Existing Homes Target Market Assessment

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U.S. Department of Energy - Weatherization and Intergovernmental Program

Introduction

This report is intended to provide an introduction to the existing homes market, and summarize some of the key points that should be considered in the planning of an effective program addressing energy efficiency in existing homes, including new initiatives sponsored by the Weatherization and Intergovernmental Program (WIP), part of the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE). The report also identifies some of the barriers that make the existing homes market so challenging to address, including complications caused by the diversity of housing types, climates, and occupant behavior. Much of the information was drawn from various studies conducted by DOE and other organizations, and complete references are provided to allow the reader to explore these studies in more detail. Related work is also being performed as part of EPA's Home Performance with Energy Star program, and through a series of retrofit research pilot projects funded by the DOE Office of Building Technologies and managed by NREL as part of Building America.

The residential buildings sector constitutes nearly ¼ of the energy consumption in the United States (see Figure 1). Because new homes are only added at a rate equivalent to about 2% of the existing housing stock each year (see Figure 2), and only about 1% of the stock is retired annually, energy use in the residential sector is dominated by existing homes (EERE, 2003). However, the existing homes sector has been a challenging market to address because homeowners are comprised of a very diverse group of decision makers, and cost-effective energy efficient retrofits can be difficult to identify. This report summarizes and identifies specific indicators that help reveal categories of households that are likely to have significant opportunities for energy efficiency, and can contribute substantially to reducing the overall energy consumption in the residential buildings sector. These households are likely to be the most promising target market for energy efficiency deployment programs.

Suitable target markets may be characterized in several ways. First, it is necessary to identify homes that will benefit from energy improvements. Geographic and demographic information such as climate, vintage, household size, and income, can serve as statistical indicators of elevated or inefficient energy use. The use of certain types of materials and equipment can predict inefficiency more directly, but it is very difficult to obtain this information at a sufficiently detailed level, and on a large scale. Second, because this program seeks to isolate the group of occupants with the ability to pay for all or part of the improvement costs, it is essential to identify homeowners with access to financial resources and the motivation to invest in energy efficiency measures. It is especially beneficial if these homeowners can be approached as a single large focused market rather than one at a time. Market segregation using the first approach will be the focus of this report. Homeowner motivation and financial resources will be mentioned briefly, but these factors are largely outside the scope of this initial study.

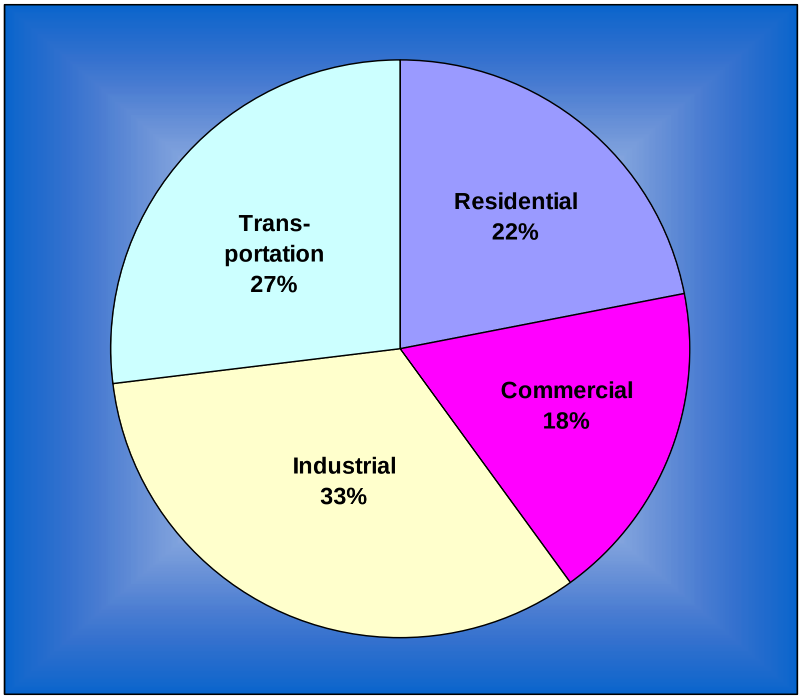


Figure 1. U.S. source energy consumption by sector (EIA, 2002). Nearly 25% of the total consumption can be attributed to residential use.

