009. With an upfront cost of $861–6,973, the total upfront investment would be $12.8 billion.

Figure 12 provides a distribution of payback periods for both of the built-in system configurations we analyzed—installing ducted heat pumps in homes with central air-conditioning and installing ductless heat pumps in homes without central air-conditioning. Of

[14] The 3.4 million figure does not include buildings with five or more apartments.

these homes 11.5% would have simple payback periods of 5 years or less (mostly homes that already have central air-conditioning), 27.4% would have payback periods of 5.1–10 years, 37.6% would have 10.1–20 year paybacks, and 23.5% would have paybacks over 20 years. For homes that already have central air-conditioning the average simple payback period is five years. For homes without central air-conditioning the average payback period is 19 years. The median simple payback periods are 4.25 years (with existing central air-conditioning) and 14.8 years (without existing central air-conditioning).

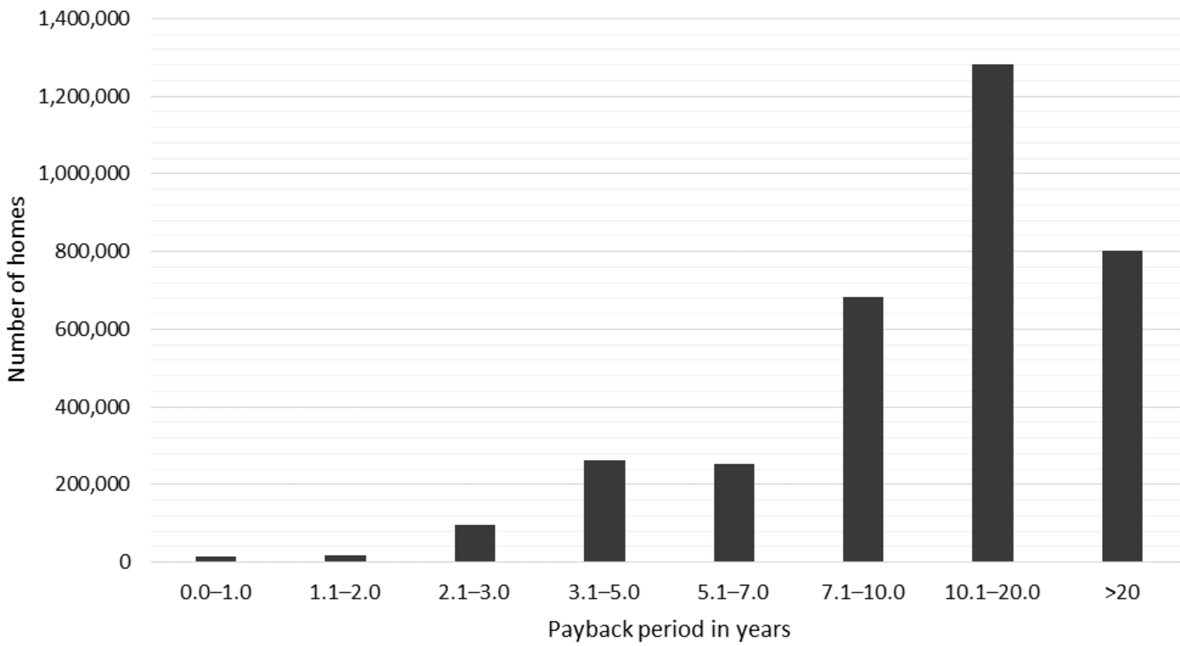

Figure 12. Distribution of simple payback periods for heat pump conversions for homes with built-in electric heating systems. These figures are for single-family homes and multifamily buildings with two to four units per building. This distribution uses the RECS weighting factors and applies to homes with built-in electric units, both with and without air-conditioning.

Figure 13 summarizes average annual energy and dollar savings by state or group of states for homes with electric baseboard heating and central air-conditioning.

Figure 13. Estimated total annual energy and dollar savings by state or group of states for homes with electric baseboard and central air-conditioning. These figures are for single-family homes and multifamily buildings with two to four units per building, and apply the weighting factors in the RECS study. *Source:* ACEEE analysis of the detailed 2009 RECS data files.

