APPENDIX 2

Summary Report:

Heating and Cooling Energy Adjustment for HUD-52667 Spreadsheet Model

Jason Glazer
GARD Analytics, Inc.

Prepared for the U.S. Department of
Housing & Urban Development, Office
of Policy Development and Research
August 22, 2012

1. Introduction

In recent years, the Department of Housing and Urban Development (HUD) has made available a Microsoft Excel spreadsheet model to assist Public Housing Authorities (PHAs) in developing utility allowances for the Section 8 Existing Housing Choice Voucher program. The spreadsheet model computes the utility allowances in a format consistent with the HUD Form HUD-52667, the form which is often used by PHAs to document the utility allowances provided.

2. Background

The U.S. Department of Housing and Urban Development (HUD) operates the Housing Choice Voucher program, also referred to as the Section 8 Existing program. The Housing and Community Development Act of 1974 authorized the Section 8 program which has been modified several times, including by the Quality Housing and Work Responsibility Act of 1998 which resulted in the current Housing Choice Voucher program. Program participants receive assistance that pays for part of the cost of an eligible rental housing unit. The program-allowed total housing cost includes not only the contract rent charged, but also an allowance for any tenant-paid utilities such as electricity, natural gas and other fuels. This program-allowed housing cost is subject to constraints on the total rent allowed for a unit with a given number of bedrooms. This means that the higher the estimated tenant-paid utility cost, the less the allowed contract rent.

Local Public Housing Authorities are required to routinely update the allowances for utility costs. To assist in this process, HUD developed a standard form called HUD-52667 to show what type of utility cost information should be provided, plus guidance on how to estimate utility allowances. The guidance included an estimate of the amount of energy consumed for each end-use (e.g. heating, water heating, lighting and refrigeration, cooking, etc.). These utility allowances are usually printed in a tabular format with values in dollars per month for each major energy use, and further subcategorized by housing structure type and number of bedrooms. For instance, there are normally different tables for single family detached, row houses, low-rise multi-family, and high-rise multi-family structure types. The recommended format with this level of detail is provided by the HUD- 52667 form.

The instructions for the HUD-52667 form were developed shortly after passage of the Housing and Community Development Act of 1974. This was at the beginning of an energy crisis that had yet to affect housing construction practices. Housing from this era had few of the conservation features that people now take for granted, such as sufficient wall and roof insulation, double-paned “thermal” windows, and efficient furnaces, heat pumps, air conditioners, and water heaters. The guidance provided for determining the utility allowances had not been significantly updated as of 2002, yet the common use of more energy conserving building practices had typically reduced the amount of energy used for heating, cooking and water heating in a typical residence. This resulted in the utility allowances, if developed according to HUD guidance, being larger than necessary to cover the energy costs for the residents. Indirectly, these larger than necessary utility allowances had the effect of lowering the allowed contract rents for some structure types. In addition, and somewhat offsetting, the housing stock has also changed since the 1970’s, especially due to larger average new home sizes.

In 2002 and 2003, GARD Analytics worked with HUD to create a spreadsheet version of HUD Form 52667. It was primarily based on data from the U.S. Department of Energy's 1997 Residential Energy Consumption Survey (RECS). The report documenting this effort was titled "Utility Allowance Model Final Report" and dated June 5, 2003. The data and assumptions used were largely derived from "A Look at Residential Energy Consumption in 1997" published by the U.S. Department of Energy - Energy Information Administration. A multiple linear regression approach was applied with the RECS data to derive correlations for most of the end-uses shown on the HUD-52667 form. For heating energy consumption, for example, the relationship developed was based on heating degree-days and number of bedrooms. Separate correlations were developed for each residential structure type.

In September 2005, the engineering firm of 2rw+di updated the energy model using data from the U.S. Department of Energy's Residential Energy Consumption Survey (RECS) from 2001 in a report titled "Utility Model Evaluation." The update also modified the spreadsheet model to adjust for building age and the use of heat pumps. The report included a review of the analytical soundness of the model and an assessment of the model's accuracy.

In February 2007, GARD Analytics updated the model as described in the report "Final Report on HUD-52667 Spreadsheet Update." This update included revising the method by which heat pump efficiencies are adjusted for climatic conditions, updating the heating energy use calculation to adjust for climatic conditions, and comparing the results of the spreadsheet with actual data. This update continued to use the data from the 2001 U.S. Department of Energy's Residential Energy Consumption Survey, since no later RECS data had been released.

In January 2011, GARD Analytics updated the model as described in "Update of the HUD-52667 Spreadsheet Model with Department of Energy Residential Energy Consumption Survey Data from 2005." In this updated report, the equations in the spreadsheet related to the energy consumption estimates for heating, cooking, air conditioning, water heating and other were updated using data from the U.S. Department of Energy's 2005 Residential Energy Consumption Survey (RECS). Overall thirty equations were updated.

3. Scope

The scope of this report is limited to recommending heating and cooling adjustment factors for homes over time and was described in the scope of work as:

> "… calculating a heating/cooling energy consumption trending factor. This factor would provide an efficiency measure that would update the heating/cooling energy consumption by fuel type from what was the average in 2001 to an estimate of what it would be in 2012. Natural gas and electric fuel (resistance and heat pumps) are of most interest for heating but guidance on whether adjustments to LPG or oil heating are appropriate is also requested. The utility trend estimation process should provide a methodology for future updates and be based in part on equipment sales, energy tax credits, and building code changes."

Adjusting the heating and cooling energy consumption from 2001 to 2012 depends primarily on the following factors:

a) heating and cooling equipment efficiency improvements based on code changes and incentive programs;

b) heating and cooling equipment retirement and replacements; and

c) housing heating and cooling load improvements such as insulation and tightness based on code changes and incentive programs.

4. Current Spreadsheet Age Adjustment

The current spreadsheet "HUD52667Model-Ver12d.xls" already includes an adjustment for age as shown in Figure 1.

	J	K	L	M
72				
73		Age of Structure Adjustment		
74			Heating	Cooling
75		Before 1980	1.43	1.43
76		1980 to 1996	1	1
77		1996 or newer	0.78	0.78
78		Mixed ages	1	1
79				
80		Selected (in use)	0.78	0.78
81				

Instructions / Location / Tariffs / Detached 52667

Figure 1. Age of Structure Adjustment Factor in HUD-52667 Spreadsheet Model

These adjustments are multiplied by the air conditioning and heating formulas used in the "Coefficient Adjustment" section of the spreadsheet. They are applied to all coefficients of the equations effectively reducing the heating and cooling energy consumption for structures 1996 or newer by 22% and increasing the energy consumption for structures built before 1980 by 43%. These factors apply to both heating and cooling equally and the use in buildings between 1980 and 1996 is equivalent to including housing units for all ages. The inclusion of the Age of Structure adjustment was done in the 2005 update by 2rw+di (2rw 2005). In that update, in Section 6.2, 2rw+di explains the basis of the update using RECS 2001 data and grouping the data into three age categories.

> "All unit types below 2,500 square feet were considered and the heating consumption was normalized for square footage, HDD, and typical heating system efficiency by fuel and heating equipment type. The resulting heat loads were averaged within each age group, and the middle group (1981-1995) was set to equal the existing HDDxBR coefficients from the HUD spreadsheet as developed by GARD Analytics. The older and newer categories were assigned factors corresponding to the ratio of their heat loads to those of the center group. These new scaling factors can be seen in the revised HUD tool on the 52667 spreadsheets directly above the table of coefficients. Age multipliers corresponding to each group are respectively, 1.43, 1, 0.78. The adjustments to utility resource consumption are carried out within the calculations on each 52667 tab by multiplying the linear coefficient for each weather-dependent end use by the appropriate age multiplier."

While the description is focused on heating loads, as shown in the figure above, the same adjustment factors are also applied to the cooling energy consumption.

Since the table of factors is based on data from RECS, when RECS is updated the table should also be updated. The update may need to also change the years that it applies to although the "Before 1980" portion is based on the premise that it represents housing units prior to energy efficiency improvements spurred by the 1970s oil crisis.

The current work is to update the results from 2001 to 2012 and is focused on updating the "Mixed Ages" option.

5. Cooling Equipment Adjustment

The Air-Conditioning, Heating, and Refrigeration Institute (AHRI), formerly ARI, has published the average efficiency of central air conditioners and heat pumps sold per year based on actual sales data provided by the air conditioning industry. The last year AHRI published that data was in 2009. Two references that include the data are DOE 2011a and Wenzel 1997. The DOE 2011a source published the graphs shown in Figure 2 and Figure 3. Wenzel 1997 published the graph shown in Figure 4 containing the same data series for an earlier time period.