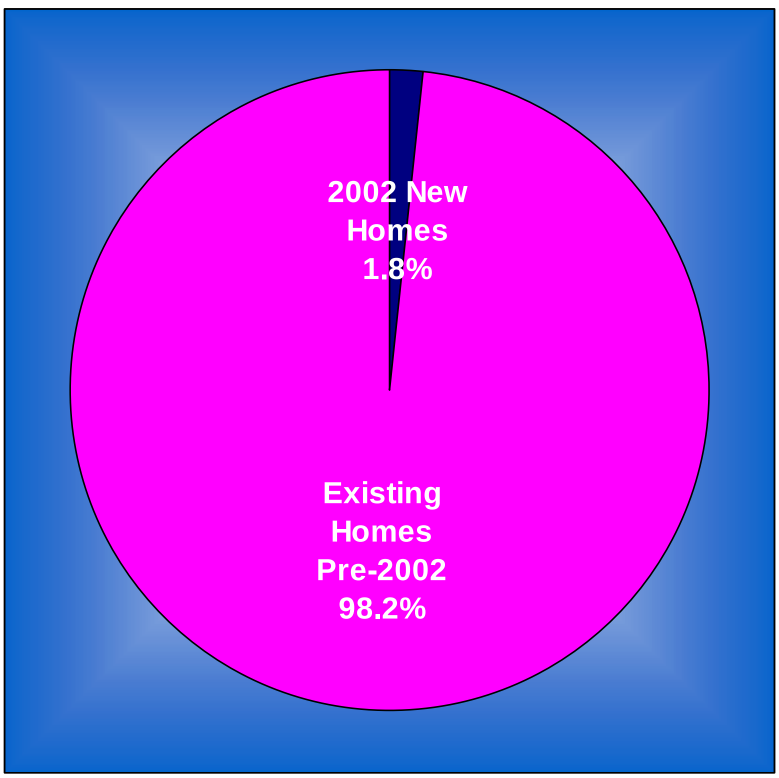


Figure 2. Single-family homes in the U.S. (EIA, 2001; U.S. Census Bureau, 2000). Existing homes built before 2002 dominate the housing stock.

Overview of the Residential Energy Market

Some basic trends in energy consumption for the residential sector are summarized in Figures 3-5. Overall, energy use on a per household basis has not changed much in the past few decades, as shown in Figure 3. Increasing floor area and greater use of air conditioning and home electronics, especially televisions and personal computers, have largely offset recent improvements in energy efficiency. Accordingly, Figure 4 shows that electricity is becoming a more dominant fuel source for residential buildings. Although there has been an increase in the percentage of homes using natural gas for heating, the overall trend for natural gas is flat because of the aforementioned escalation of electricity use. The trend toward increased heating loads due to larger house sizes is largely offset by better insulated building envelopes, more efficient furnaces, and a shift in new construction toward warmer southern climates (EERE, 2003). Nationwide, refrigeration is showing a downward trend in end-use energy consumption, while electricity use for plug loads is escalating at a much more rapid pace (~2% per year) than the increase in housing stock (~1% per year) would predict (see Figure 5). (EERE, 2003; EIA, 2003)