It should be noted that built-in units generally have individual-room thermostats, enabling energy savings when temperatures in unused rooms are reduced. Central heat pumps generally do not have this feature. Most ductless heat pumps have individual-room temperature controls and therefore benefit from the same zoning effect as built-in units. Thus savings from replacing built-in systems in homes with central air-conditioning may be a little lower than shown here. Furthermore, in the North use of supplemental heating methods such as wood is common in homes with electric resistance heat. An evaluation of ductless heat pump programs in the Northwest found average electric savings of 33% as a result of these factors, somewhat less than the average savings we estimated here. It found higher savings in the milder, western climates, while observing lower savings in the more severe heating climates, where wood use was prevalent (Ecotope 2014). On the other hand the study also found that the residents in the ductless heat pump pilot program under evaluation averaged 60 years of age, and it is unclear whether these households will continue using as much wood as they get older. The study also noted health benefits from reduced woodstove pollution after ductless heat pumps were installed (J. Harris, chief transformation officer, Northwest Energy Efficiency Alliance, pers. comm., March 23, 2016).

Discussion and Next Steps

Our analysis finds that converting from electric resistance heat to heat pumps can cut electricity use for home heating by a little more than half on average. However the economics of conversion vary depending on whether the home has central air-conditioning and a variety of other factors such as cost of conversion, current energy consumption, and impact of climate on heat pump efficiency. Converting electric furnaces is often attractive from both an energy-saving and an economic point of view in the 88% of electric furnace homes and 17% of electric-baseboard homes that already have central air-conditioning systems. In these cases a heat pump can be installed when the existing air conditioner needs replacement. Payback periods are also sometimes reasonable for converting electric furnaces in homes without central air conditioners when the electric furnace needs replacement. For homes with built-in electric systems but without central air-conditioning, payback periods will often be long, although the addition of air-conditioning will be attractive to some owners.

These savings are based on estimates of typical conversion costs, but costs are likely to vary from home to home and region to region. Additional data collection on actual costs in particular regions would be useful. Furthermore we base this analysis on current equipment and energy costs and current technologies. As costs and technologies change, this analysis should be revised.[15]

[15] For example, both ducted and ductless heat pumps continue to improve, several efforts are underway to continue these improvements including work by the US Department of Energy (DOE) and the Electric Power Research Institute (EPRI) to develop ducted heat pumps that function better in cold climates. (See energy.gov/eere/buildings/listings/heating-ventilation-and-air-conditioning-projects and aceee.org/sites/default/files/pdf/conferences/mt/2016/Domitrovic_MT16_SessionC4_3.22.16.pdf.) The federal minimum efficiency standard for ducted heat pumps will increase to 8.8 HSPF in 2023, and at that time the ENERGY STAR specification for heat pumps will likely be above 9.0 HSPF. Ductless heat pumps are now

The South looks to be a particularly promising region for conversions to heat pumps, as electric furnace saturation is high in the South, most homes have central air-conditioning, and relatively mild temperatures mean that heat pump efficiency is high. We recommend that program administrators in the South consider introducing new heat pump programs, starting with analysis of opportunities within their service areas and proceeding to pilot programs if the results are promising. Once programs have been in operation for more than a year, an ex post analysis of billing and weather data should be conducted to determine actual weather-normalized energy savings, and the results should be compared to the estimates in this study.

In the North, efforts are likely to focus on ductless heat pumps because many of the homes with electric heat lack ducts. In addition several ductless systems have been optimized for cold climates (NEEP 2014).[16] We also suggest that efforts in the North should target market niches with better-than-average economics. These include the Northwest, where the relatively mild climate, high saturation of built-in units, and extensive network of experienced ductless heat pump contractors create an opportunity, and Vermont, which has high electric costs that make the economics more attractive and a growing contractor network.[17]

Conclusion

This analysis finds that substantial energy and dollar savings are possible by converting homes to heat pumps if they already have central air-conditioning but use electric resistance heat. Conversion generally makes much less sense if a home does not already have central air-conditioning, unless the owner wants to add air-conditioning and is willing to pay for this amenity. Further localized analysis would be useful, perhaps leading to pilot programs in regions where this localized analysis shows favorable energy and economic savings.

dominant in much of the world, and the best units have efficiencies significantly higher than those we analyze here.

[16] While there are a few ducted systems that perform reasonably well in cold climates, there is a need to develop more and better cold-climate ducted heat pumps.

[17] In Vermont and other northeastern states there are also opportunities to install cold-climate heat pumps to replace oil-fired furnaces and boilers.

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Appendix A. Methodological Details

The goal of our study was to determine the economics of replacing electrical heating equipment, specifically electric furnaces and built-in electric heaters, with heat pumps. For this we needed to calculate the energy saved in each home if a heat pump were used to meet its space-heating needs, instead of an electric furnace or electric baseboard heaters. We assumed that the heat pumps would be installed at the time of replacement of old electrical cooling and heating equipment.