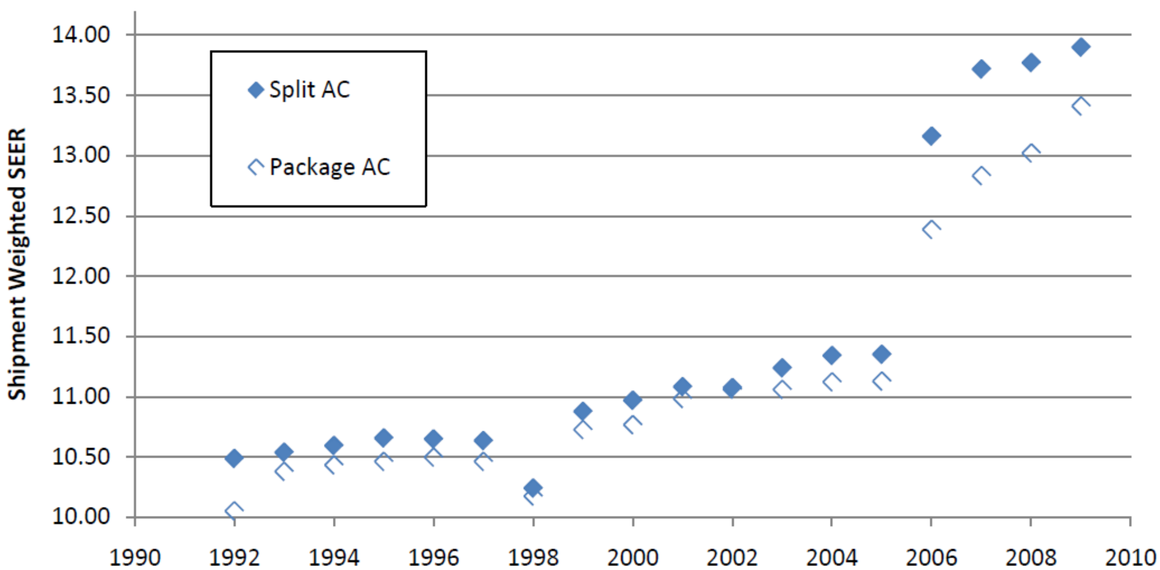


Figure 2. Central Air Conditioner Historical Shipment-Weighted Efficiencies

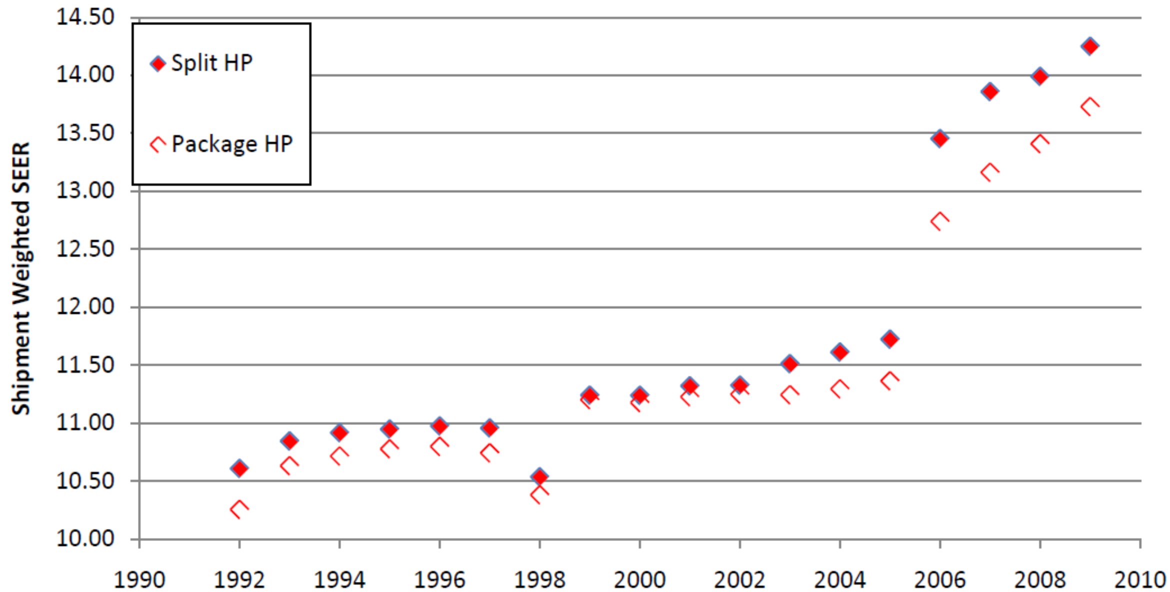


Figure 3. Heat Pump Historical Shipment-Weighted Efficiencies

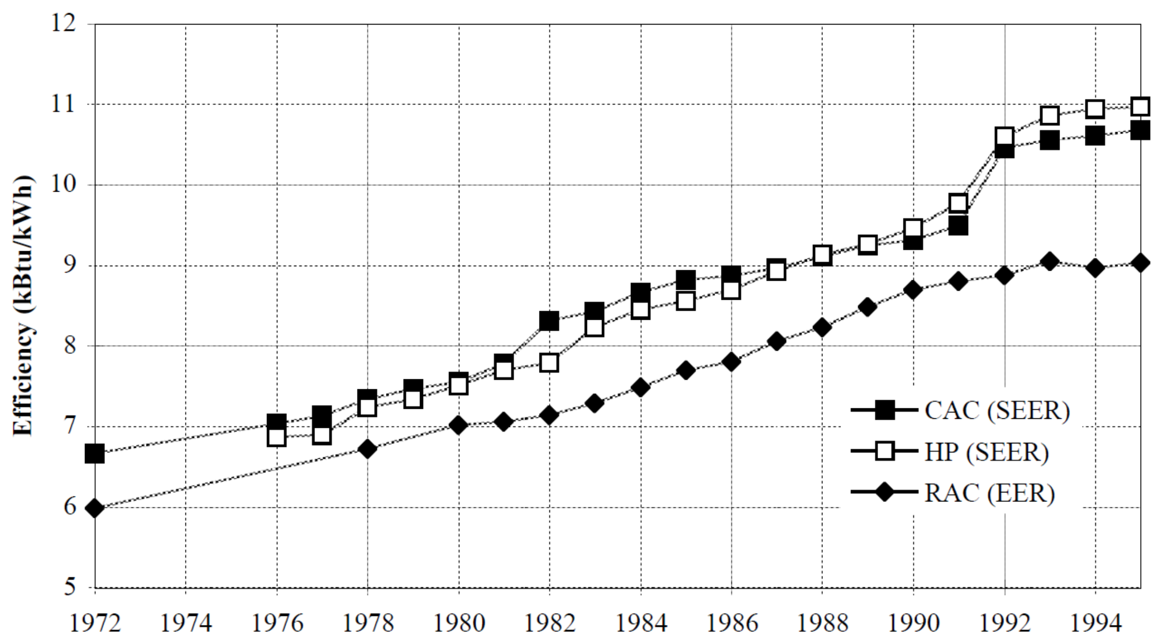


Figure 4. Shipment Weighted Efficiencies for Cooling Equipment 1972-1995

The actual data used to generate these charts was not provided and was not made available from AHRI so values were estimated from the graphs themselves. For years with data missing in the 1970s, values were interpolated. For years beyond 2009, data from years 1992 to 2005 were used (except 1998 since it appeared anomalous) to create a linear regression that was used to extrapolate. The resulting estimated shipment weighted efficiencies are shown in Figure 5 and Table 1.

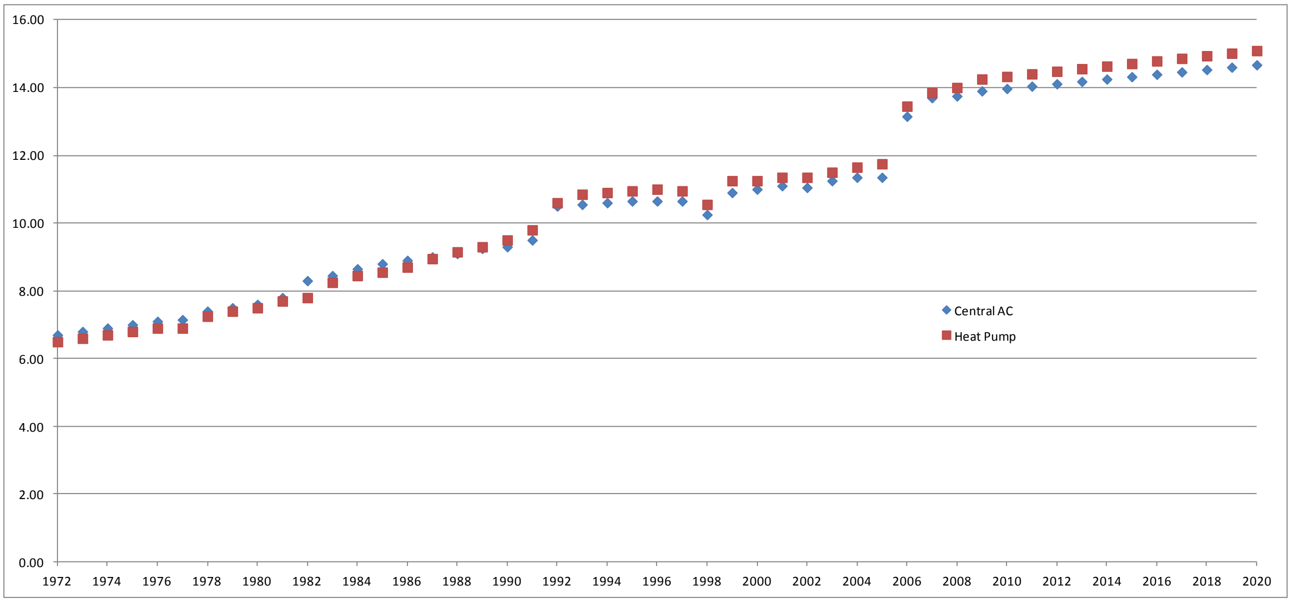


Figure 5. Estimated Shipment Weighted Cooling Efficiencies

Two distinct rapid increases in cooling efficiency appear in 1992 and 2006. The 2006 bump is based on a change to the minimum efficiency requirements for air conditioning units. The change in 1992 may also be due to a minimum efficiency requirement change but is also the boundary between the data taken from two different data sources so it may be also due to the differences described in those data sources.

Table 1. Estimated Shipment Weighted Cooling Efficiencies

Year	Central AC	Heat Pump
1972	6.70	6.50
1973	6.80	6.60
1974	6.90	6.70
1975	7.00	6.80
1976	7.10	6.90
1977	7.15	6.90
1978	7.40	7.25
1979	7.50	7.40
1980	7.60	7.50
1981	7.80	7.70
1982	8.30	7.80
1983	8.45	8.25
1984	8.65	8.45
1985	8.80	8.55
1986	8.90	8.70
1987	9.00	8.95
1988	9.10	9.15
1989	9.25	9.30
1990	9.30	9.50
1991	9.50	9.80
1992	10.50	10.60
1993	10.55	10.85
1994	10.60	10.90
1995	10.65	10.95
1996	10.65	11.00
1997	10.65	10.95
1998	10.25	10.55
1999	10.90	11.25
2000	11.00	11.25
2001	11.10	11.35
2002	11.05	11.35
2003	11.25	11.50
2004	11.35	11.65
2005	11.35	11.75
2006	13.15	13.45
2007	13.70	13.85
2008	13.75	14.00
2009	13.90	14.25
2010	13.97	14.33
2011	14.04	14.40
2012	14.11	14.48
2013	14.18	14.56
2014	14.25	14.63
2015	14.32	14.71
2016	14.39	14.78
2017	14.46	14.86
2018	14.53	14.94
2019	14.60	15.01
2020	14.67	15.09

The shipment weighted efficiency data describes what is sold each year but does not describe what is currently installed in homes for a given year. Air conditioning equipment is durable and usually lasts for many years. The Residential Energy Consumption Survey from DOE EIA provides information about the distribution of ages of air conditioning equipment. For the last three surveys available the distribution of ages is shown below in Figure 6 as a fraction of installed equipment.