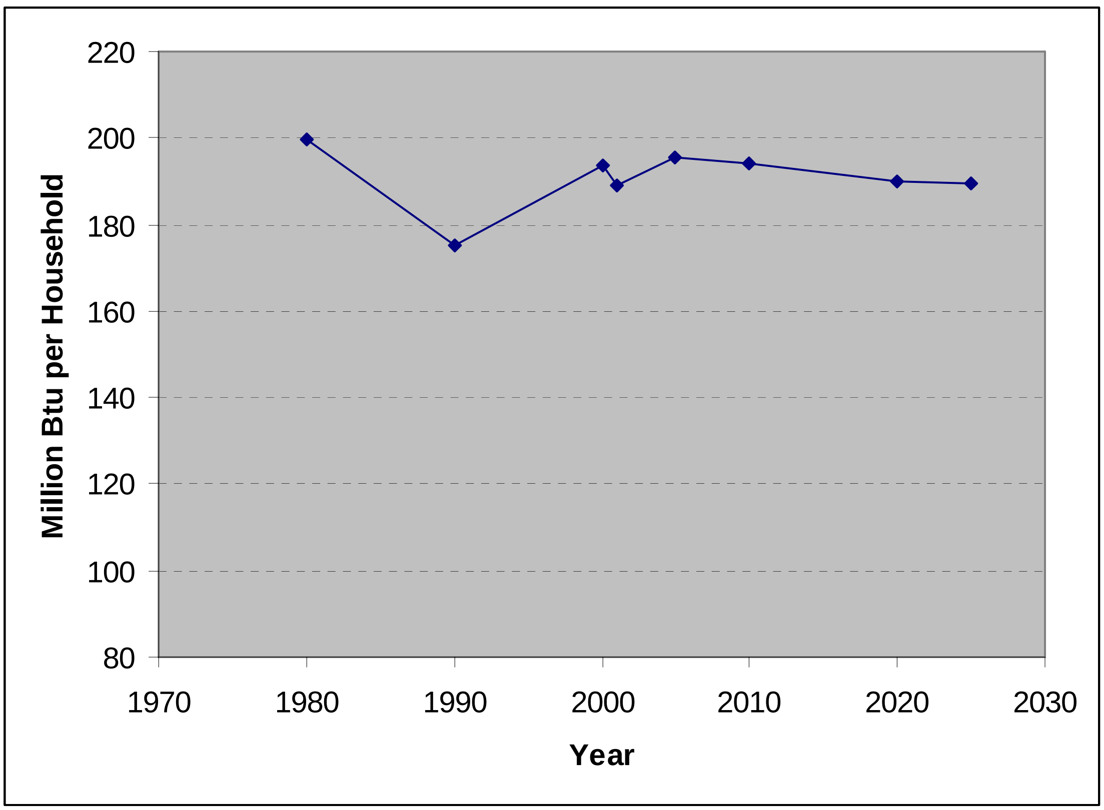


Figure 3. Household energy consumption trends since 1980. (EERE, 2003)