OUR DATA

For our analysis we identified homes in the RECS data set (EIA 2013) that use electric resistance heat as their primary heating fuel. We excluded units in buildings with five or more apartments, as explained in the main report text, and separated the remaining homes into two categories: those using electric furnaces and those with electric baseboard heating. Furthermore we analyzed homes with and without central air-conditioning within the two categories. In homes with electric baseboard heat and no central air-conditioning, we differentiated between homes with five or fewer rooms and homes with more than five rooms. Thus we examined the economics of heat pump installations for five categories of homes. Figure A1 summarizes these categories.

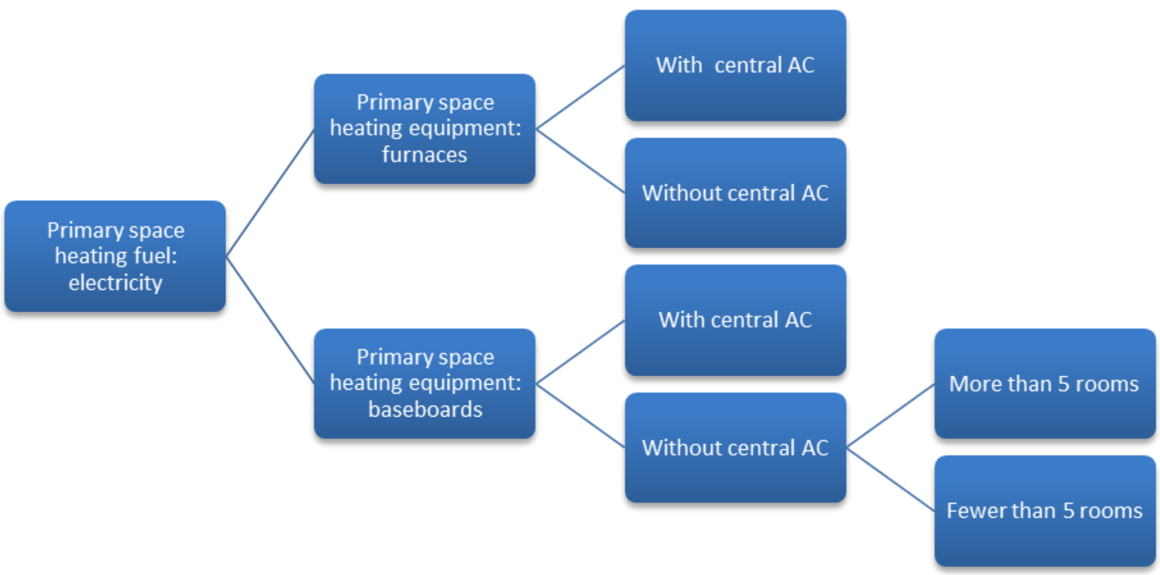

Figure A1. Breakdown of homes chosen from RECS data for our analysis

Some electrically heated homes also use heat pumps as their primary heating source. We did not include these homes in our analysis, as they already use heat pumps.

HSPF AND HSPF ADJUSTMENT FACTOR

HSPF is a measure of the seasonal efficiency of a heat pump in heating mode. Heat pumps use electricity as input and produce heat by squeezing it out of outdoor air. Electricity is measured in kWh, and heat energy is measured in thousands of British thermal units (kBtus). HSPF is expressed as the Btus produced per watt-hour (Wh) of electricity consumed by heat pumps.

Manufacturers of heat pumps typically provide this information in product literature and databases, and the manufacturer trade organization, called the Air-Conditioning, Heating, and Refrigeration Institute (AHRI), maintains a directory of verified ratings.[18]

Ducted Heat Pumps

For our analysis, as discussed in the body of the main report, we assumed that heat pumps used to replace equipment in homes with ducts (i.e., with electric furnaces and/or central air-conditioning) have an HSPF of 8.5 Btus/Wh, which is the minimum value for ENERGY STAR–certified heat pumps. However the performance of heat pumps declines with the severity of winter temperatures. Fairey et al. (2004) have developed formulas to account for this decrease in performance. The formula that they developed and we used is as follows. It calculates the percentage decrease in HSPF as a function of winter design temperatures:

$$\% \text{ decrease} = a + b * \text{temp} + c * \text{temp}^2 + d * \text{HSPF}$$

Table A1 provides the formula coefficients developed by Fairey et al. (2004).