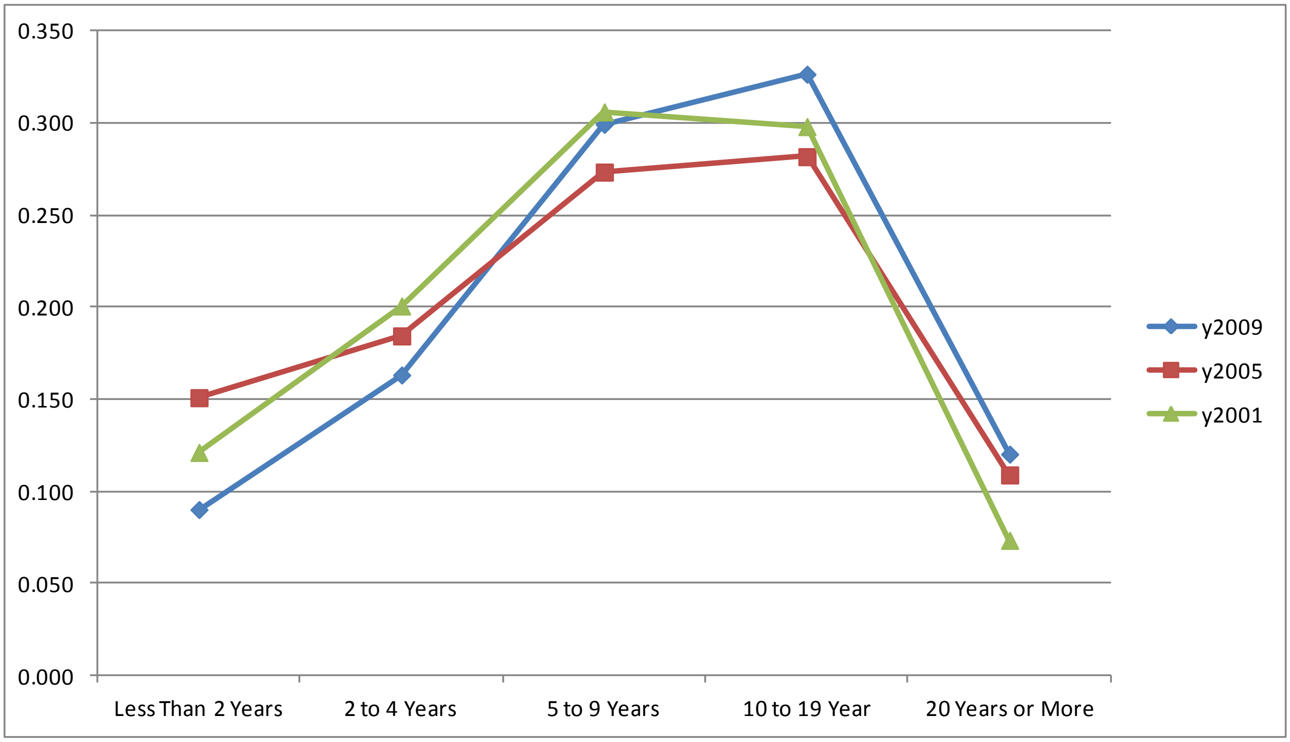


Figure 6. RECS Fraction of Ages for Air Conditioning Equipment in Housing Units

The overall shape did not vary significantly for the three surveys. Since the most recent survey for 2009 residences included slightly higher resolution by data splitting out the 10-19 year bracket into 10-14 years and 15-19 years, the data from that survey was used. The data was annualized by assuming an even distribution of equipment ages for each of the RECS age bins. In addition, it was assumed that the 20 years or more bin was allocated across 10 years from 20 to 29 years from the base year. The following table shows the weighting by years from the base year for air conditioning equipment.

Table 2. Air Conditioning Age Weighting Fraction

Year From Base	*Fraction*
29 year	0.0120
28 year	0.0120
27 year	0.0120
26 year	0.0120
25 year	0.0120
24 year	0.0120
23 year	0.0120
22 year	0.0120
21 year	0.0120
20 year	0.0120
19 year	0.0198
18 year	0.0198
17 year	0.0198
16 year	0.0198
15 year	0.0198
14 year	0.0456
13 year	0.0456
12 year	0.0456
11 year	0.0456
10 year	0.0456
9 year	0.0599
8 year	0.0599
7 year	0.0599
6 year	0.0599
5 year	0.0599
4 year	0.0544
3 year	0.0544
2 year	0.0544
1 year	0.0451
0 year	0.0451

The age fractions are applied to the shipment weighted efficiencies for each year from 2001 to 2020. To estimate the installed average efficiency, the age fractions are multiplied by the shipment weighted efficiencies and totaled for each year. Table 3 and Figure 7 show the results of this analysis.

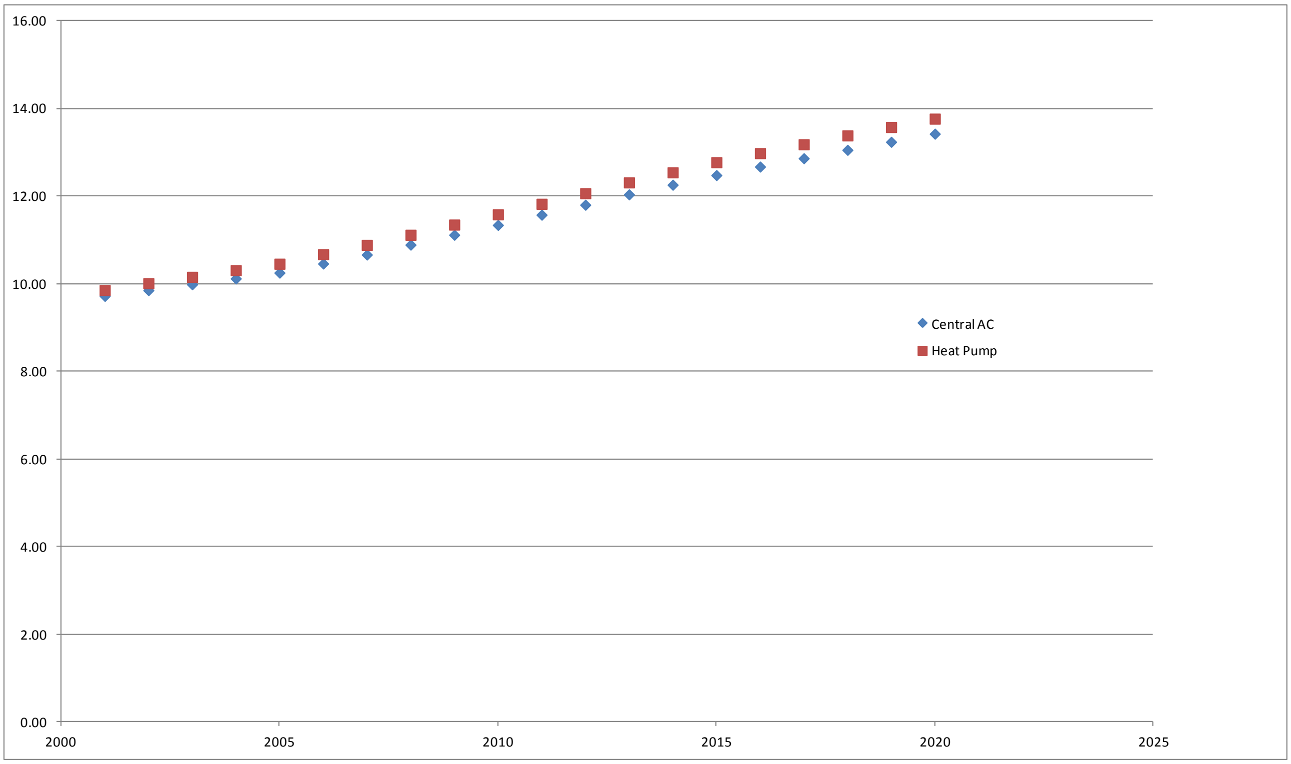


Figure 7. Estimated Average Cooling Efficiency Installed in Residences

Table 3. Estimated Average Cooling Efficiency Installed in Residences

Year	*Central AC*	*Heat Pump*
2001	9.72	9.85
2002	9.85	10.01
2003	9.99	10.16
2004	10.12	10.31
2005	10.25	10.46
2006	10.46	10.67
2007	10.66	10.89
2008	10.89	11.12
2009	11.12	11.35
2010	11.34	11.58
2011	11.57	11.82
2012	11.80	12.06
2013	12.04	12.31
2014	12.26	12.54
2015	12.48	12.77
2016	12.67	12.98
2017	12.86	13.18
2018	13.05	13.38
2019	13.24	13.58

2020	13.42	13.77

Assuming that 2001 is the baseline level, Table 3 can be expressed as multipliers for the efficiency as shown in Table 4, below.

Table 4. Estimated Cooling Equipment Efficiency Multiplier

Year	*Central AC*	*Heat Pump*
2001	1.000	1.000
2002	1.014	1.016
2003	1.027	1.031
2004	1.041	1.046
2005	1.055	1.061
2006	1.076	1.083
2007	1.097	1.105
2008	1.120	1.128
2009	1.144	1.152
2010	1.167	1.175
2011	1.191	1.200
2012	1.214	1.224
2013	1.238	1.250
2014	1.261	1.273
2015	1.284	1.296
2016	1.304	1.317
2017	1.323	1.338
2018	1.343	1.358
2019	1.362	1.378
2020	1.381	1.397

Table 4 indicates that central air conditioning is 21% more efficient in 2012 compared to 2001 and correspondingly heat pumps are 22% more efficient.

The use of these multipliers for the cooling efficiency requires accepting several assumptions:

1. That the ratio of current and past energy efficiency measures expressed in SEER represents a reasonable proxy for the change in energy consumption for cooling equipment.
2. That the future changes in shipment-weighted efficiency continues at the same rate as it has in the past.
3. That the durability of air conditioning equipment and likelihood of air conditioning replacement based on age stays at the same kind of distribution as it was in 2009.
4. That the regional or climate variation of efficiency does not change with time.

6. Heating Equipment Adjustment

The heating equipment adjustment factor was derived in a similar way to the cooling equipment adjustment factors. For heat pumps the efficiency of the cooling and heating portions are intrinsically linked. The same compressor and compressor motor, indoor and outdoor fans, and heat exchangers are all used for both heating and cooling. Given this the adjustment used for heat pump cooling should be appropriate for heat pump heating as well. Furnaces and boilers must also be addressed. Since furnaces represent the bulk of the residential market with boilers only representing about 12% of the housing units (RECS 2009) furnaces are the focus of this analysis.