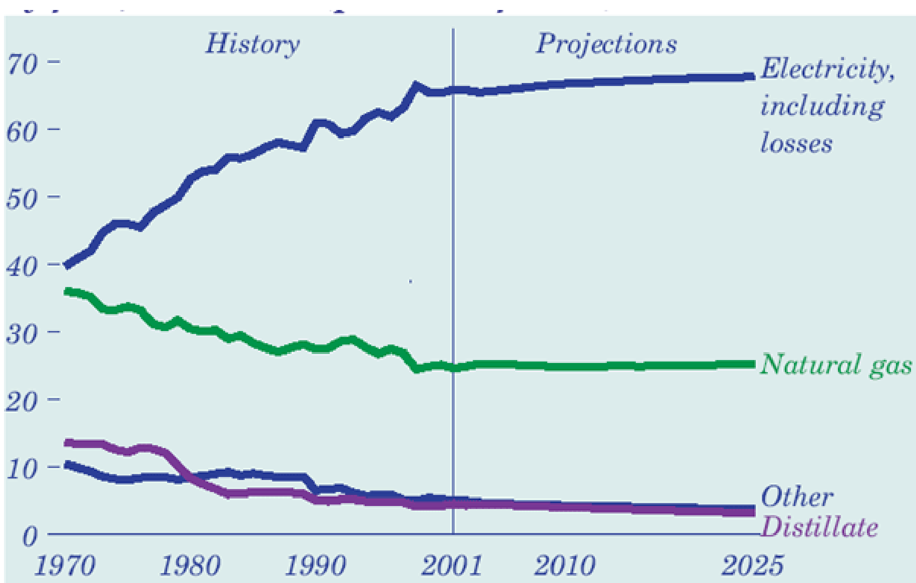


Figure 4. Percent source energy consumption by fuel projected through 2025 for residential buildings, indicating an escalating reliance on electricity. (EIA, 2003)

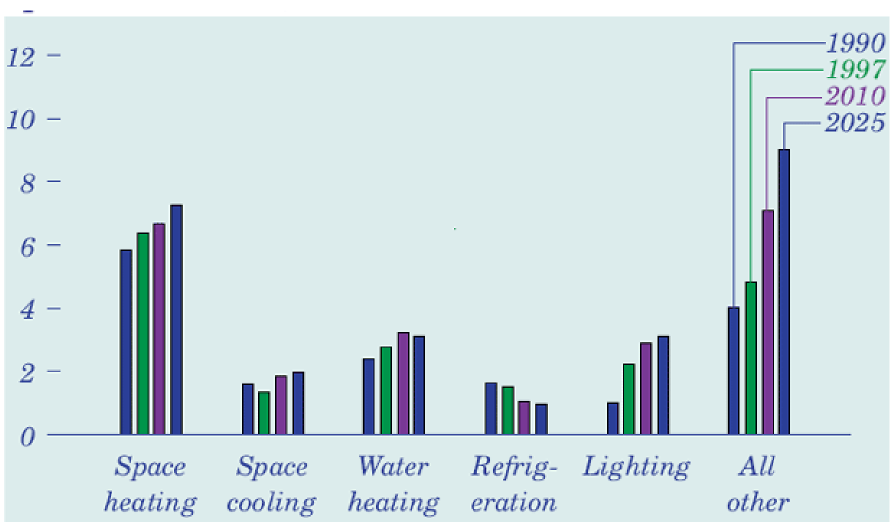


Figure 5. Nationwide source energy consumption by end-use projected through 2025 for residential buildings (in quadrillion Btus). (EIA, 2003)

Demographic Predictors of High Energy Use and Inefficiency

Certain categories of houses make up a larger portion of nationwide energy consumption than others. As shown in Figure 6, single-family detached houses dominate the consumption of energy in the residential sector. This does not imply that the other categories are negligible or that many of the same technology deployment approaches developed for single-family detached homes would not apply equally well to all sectors. But there are some important differences that must be considered in light of the focus of this report, such as the fact that landlords generally make retrofit decisions for apartment buildings (a large percentage of multi-family homes), but do not pay the utility bills. As a result, minimizing first cost is often the primary driver of retrofit decisions for rented homes and apartments. Also, the multi-family sector is currently addressed through DOE’s Rebuild America Program, so it is less essential that it be emphasized by new EERE initiatives. Though mobile homes are built to a less stringent energy standard (HUD-Code) compared to most site-built homes[1], the overall effect of energy savings in this sector will be small even with perfect market penetration, because mobile homes only represent about 5% of nationwide residential energy consumption. For these reasons, single-family detached homes appear to represent the largest potential for energy savings and will be the focus of the remainder of this report.