Table A1. Formula coefficients for adjusted HSPF

Coefficients for % decrease in performance	HSPF < 8.5	HSPF $\geq$ 8.5
a	0.1392	0.1041
b	−0.00846	−0.00882262
c	−0.0001074	−0.0001153
d	0.0228	0.02817
R-square	0.9649	0.9648

In order to preserve confidentiality the RECS data set does not list towns or cities, information we would need to identify winter design temperature for each home. RECS does provide HDD for each home.[19] Therefore we needed to determine a relationship between 30-year HDD averages and winter design temperature, using regression analysis. For our data set we used data published by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE).[20] Our formula is:

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[18] www.ahridirectory.org/ahridirectory/pages/home.aspx.

[19] HDD are calculated for each day of the heating season and represent the difference between 65°F and the average temperature on that day. The assumption is that heat is needed only when the outdoor temperature drops below 65°F and that the need for heating increases as the outdoor temperature drops. HDD values for each day are summed to provide an annual value. Some years are warmer than other years, so HDD are often reported as 30-year averages for a location.

[20] Available at www.captiveaire.com/CatalogContent/Fans/Sup_MPU/doc/Winter_Summer_Design_Temps_US.pdf?v=17112015.

$$Winter\ design\ temp = x^1 + y^1 * 30\text{–}\ year\ HDD$$

Table A2 provides formula coefficients, and figure A2 illustrates the relationship between winter temperature and HDD for US locations in our data set.

Table A2. Formula coefficients for calculating winter design temperature

Coefficients for winter design temp	Value
x_1	45.5456842
y_1	-0.006401593
R-square	0.8905
Adjusted R-square	0.8903

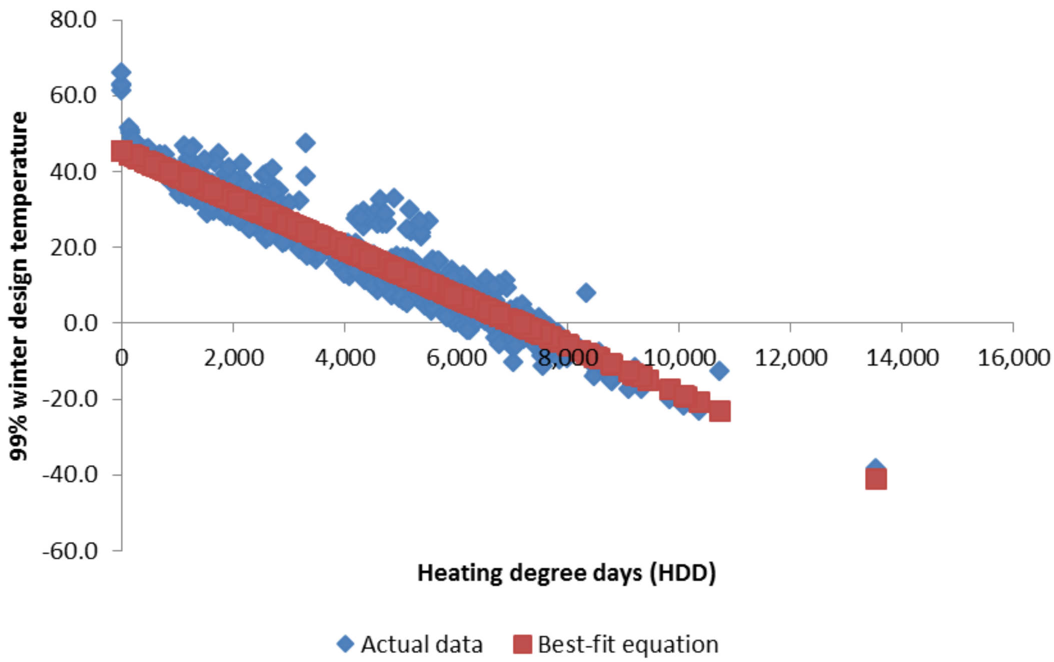

Figure A2. Plot of winter design temperature and 30-year HDD, showing best fit line