Table 5 is from DOE 2011a and its derivation was described as:

> "Based on the historical furnace shipment information sorted by AFUE, DOE constructed percentile tables by AFUE shipments of furnaces for 2005 and prior years. AHRI shipments data for non-weatherized gas furnaces indicate that housing units in the northern region receive more efficient furnaces. Therefore, DOE developed two historical AFUE shipment distributions—one for the northern region and one for the southern region—for non-weatherized gas furnaces."

Table 5. Historical Fraction of Regional Gas Furnace Shipments by AFUE Bins

Year	North Region			South Region		
	>78 AFUE	78 to <90	>90 AFUE	>78 AFUE	78 to <90	>90 AFUE
2005	0.0%	48.8%	51.2%	0.0%	81.6%	18.4%
2004	0.0%	52.2%	47.8%	0.0%	83.6%	16.4%
2003	0.0%	53.7%	46.3%	0.0%	83.6%	16.4%
2002	0.0%	59.0%	41.0%	0.0%	85.2%	14.8%
2001	0.0%	57.7%	42.3%	0.0%	86.0%	14.0%
2000	0.0%	64.6%	35.4%	0.0%	89.6%	10.4%
1999	0.0%	64.9%	35.1%	0.0%	89.5%	10.5%
1998	0.0%	64.6%	35.4%	0.0%	89.8%	10.2%
1997	0.0%	62.9%	37.1%	0.0%	87.8%	12.2%
1996	0.0%	64.8%	35.2%	0.0%	89.8%	10.2%
1995	0.0%	68.3%	31.7%	0.0%	88.9%	11.1%
1994	0.0%	66.6%	33.4%	0.0%	87.6%	12.4%
1993	0.0%	70.2%	27.4%	0.0%	86.8%	10.2%
1992	2.4%	59.3%	34.0%	3.0%	80.2%	10.7%
1991	6.7%	23.9%	29.7%	9.1%	30.9%	9.3%
1990	46.3%	22.3%	25.3%	59.8%	27.4%	7.9%
1989	52.4%	17.4%	24.3%	64.6%	21.2%	7.6%
1988	58.3%	19.6%	25.7%	71.2%	24.2%	8.1%
1987	54.8%	18.3%	23.7%	67.8%	22.2%	7.4%
1986	58.0%	18.7%	10.2%	70.4%	20.1%	3.2%
1985	71.1%	17.3%	16.2%	76.7%	19.6%	5.1%
1984	66.5%	18.2%	17.8%	75.3%	20.9%	5.6%
1983	64.0%	7.8%	22.9%	73.5%	9.4%	7.2%
1982	69.3%	8.2%	19.2%	83.4%	9.6%	6.0%
1981	72.6%	8.6%	15.6%	84.4%	9.7%	4.9%
1980	75.9%	9.0%	11.9%	85.4%	9.8%	3.7%
1979	79.1%	3.9%	5.9%	86.5%	4.1%	1.9%
1978	90.2%	1.4%	0.0%	94.1%	1.4%	0.0%
1977	98.6%	0.9%	0.0%	98.6%	0.9%	0.0%
1976	99.1%	0.5%	0.0%	99.1%	0.5%	0.0%
1975	99.5%	0.0%	0.0%	99.5%	0.0%	0.0%
1966 to 1974	100.0%	0.0%	0.0%	100.0%	0.0%	0.0%

Table 5 contains a minor error. For the less than 78 AFUE columns, the rows are shifted by one year (which was reported to DOE). The North and South Regions should each add up to 100%. The North and South Regions are defined from the same source as shown below.

Northern Region States (Rest of Country)		Southern Region States
Alaska	Pennsylvania	Alabama
Colorado	Rhode Island	Arizona
Connecticut	South Dakota	Arkansas
Idaho	Utah	California
Illinois	Vermont	Delaware
Indiana	Washington	Dist. of Columbia
Iowa	West Virginia	Florida
Kansas	Wisconsin	Georgia
Maine	Wyoming	Hawaii
Massachusetts		Kentucky
Michigan		Louisiana
Minnesota		Maryland
Missouri		Mississippi
Montana		Nevada
Nebraska		New Mexico
New Hampshire		North Carolina
New Jersey		Oklahoma
New York		South Carolina
North Dakota		Tennessee
Ohio		Texas
Oregon		Virginia

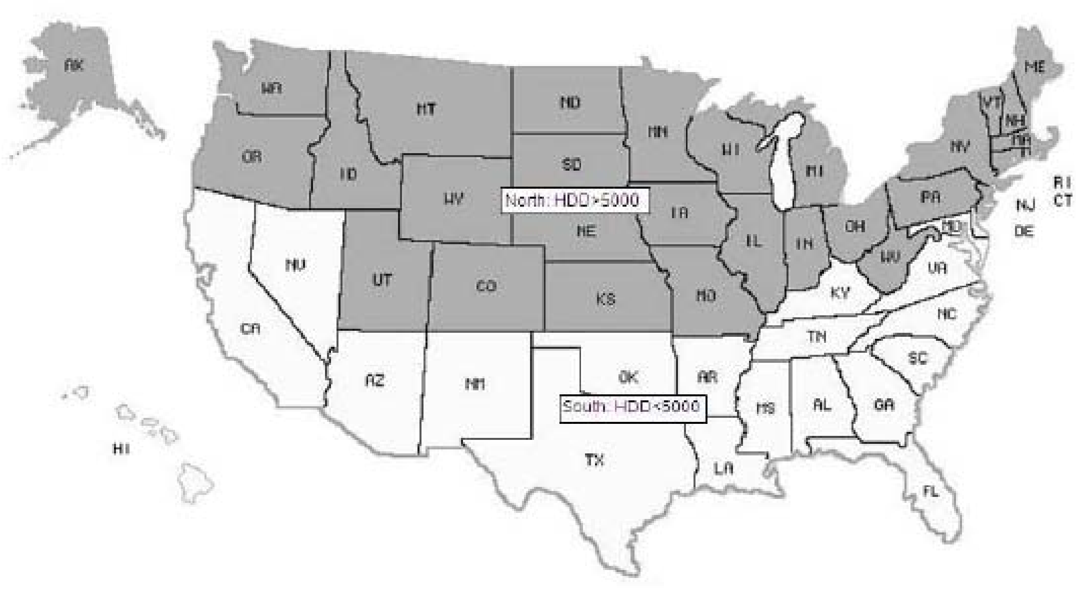


Figure 8. Map of the Regions for the Final Rule Analysis of Furnace Standards

For years after 2005, projections were made by assuming the same trend in the market share of >90% AFUE furnaces. Based on the 1979 to 2005 data when those furnaces were being sold, the following graph shows the linear relationship assumed.

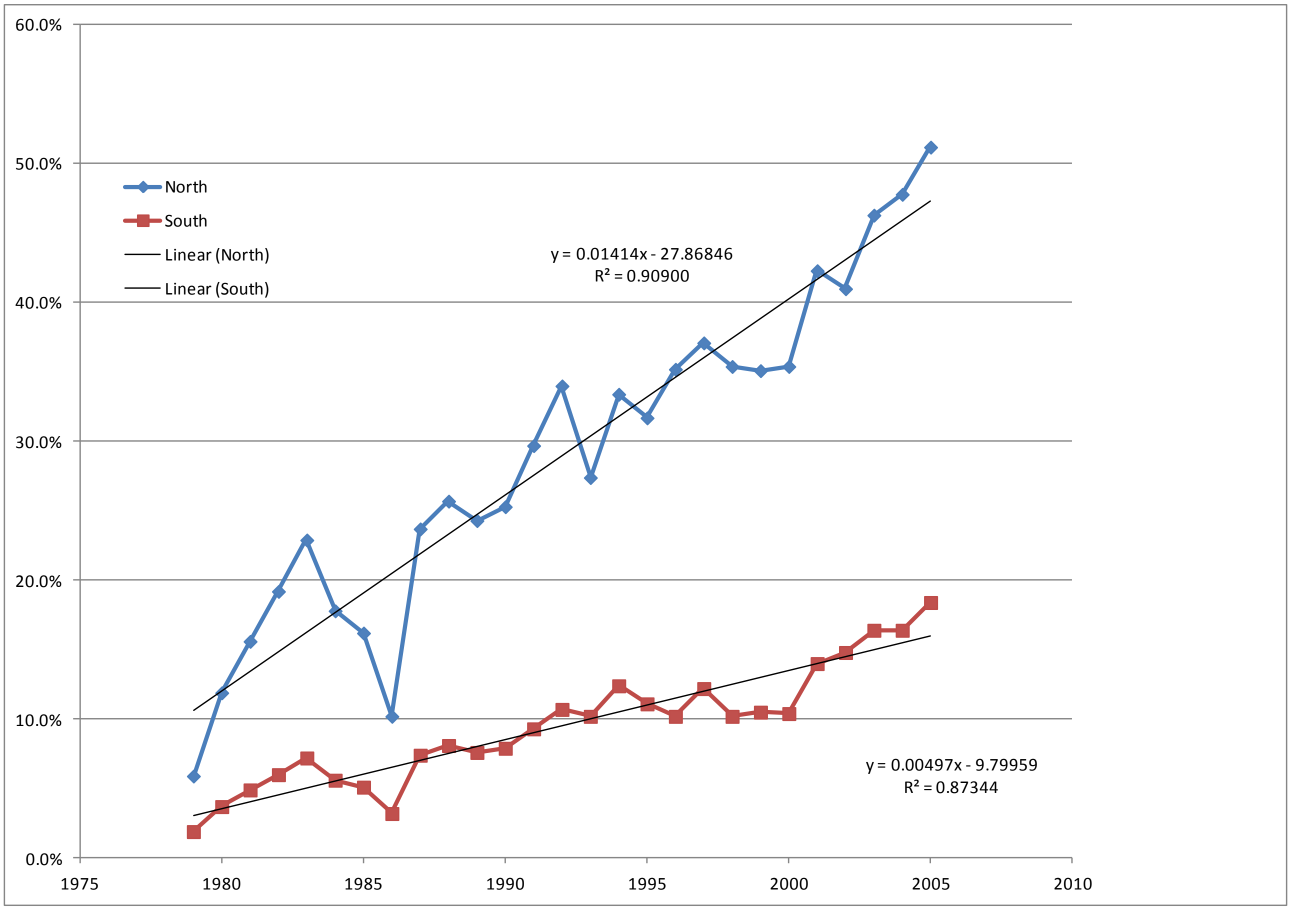


Figure 9. Fraction of >90%AFUE Furnaces in North and South Regions with Linear Expressions

No furnaces using less than 78% AFUE were assumed to be sold after 2005 since furnaces are required by law in the U.S. to have that minimum efficiency. The balance of the market was assumed to be in the 78 to 90 AFUE bracket.