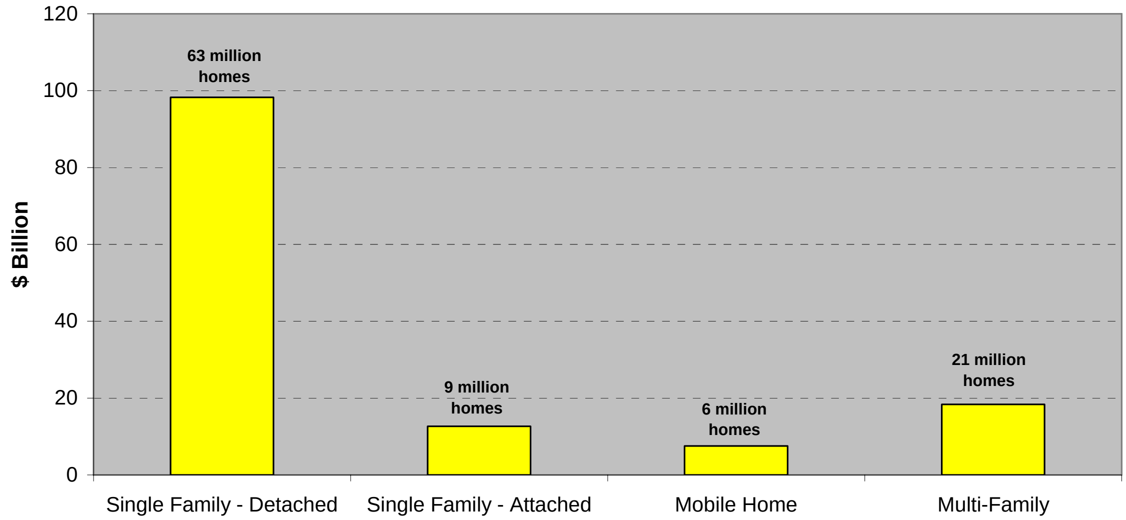


Figure 6. Nationwide energy expenditures by housing type (EIA, 1999). Number of houses in each category is indicated above the column. Single-family detached homes represent the largest fraction.

House ownership is another household characteristic that may help narrow the emphasis of new existing homes programs. As shown in Figure 7, almost 90% of single-family detached homes are owner-occupied, while very few are rented. Renters are much more common in the three categories of houses that were designated as a lower priority based on Figure 6 (single-family attached houses, mobile homes, and multi-family housing).

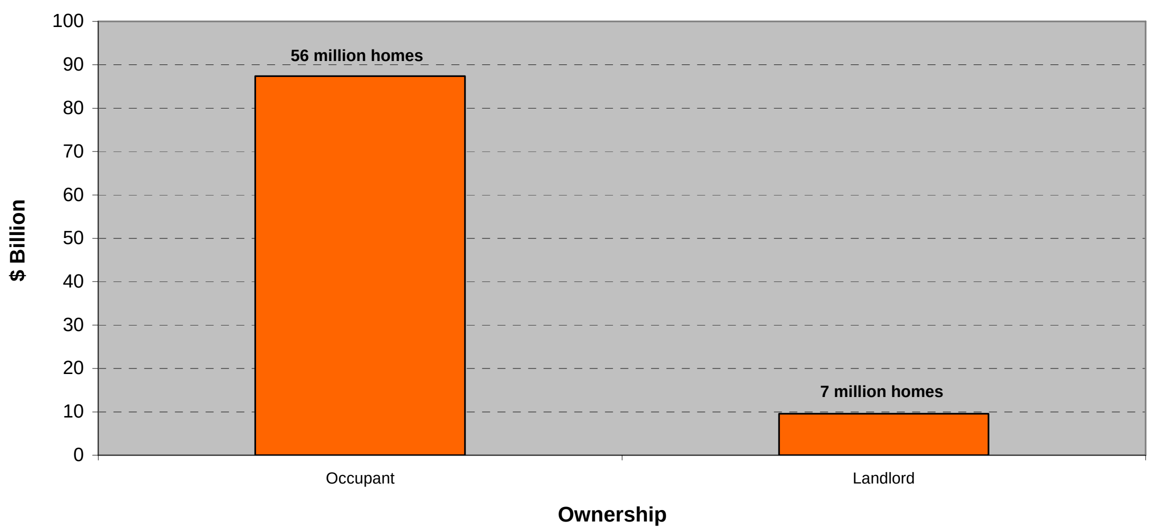


Figure 7. Nationwide energy expenditures sorted by ownership for detached single-family homes (EIA, 1999). A large majority is owner-occupied.