Ductless Heat Pumps

The HSPF adjustment described above applies to ducted heat pumps. In our analysis we use ducted heat pumps to replace electric furnaces and electric baseboard heat in homes with ducted central air-conditioning. For homes without ducts we instead use ductless heat pumps. To estimate the performance of ductless heat pumps, we used a detailed evaluation of a ductless heat pump pilot program in the northwestern United States (Ecotope 2014). This study reports the actual seasonal coefficient of performance (COP) of ductless heat pumps in five regions of the Northwest. COP is equal to seasonal HSPF divided by 3.412. The ductless heat pumps used in this study had rated HSPFs ranging from about 10 to 12 and rated COPs ranging from about 2.9 to 3.5.[21] The regions in the Ecotope study vary from about 4,222 to 7,035 HDD (30-year average). We developed a simple regression equation for these five regions:

$$COP \; = x^2 + y^2 * 30\text{–}year\ HDD$$

Because our sample size was small (five), the R-square is not very good, but it is the best we can do with the available data. Table A3 presents coefficients for this formula, and figure A3 shows a plot of seasonal COP by HDD.

Table A3. Formula coefficients for calculating COP of ductless heat pumps

Coefficients for COP	Value
x_2	4.319641711
y_2	-0.000242756
R-square	0.678
Adjusted R-square	0.571

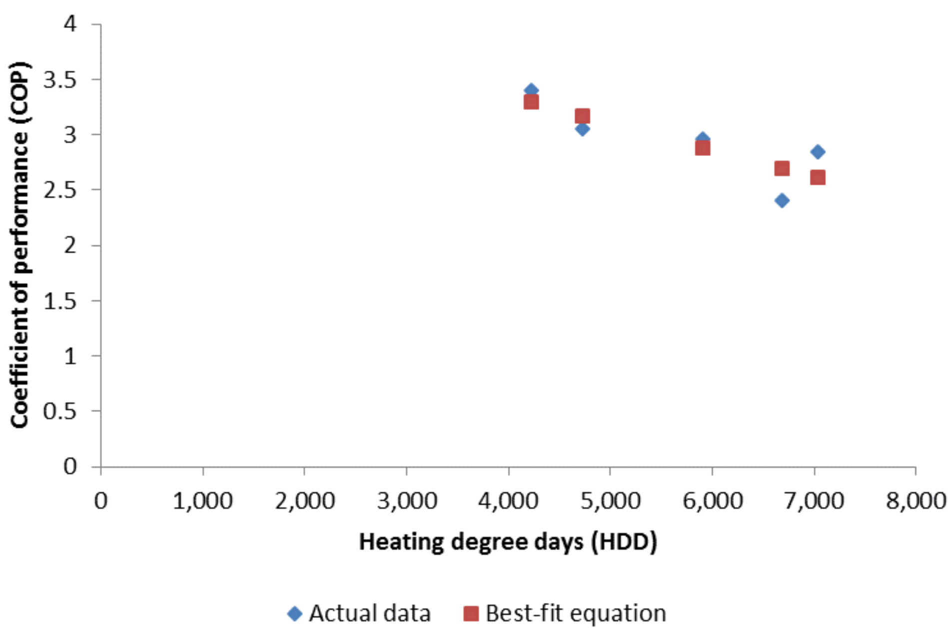

Figure A3. Plot of seasonal COP and HDD, showing best fit line

ENERGY SAVINGS

The RECS data (EIA 2013) include the yearly kWh consumed for space heating of each home that uses electrical resistance equipment, as well as the Btus produced by that equipment. To

[21] There are 3.412 Btus in 1 Wh.

determine heating energy savings from heat pump replacements in these homes, we calculated the difference in kWh consumption between electric resistance equipment and heat pumps employed to provide the heat required in that home (in Btus). We calculated the electric consumption (in kWh) of heat pumps using the adjusted HSPF values and space-heating Btus.

For homes that currently have central air conditioners, we did not include any cooling savings because we assumed that the cooling performance of new central air conditioners and new heat pumps would be similar. However, in homes that currently have room air conditioners, central heat pumps and ductless heat pumps are more efficient, so there will be cooling-energy savings in order to provide the same amount of cooling that homes currently have.[22] We estimated cooling savings on a percentage basis using the estimated seasonal energy efficiency ratio (SEER) for different types of equipment. Table A4 shows our assumptions. We multiplied the percentage cooling savings by the 2009 cooling energy consumption of each home with a room air conditioner to estimate cooling savings in kWh.

[22] In actuality a home with a heat pump is likely to be cooled more, but this extra cooling has value to the residents. For purposes of our analysis we assume these effects offset each other.