To determine the AFUE that should be represented by each of the bins, the following graph shown in Figure 10 indicates that 80% AFUE is the best representation of the 78% to 90% AFUE group and that 93% AFUE is the best representative efficiency for the >90% AFUE group.

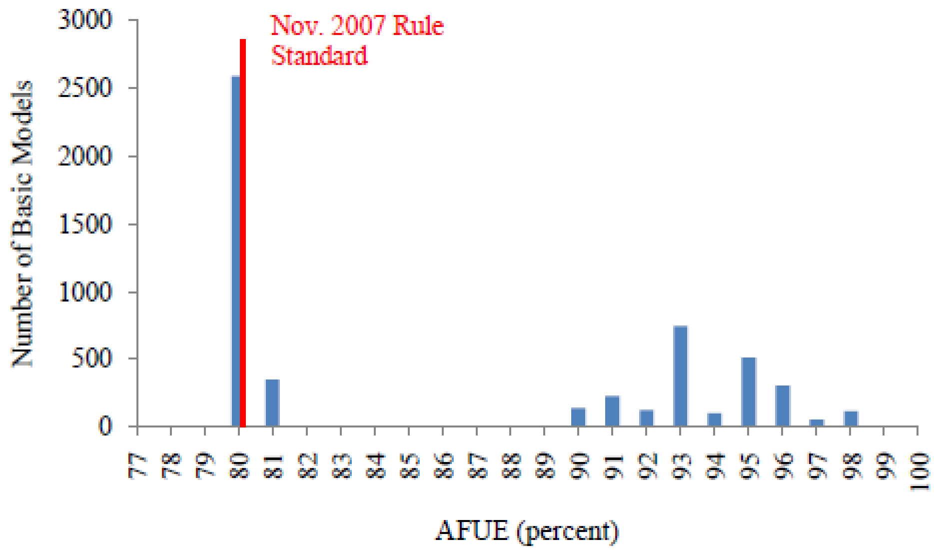
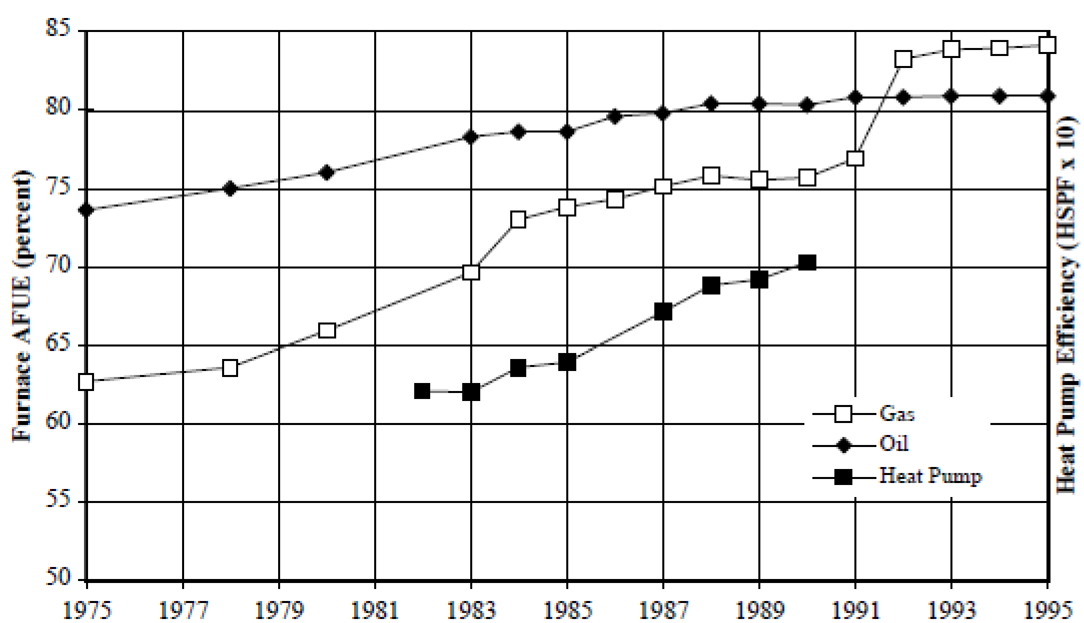


Figure 10. Distribution of Non-Weatherized Gas Furnace Models by AFUE

The following graph shows the trend in average furnaces and heat pumps from 1975 to 1995. Given that the market in 1975 was comprised exclusively of the <70% AFUE group according to Figure 11, looking up that value from this graph shows that 74% AFUE should be used.



Source: US DOE 1982b; LBNL calculations from ACHR News 1996 for Furnaces; ARI 1991 for Heat Pumps; Electric Furnaces assumed to be 100% efficient.

Figure 11. Shipment-Weighted Efficiencies for Residential Furnaces and Heat Pumps, 1975-1995

So the representative AFUE used for each range is shown in Table 6, shown below.

Table 6. Representative AFUE Used for Each Range

AFUE Range	*Representative AFUE*
< 78	74
78 to 90	80
> 90	93

Combining the market fractions for the different ranges of AFUE with the representative AFUE, allows an average market AFUE to be estimated.

Since the HUD Utility Model spreadsheet does not differentiate between northern and southern states, the adjustment factor should be independent of region. The DOE 2011a reference contains a regional shipment market share estimate for gas furnaces (Table 7). For the years shown, those values were used. For years prior to 1992, the average for the 1990s was used and for years after 2005, the average for the 2000s was used.

Table 7. Furnace Regional Shipment Market Shares for Non-Weatherized Gas Furnaces

Year	*North*	*South*
1992	54.5%	45.5%
1993	51.7%	48.3%
1994	53.9%	46.1%
1995	54.2%	45.8%
1996	53.1%	46.9%
1997	52.6%	47.4%
1998	51.3%	48.7%
1999	51.9%	48.1%
2000	51.8%	48.2%
2001	48.7%	51.3%
2002	49.2%	50.8%
2003	49.8%	50.2%
2004	48.2%	51.8%
2005	48.8%	51.2%
2006	48.4%	51.6%
2007	50.1%	49.9%
2008	55.0%	45.0%
2009	55.1%	44.9%
average	51.6%	48.4%

1990s average	52.9%	47.1%
2000s average	50.5%	49.5%

The national average was computed for the AFUE. Figure 12 shows the North Region, South Region and a National Region for shipment of gas furnaces. This graph includes estimates for future years based on the trend of years for data that was present. The greater average AFUE in the northern states seems reasonable since more heating would prompt greater investment in higher efficiency heating equipment.

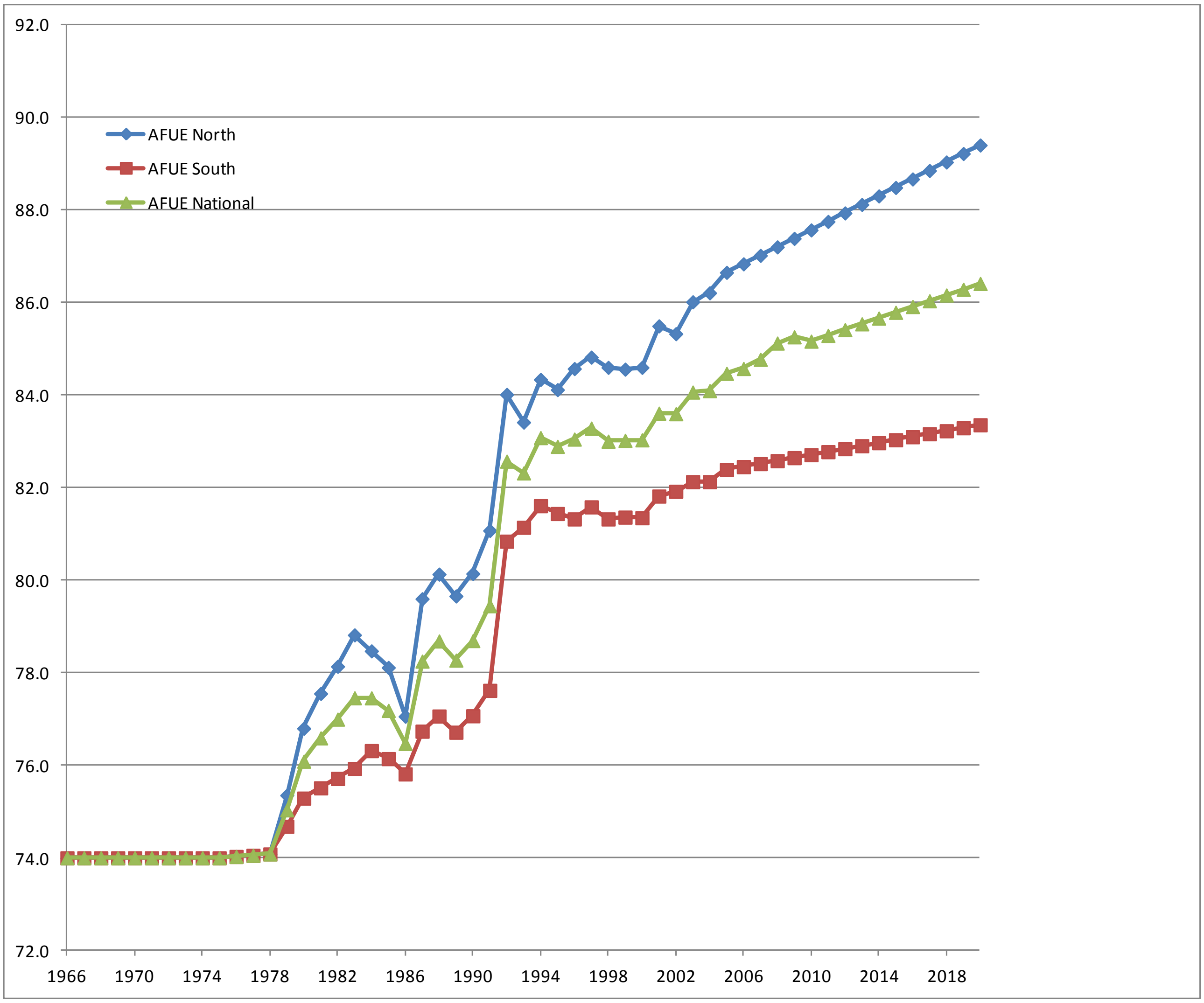


Figure 12. Estimated Shipment Weighted Furnace AFUE

Like air conditioning equipment, the shipment weighted efficiency data describes what is sold each year but does not describe what is currently installed in homes for a given year. Fortunately, the Residential Energy Consumption Survey from DOE EIA provides information about the distribution of ages of heating equipment. For the last three surveys available the distribution of ages is shown below in Figure 13 as a fraction of installed equipment.