[1] Depending whether or not a statewide energy code such as the Model Energy Code (MEC) or International Energy Conservation Code (IECC) is enforced.

Figure 8 shows the effect of vintage, or age of the house, on nationwide energy expenditures. There is clearly a large amount of money spent on energy for houses of each vintage, so no market segregation is recommended based the total amount of energy expenditures nationwide. However, to evaluate whether vintage is a useful predictor of energy efficiency, energy consumption must be normalized to adjust for number of households and differences in floor area. The most readily available indicator of energy efficiency is energy intensity (or normalized energy use), defined as source energy divided by conditioned floor area (kBtu/ft^2). Source energy includes a multiplier of 3.25 for electricity to account for energy lost in the generation and distribution process.[2] Using this approach, home vintage appears to be an important predictor of normalized energy use. Figure 9 shows the strong downward trend in energy intensity relative to vintage, especially when site energy is the basis of comparison. Reduced space heating energy is the dominant reason for the downward trend in energy intensity for newer houses, as shown in Figure 10. The difference in heating energy is likely caused by a combination of better-insulated building envelopes and more efficient furnaces in newer homes. Energy use for domestic hot water is also lower for newer houses, but there is no obvious trend for space cooling or other end-uses. For all vintages, it is clear that space heating is the most prominent end-use, followed by appliances and lighting, hot water, and space cooling.

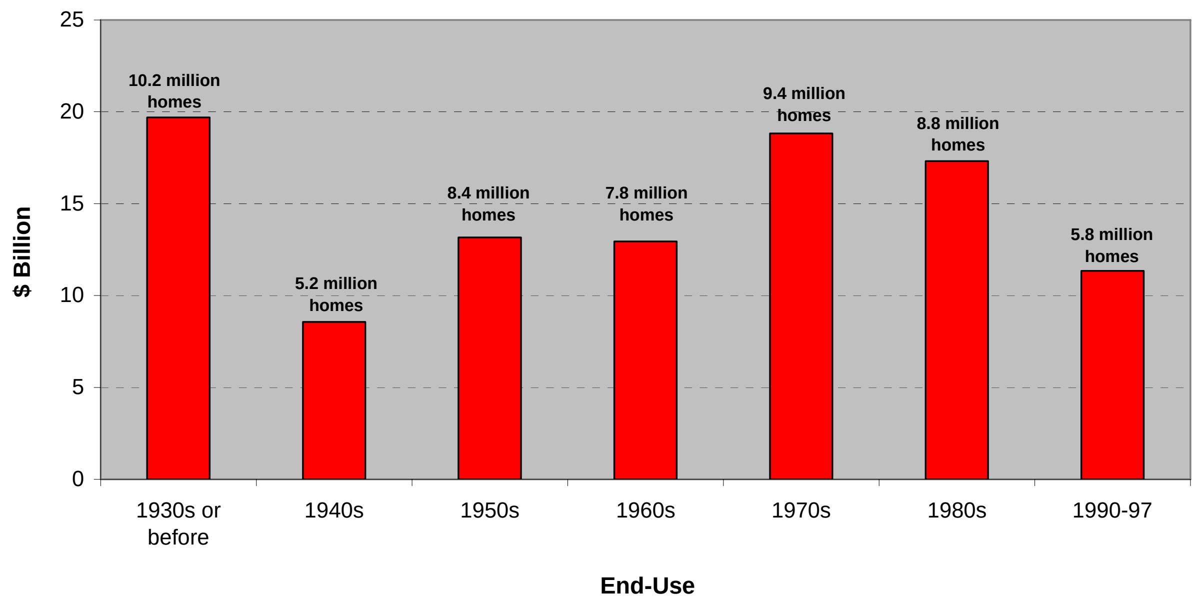


Figure 8. Nationwide energy expenditures by vintage (EIA, 1999).