Table A4. Estimation of cooling-energy savings from replacing room air conditioners with heat pumps

Factor	Value	Assumption
Room air conditioners		
Rated EER	11.1	2014 standard (for 8,000–13,000 Btus/hour products)
	12.0	ENERGY STAR
	11.55	Estimate average unit midway between standard and ENERGY STAR
Estimated SEER	12.55	Estimate 1 point more than EER. It is about 2 points more for central AC but will be less for room AC.
Ductless heat pumps		
SEER	20	Estimate by eyeballing CEE-AHRI ductless database, 3/27/16
Cooling savings	37%*	(20 – 12.55) / 20
Ducted air-source heat pumps		
SEER	16	ENERGY STAR is 14.5, but few units are 14.5; 16 is very common.
	22%	(16 –12.55) / 16

* The Northwest Regional Technical Forum estimates 50% cooling savings from moving from a room air conditioner to a ductless heat pump, but this estimate uses the efficiency of the current stock of room air conditioners, which are not as efficient as the new room air conditioners we assume. See rtf.nwcouncil.org/measures/measure.asp?id=128. The impact of 37% versus 50% savings on our calculations is generally a de minimis effect.

Yearly savings for homes with electric furnaces ranged from 3 kWh to 6,099 kWh, while savings for homes with electric baseboards ranged from 120 kWh to 8,642 kWh. These figures include heating savings and also include cooling savings for homes with room air conditioners but not central air conditioners.[23]

DOLLAR SAVINGS

The RECS data (EIA 2013) include the average 2009 electricity prices for each home. We calculated yearly dollar savings for each home using the yearly kWh savings and average electricity prices in 2009.

COSTS OF CONVERSION TO HEAT PUMPS

Depending on the type of electric resistance equipment currently installed in a home, the costs of conversion to heat pumps can vary. We estimated the costs of different types of equipment from US Department of Energy (DOE) Technical Support Documents (TSDs) and other sources as identified in table A5.

[23] If a home had both central and room air conditioners, we had no way to estimate the relative energy use of each. Given this uncertainty, in order to be conservative we did not include any cooling-energy savings.

Table A5. Equipment and installation costs

Equipment type	Cost	Source
Ducted heat pump (SEER 15)	$5,393	www.regulations.gov/#!documentDetail;D=EERE-2014-BT-STD-0048-0071 (December 2015)
Ducted central air conditioner (SEER 15)	$4,652	Includes blower and coil. Source same as above.
Electric furnace	$2,615	www.homeadvisor.com/cost/heating-and-cooling/install-a-furnace/ (consulted 1/8/2016)
One ductless heat pump	$3,874	Ecotope 2014
Two ductless heat pumps	$6,973	Two times row above minus an estimated 10% discount for buying and installing two units at the same time
Room air conditioner	$419	DOE estimates $498 for a unit with a capacity of 8,000–13,000 Btus/hour (the most common size). See www.regulations.gov/#!documentDetail;D=EERE-2007-BT-STD-0010-0053. This estimate uses 2009 dollars, so we adjust to 2013 dollars using the Federal Reserve Bank GDP deflator. We also estimate that the average room air conditioner is midway through its 10-year life and thus discount this cost using a 5% real discount rate for 5 years.

These cost estimates include typical installation costs for each type of system. ACEEE strongly recommends that quality installation practices be employed to better ensure that both air conditioners and heat pumps operate at their designed performance levels over time.[24]

Using these installed equipment costs we estimated conversion costs, as table A6 summarizes.

[24] See for example www.acca.org/standards/quality.

Table A6. Estimated conversion costs

Conversion	Incremental cost	Rationale
Electric furnace with central AC to ducted HP (SEER 15/HSPF 8.5)	$711	Based on difference in cost between an HP and central AC, as given in table A5
Electric baseboard with central AC to ducted HP	$861	Same as above plus $150 for the incremental cost of an HP thermostat and running a wire from the thermostat to the backup heating coils
Electric furnace without central AC to ducted HP	$2,778	Cost of HP minus cost of electric furnace
Electric baseboard without central AC to ductless HP (homes with five rooms or fewer)	$3,874	One ductless heat pump
Same as above but more than five rooms	$6,973	Two ductless heat pumps
Credit for room AC	-$419	For homes with room AC but not central AC, we credit the cost of one replacement room AC unit. Some homes have more than one room AC, but RECS does not have data on number of room ACs per home, so to be conservative, we assume one per home with room ACs.

SIMPLE PAYBACK

Using the yearly dollar savings divided by the costs of conversion, we calculated the simple payback period in years for each home in our sample.