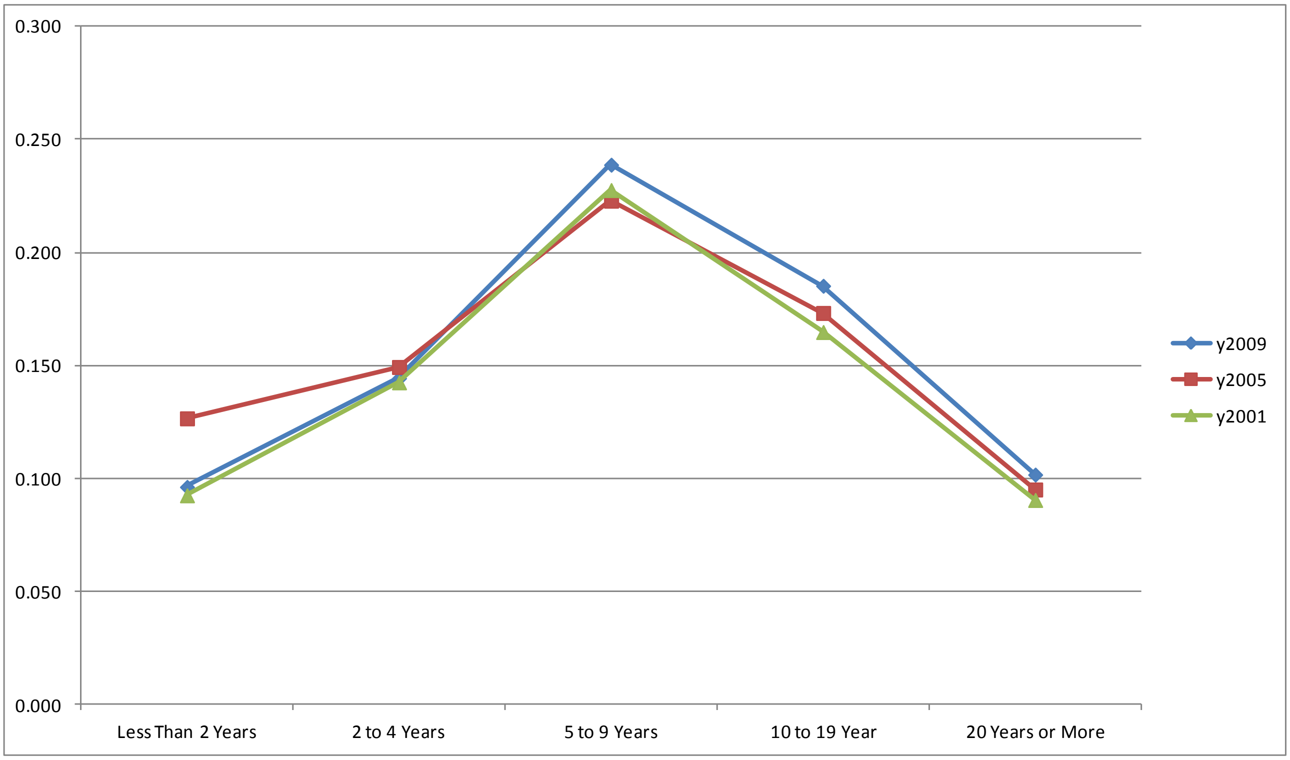


Figure 13. RECS Fraction of Ages for Heating Equipment in Housing Units

Since the overall shape was very similar for all three surveys, the results for the 2009 survey was used and annualized assuming an even distribution of equipment ages for each RECS bin. In addition, it was assumed that the 20 years or more bin was allocated across 10 years from 20 to 29 years from the base year. The following table shows the weighting by years from the base year for heating equipment.

Table 8. Heating Equipment Age Weighting Fraction

Year from Base	*Fraction*
29 year	0.0233
28 year	0.0233
27 year	0.0233
26 year	0.0233
25 year	0.0233
24 year	0.0233
23 year	0.0233
22 year	0.0233
21 year	0.0233
20 year	0.0233
19 year	0.0203
18 year	0.0203
17 year	0.0203
16 year	0.0203
15 year	0.0203
14 year	0.0371
13 year	0.0371
12 year	0.0371
11 year	0.0371
10 year	0.0371
9 year	0.0478
8 year	0.0478
7 year	0.0478
6 year	0.0478
5 year	0.0478
4 year	0.0481
3 year	0.0481
2 year	0.0481
1 year	0.0481
0 year	0.0481

The age fractions are applied to the shipment weighted efficiencies for each year from 1995 to 2020. To estimate the installed average AFUE, the age fractions are multiplied by the shipment weighted efficiencies and totaled for each year. Table 9 and Figure 14 show the results of this analysis.

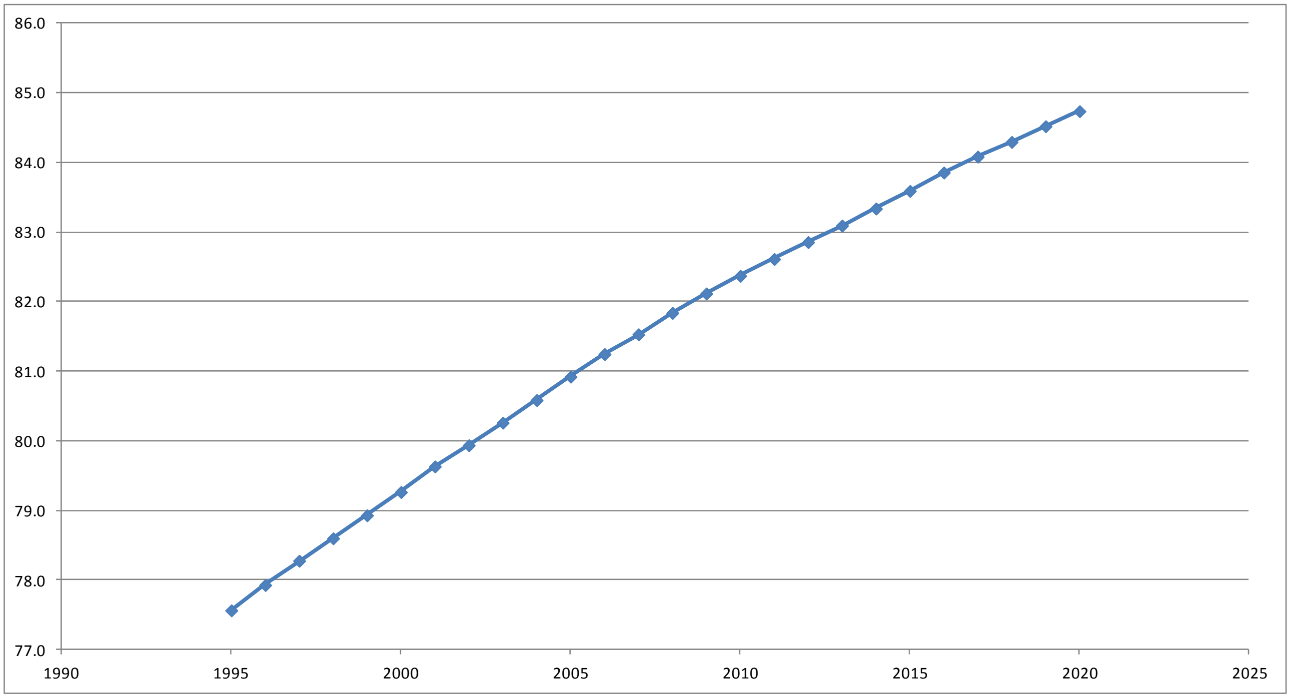


Figure 14. Estimated Average Furnace AFUE Installed in Residences

Table 9. Estimated Average Furnace AFUE Installed in Residences

Year	*AFUE*
1995	77.6
1996	77.9
1997	78.3
1998	78.6
1999	78.9
2000	79.3
2001	79.6
2002	79.9
2003	80.3
2004	80.6
2005	80.9
2006	81.2
2007	81.5
2008	81.8
2009	82.1
2010	82.4
2011	82.6
2012	82.9
2013	83.1
2014	83.3
2015	83.6
2016	83.9
2017	84.1
2018	84.3
2019	84.5
2020	84.7

Assuming that 2001 is the baseline level, Table 9 can be expressed as multipliers for the efficiency in Table 10 shown below.

Table 10. Estimated Furnace AFUE Efficiency Multiplier

Year	AFUE
1995	0.974
1996	0.979
1997	0.983
1998	0.987
1999	0.991
2000	0.995
2001	1.000
2002	1.004
2003	1.008
2004	1.012
2005	1.016
2006	1.020
2007	1.024
2008	1.028
2009	1.031
2010	1.034
2011	1.037
2012	1.040
2013	1.043
2014	1.047
2015	1.050
2016	1.053
2017	1.056
2018	1.059
2019	1.061
2020	1.064

This indicates that the furnaces are 4% more efficient in 2012 compared to 2001.

The use of these multipliers for the heating efficiency requires accepting several assumptions:

1. That the ratio of current and past energy efficiency measures expressed in AFUE represents a reasonable proxy for the change in energy consumption for heating equipment.
2. That future market changes in high efficiency furnaces continues at the same rate as it has in the past.
3. That the durability of heating equipment and likelihood of heating replacement based on age stays at the same kind of distribution as it was in 2009.
4. The change in efficiency for furnaces is similar to all types of fuel fired heating equipment efficiencies.

7. EnergyStar Market Trends

While not incorporated into the analysis, one possible future enhancement could be to utilize data for the market share of high efficiency equipment. AHRI no longer publishes data for shipment-weighted air conditioning or heat pump efficiency. AHRI still does report overall shipments of equipment so if an estimate of the fraction of equipment sold at a higher than minimum efficiency level was available, it could provide the data needed to estimate of the overall market average efficiency. One program that does monitor the efficiency of equipment is the EPA's ENERGY STAR program. They publish "ENERGY STAR Unit Shipment and Market Penetration Report Calendar Year 2010 Summary" (EPA 2010) and similar reports since 2005 that have covered heating and cooling equipment. The following table and graph show the data.