[2] This site-source energy multiplier is a national average based on the nationwide mix of fossil fuel, nuclear, hydro, and renewable energy power plants.

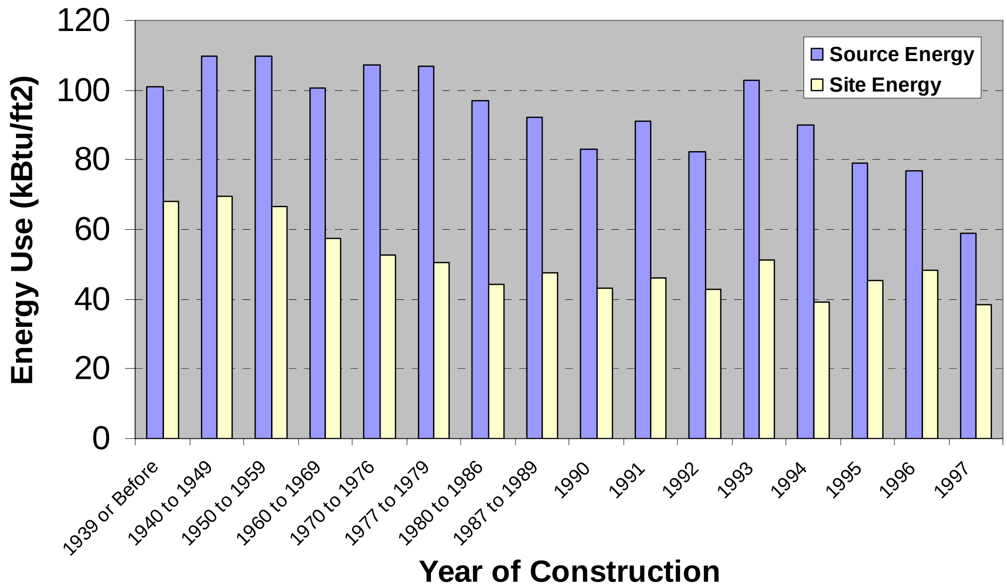


Figure 9. Normalized site and source energy consumption by year of construction (EIA, 1999), illustrating downward trend for more recent vintages. Note: Source energy includes generation and distribution losses for electricity.