Appendix B. Additional Figures

ELECTRIC FURNACES WITHOUT CENTRAL AIR-CONDITIONING

Figure B1 displays the kWh and dollar savings for heat pump installations in homes with electric furnaces and without central air-conditioning.

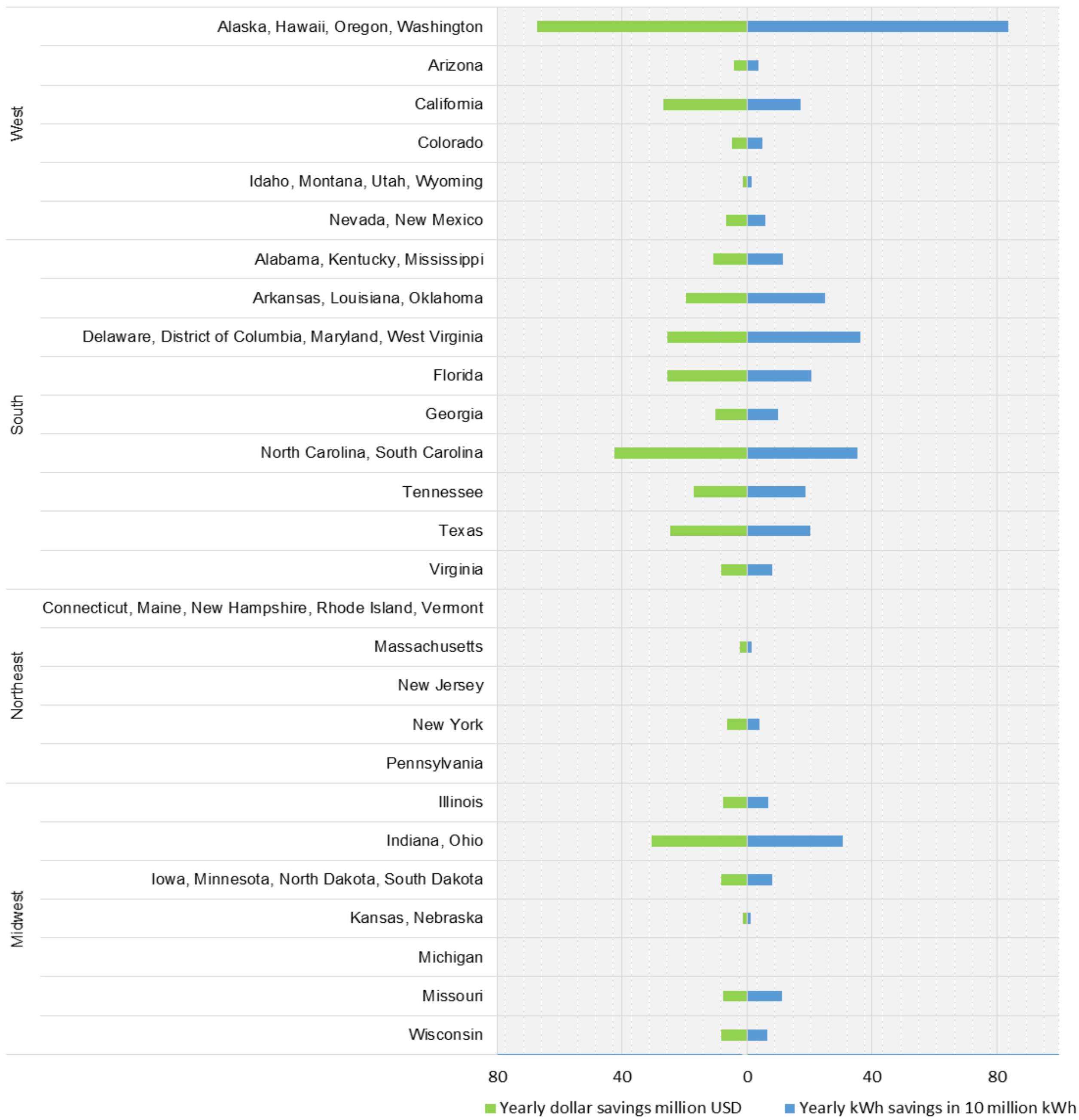

Figure B1. Estimated total annual kWh and dollar savings by state or group of states from converting electric furnaces to ducted heat pumps in homes that do not have central air-conditioning. These figures are for single-family homes and multifamily buildings with two to four units per building, and apply the weighting factors in the RECS study. *Source:* ACEEE analysis of the detailed 2009 RECS data files.