Table 11. ENERGY STAR Unit Shipment Market Penetration

Year	*Air-Source Heat Pumps*	*Central Air Conditioners*	*Residential Gas Furnaces*
2005	27%	19%	37%
2006	21%	18%	35%
2007	18%	21%	32%
2008	21%	19%	43%
2009	32%	17%	50%
2010	46%	27%	61%

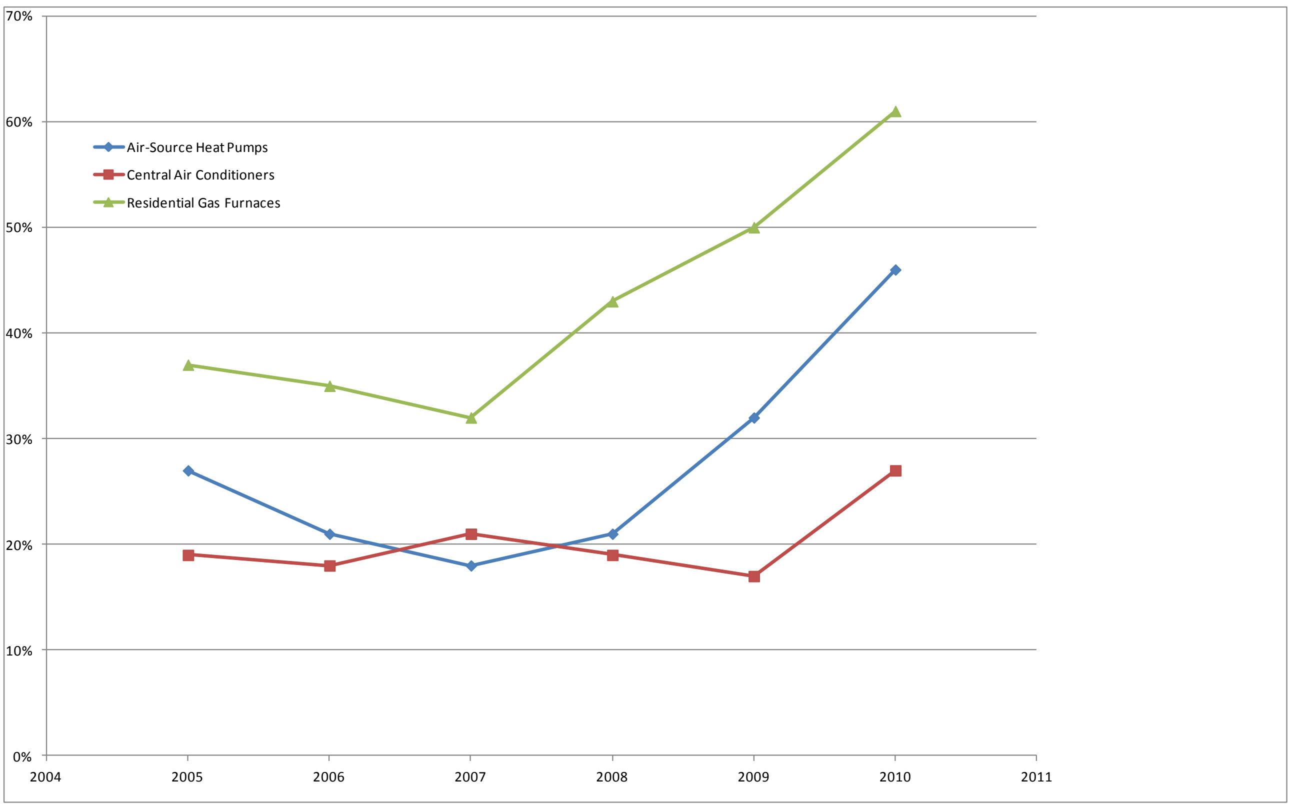


Figure 15. ENERGY STAR Unit Shipment Market Penetration

The reason this data was not used is that it does not show the efficiency level for the equipment sold, but simply that it met the minimum requirements for being branded as ENERGY STAR equipment.

8. Heating and Cooling Load Improvements

Besides the improvements in homes related to heating equipment and cooling equipment, homes have also gotten more efficient based on improvements to the shell of the home with more insulation in walls, roofs, and foundations, more panes of glass and special coatings for windows, reduced infiltration due to continuous air barriers as well as weather stripping, and more reflective roofs and window shades to reduce cooling requirements. This includes homes that are designed to be passively heated by the sun or other more advanced strategies. These improvements are not only applied at the time that homes are constructed but are frequently applied later in the life of residences. This is especially true for roof insulation and window replacement, two very common enhancements to residential buildings to specifically reduce energy consumption and cost. For new construction, local building codes often reference different versions of energy codes such as IECC. Depending on the timing of the revisions to the code, different versions of the IECC have been used with differing levels of efficiency. Numerous different programs exist that encourage new construction that is more efficient than the building codes both at the local, utility, state, and national levels. Likewise, similar programs exist for older residences that want to reduce their utility bills. From an internal load perspective which impacts both heating and cooling energy consumption, compact fluorescent lighting has increased in market share compared to incandescent lighting and some home owners and renters have started used LED lighting technologies to reduce energy consumption further. On the other hand, more different electrical loads occur in residences than ever before including various types of computers, phones, tablets, small and large appliances, and audio/visual equipment. In many homes, more internal loads exist today than they ever have in the past. Overall, the complexity of the market and the many different technologies that are part of the market make it difficult to characterize residential building shell, water heating, and internal load improvements.

The Annual Energy Outlook published by USDOE's Energy Information Administration "presents long term projection of energy supply, demand and prices through 2035 based on results from EIA's National Energy Modeling System (NEMS)." (DOE 2011b). The background is documented in "Assumptions to the Annual Energy Outlook 2012" and the shell efficiency is described as:

> "The shell integrity of the building envelope is an important determinant of the heating and cooling load for each type of household. In the NEMS Residential Demand Module, the shell integrity is represented by an index, which changes over time to reflect improvements in the building shell. The shell integrity index is dimensioned by vintage of house, type of house, fuel type, service (heating and cooling), and Census Division. The age, type, location, and type of heating fuel are important factors in determining the level of shell integrity. Housing units heated with electricity tend to have less air infiltration rates than homes that use other fuels. Homes are classified by age as new (post-2005) or existing. Existing homes are represented by the RECS 2005 survey and are assigned a shell index value based on the mix of homes that exist in the base year (2005). The improvement over time in the shell integrity of these homes is a function of two factors—an assumed annual efficiency improvement and improvements made when real fuel prices increase (no price-related adjustment is made when fuel prices fall). For new construction, building shell efficiency is determined by the relative costs and energy bill savings

> for several levels of heating and cooling equipment, in conjunction with the building shell attributes. The packages represented in NEMS range from homes that meet the International Energy Conservation Code (IECC) to homes that are built with the most efficient shell components. Shell efficiency in new homes increases over time when energy prices rise, or the cost of more efficient equipment falls, all else equal."

The NEMS uses a "Building Shell Efficiency Index" which corresponds directly to an assessment of the efficiency of the building shell as it impacts heating and cooling loads based on an index from a given year. It is broken down into space heating and space cooling and within each category for New Construction, Pre-2005 Homes, and All Homes. For the Pre-2005 category, for Annual Energy Outlooks published in 2008 or earlier, the year used is 1998. The values for these indices are available in spreadsheets from the following internet reference for years of the Annual Energy Outlook from 1996 to 2011 under "supplemental tables" and then choosing the residential spreadsheet.

http://www.eia.gov/forecasts/aeo/archive.cfm

The 2012 version of the spreadsheet includes annual Building Shell Efficiency Indices for all homes modifying the cooling load in 2009 at 0.97 and trend downward to 0.93 in 2035. For the heating load, the values are 0.92 in 2009 to 0.79 in 2035. The difference between heating and cooling reflect a projection that homes will continue to get more energy efficient during the heating season by using insulation and insulating windows but that smaller improvements will be made to offset cooling loads.

The data for the Building Shell Efficiency Index could be used directly but the 2012 version does not include a value for 2001. Previous versions of the Annual Energy Outlook (AEO) were used to determine index values for previous years. The Building Shell Efficiency Index was based on 1.0 for year 2005 in AEO2005 to AEO2012 but different base years for earlier versions. The values of the Building Shell Efficiency Index for previous years were adjusted to be consistent with the 2005 baseline. The following graphs show all of the values for the space heating and space cooling for Building Shell Efficiency Index for various Annual Energy Outlook versions.

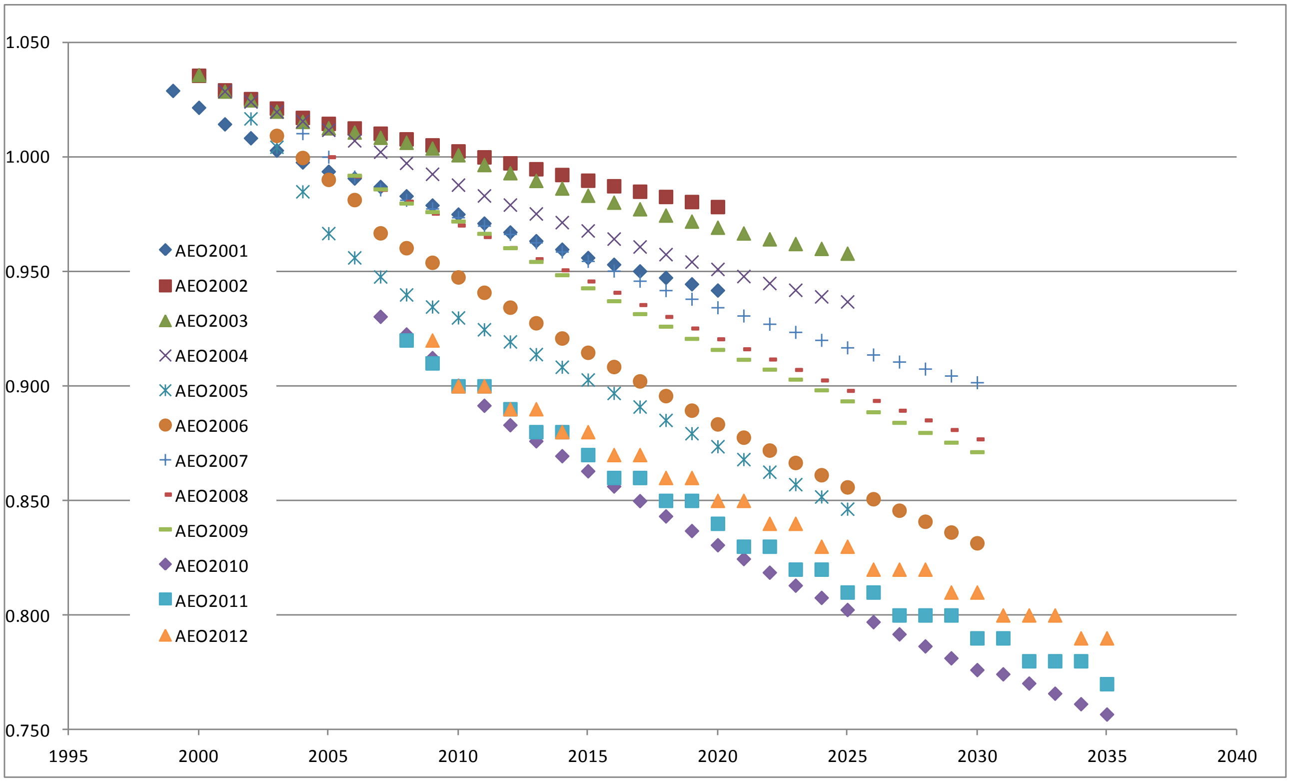


Figure 16. Heating Building Shell Efficiency Index for Various Annual Energy Outlooks