ELECTRIC BUILT-IN UNITS WITHOUT CENTRAL AIR-CONDITIONING

Figure B2 displays the kWh and dollar savings for heat pump installations in homes with electric built-in units and without central air-conditioning.

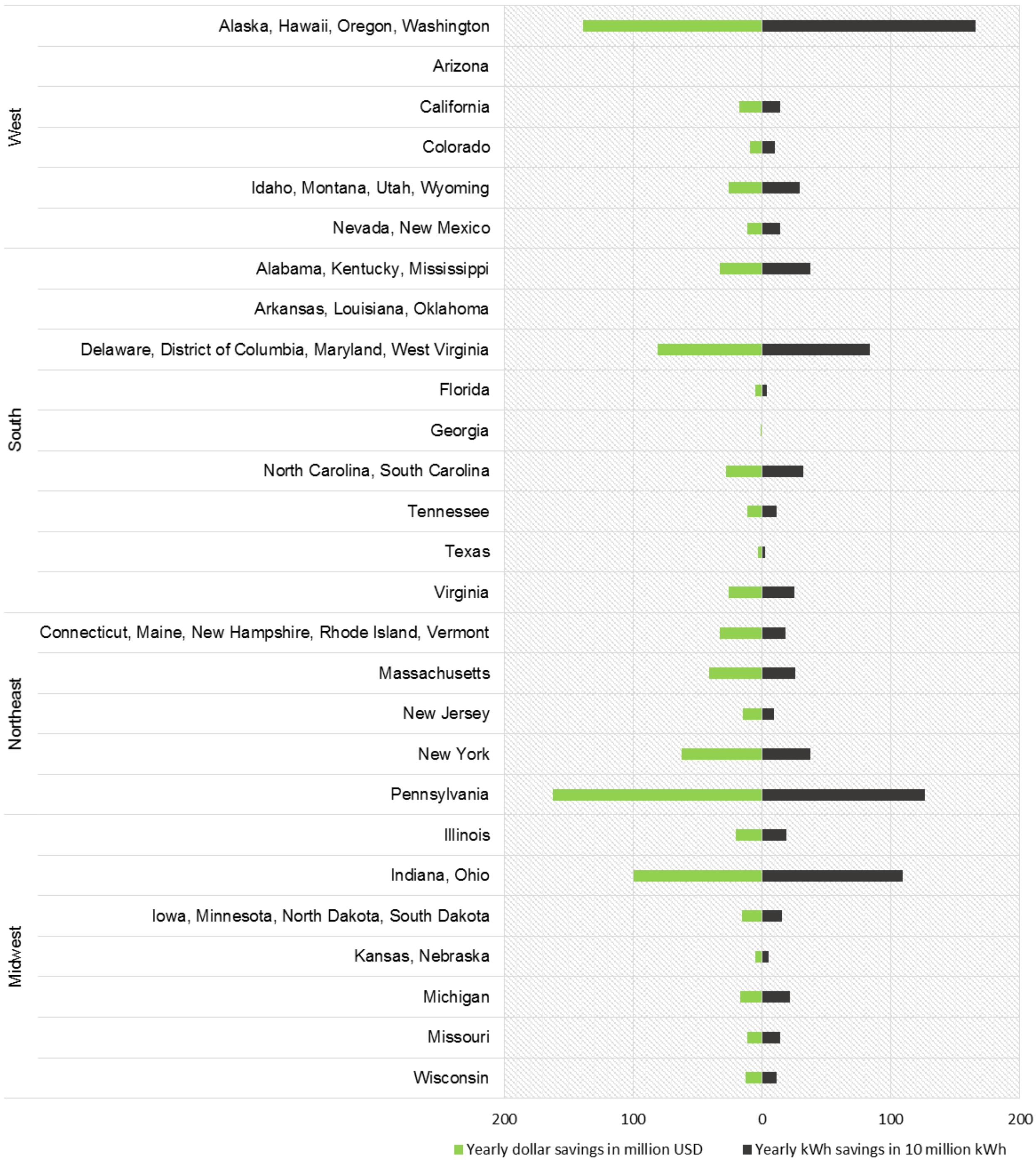

Figure B2. Estimated total annual kWh and dollar savings by state or group of states from converting electric built-in units to ducted heat pumps in homes that do not have central air-conditioning. These figures are for single-family homes and multifamily buildings with two to four units per building, and apply the weighting factors in the RECS study. *Source:* ACEEE analysis of the detailed 2009 RECS data files.