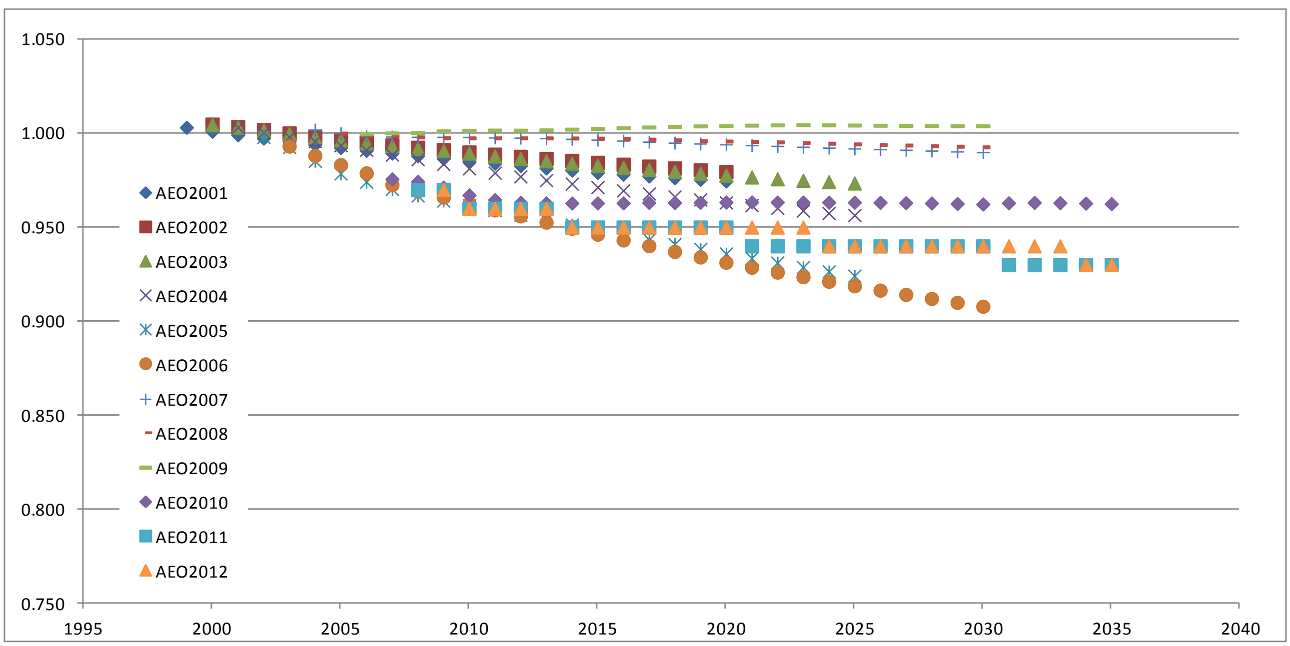


Figure 17. Cooling Building Shell Efficiency Index for Various Annual Energy Outlooks

The values for 2008 were taken from AEO 2011 and back to 1999 from AEO2001. The 2001 value is from AEO2004. When these selected values are shown and adjusted to the same base year of 2005 the following figure and table show the values.

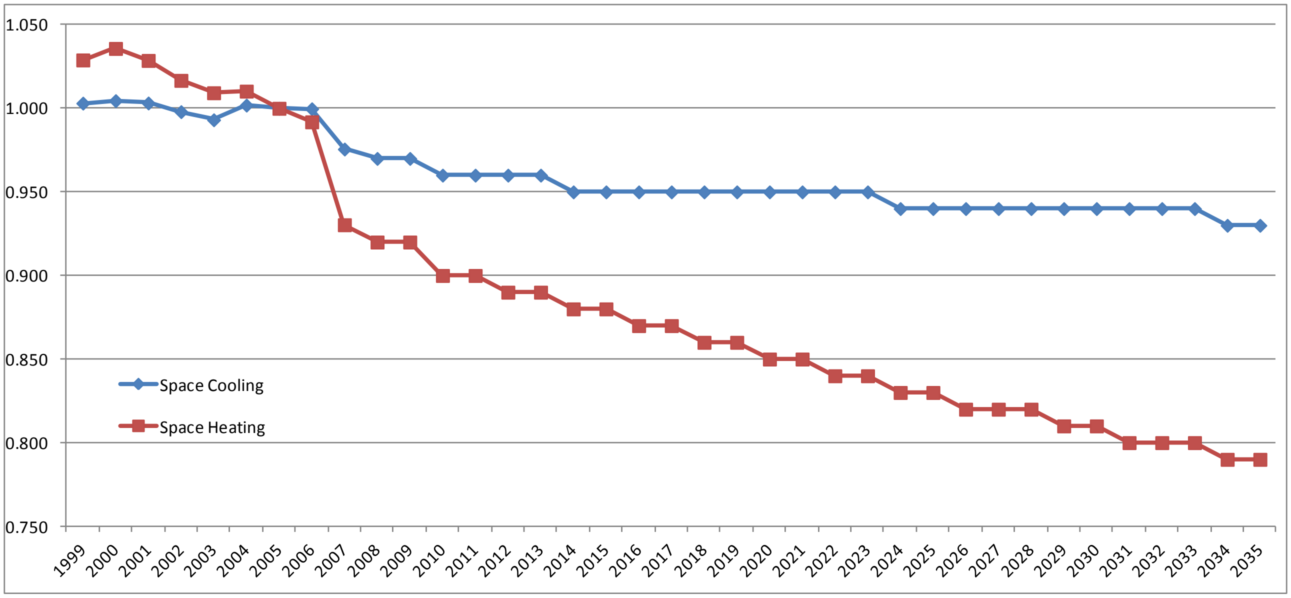


Figure 18. Building Shell Efficiency Index using 2005 Baseline

Table 12. Building Shell Efficiency Index using 2005 Baseline

	Cooling	*Heating*
1999	1.003	1.029
2000	1.005	1.036
2001	1.003	1.029
2002	0.998	1.017
2003	0.993	1.009
2004	1.002	1.010
2005	1.000	1.000
2006	1.000	0.992
2007	0.976	0.930
2008	0.970	0.920
2009	0.970	0.920
2010	0.960	0.900
2011	0.960	0.900
2012	0.960	0.890
2013	0.960	0.890
2014	0.950	0.880
2015	0.950	0.880
2016	0.950	0.870
2017	0.950	0.870
2018	0.950	0.860
2019	0.950	0.860
2020	0.950	0.850
2021	0.950	0.850
2022	0.950	0.840
2023	0.950	0.840
2024	0.940	0.830
2025	0.940	0.830
2026	0.940	0.820
2027	0.940	0.820
2028	0.940	0.820
2029	0.940	0.810
2030	0.940	0.810
2031	0.940	0.800
2032	0.940	0.800
2033	0.940	0.800
2034	0.930	0.790
2035	0.930	0.790

The ratio of the 2012 value to the 2001 value is 0.957 for cooling and 0.865 for heating. These represent a reduction of both the residential heating and cooling loads. The cooling load has been reduced 4% by 2012 compared to 2001 and the heating load has been reduced 13%.

9. Recommendations

The report describes factors for adjusting the heating and cooling energy consumptions in the HUD-52677 spreadsheet to reflect current consumption since the spreadsheet is based on consumption in 2001. The factors included for cooling show an air conditioning reduction of 21% and heat pump reduction of 22%. For heating, there was a reduction of 4% for furnaces, 22% for heat pumps and no change for electric resistance heat. The equipment efficiency improvement factors should be multiplied by the change to the load improvements for residences focused on shell improvements for heating of 4% for cooling and 13% for heating for the overall improvement from 2001 and 2012.

While the goal was to derive a method to update these adjustments each year, only data on the residential shell load improvements were found in a source that is updated each year in the Annual Energy Outlook. The heating and cooling efficiency improvements were estimated for future years but are not from a source that gets updated annually. Since ENERGY STAR equipment sales are monitored each year it could possibly be used as basis for computing the average shipment weighted equipment efficiency. Also, the Annual Energy Outlook does contain similar data that may be used for estimating the average installed heating and cooling efficiency but its derivation was not sufficiently described.

10. Bibliography

2rw 2005. Utility Model Evaluation. 2rw+di. Charlottesville, Virginia. September 2005.

DOE 2011a. Technical Support Document: Energy Efficiency Program for Consumer Products: Residential Central Air Conditioners, Heat Pumps, and Furnaces. June 2011.

DOE 2011b. Annual Energy Outlook 2011 with Projections to 2035. DOE/EIA-0383(2011). U.S. Energy Information Administration. April 2011.

DOE 2012. Assumptions to the Annual Energy Outlook 2012. U.S. Energy Information Administration. DOE/EIA-0554(2012). August 2012.

EPA 2010. ENERGY STAR® Unit Shipment and Market Penetration Report Calendar Year 2010 Summary.

Wenzel 1997. Energy Data Sourcebook for the U.S. Residential Sector. Tom P. Wenzel, Jonathan G. Koomey, Gregory J. Rosenquist, Marla Sanchez, and James W. Hanford September 1997