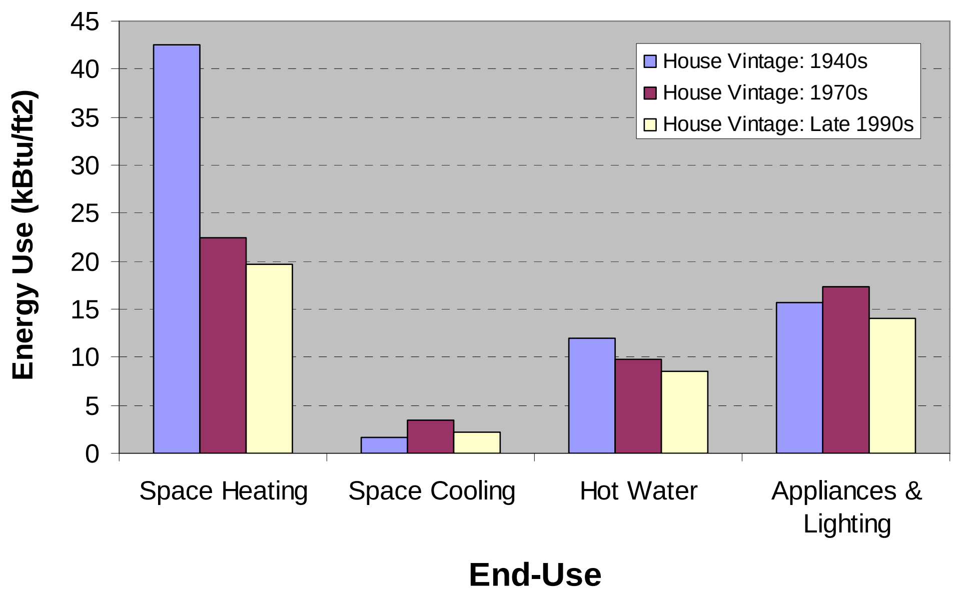


Figure 10. Normalized site energy intensity by house vintage and end-use (EIA, 1999). Space heating dominates energy use in older vintage homes.

If energy expenditures are sorted by household income, as shown in Figure 11, each income category appears to be important in terms of nationwide impact. When this data is normalized, as shown in Figure 12, it becomes more evident that low-income households tend to use more energy than wealthier households for the same size house. Household income correlates most strongly with heating energy. The same is true for age of heating equipment, as shown in Figure 13. There is certainly a linkage between low-income households, old equipment, and old houses, which makes it difficult to say which is the underlying cause of elevated energy use for space heating. However, it's clear that all three of these variables are predictors of high heating energy use, and therefore they all help to define a target market for energy retrofits.

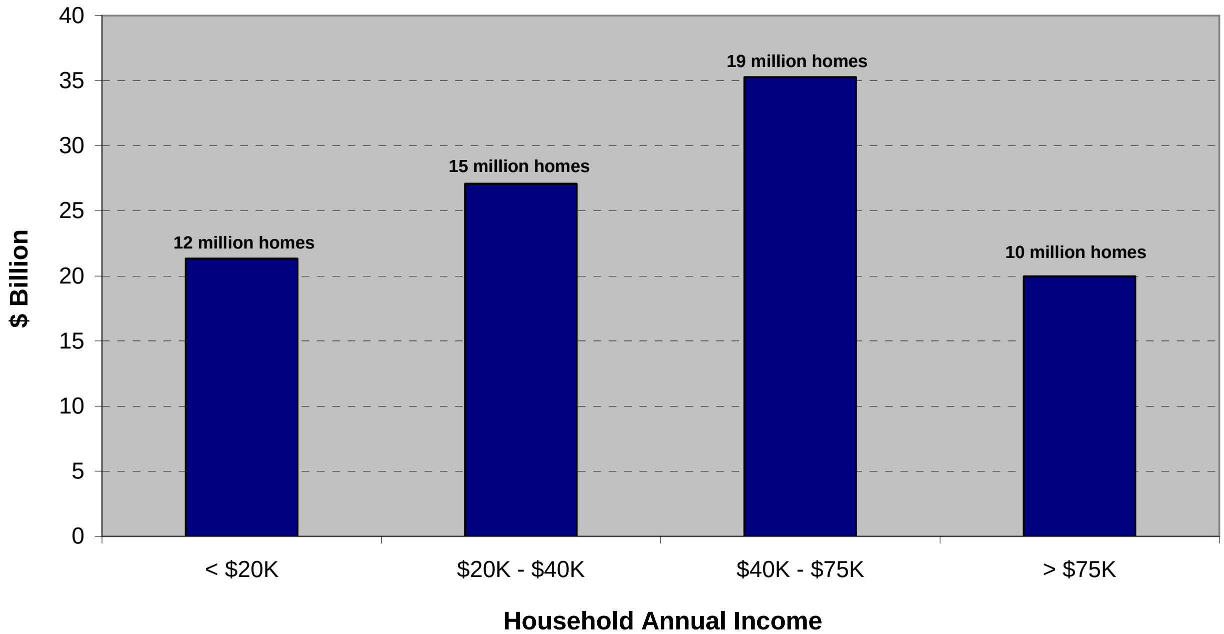


Figure 11. Nationwide energy expenditures by household income (EIA, 1999).

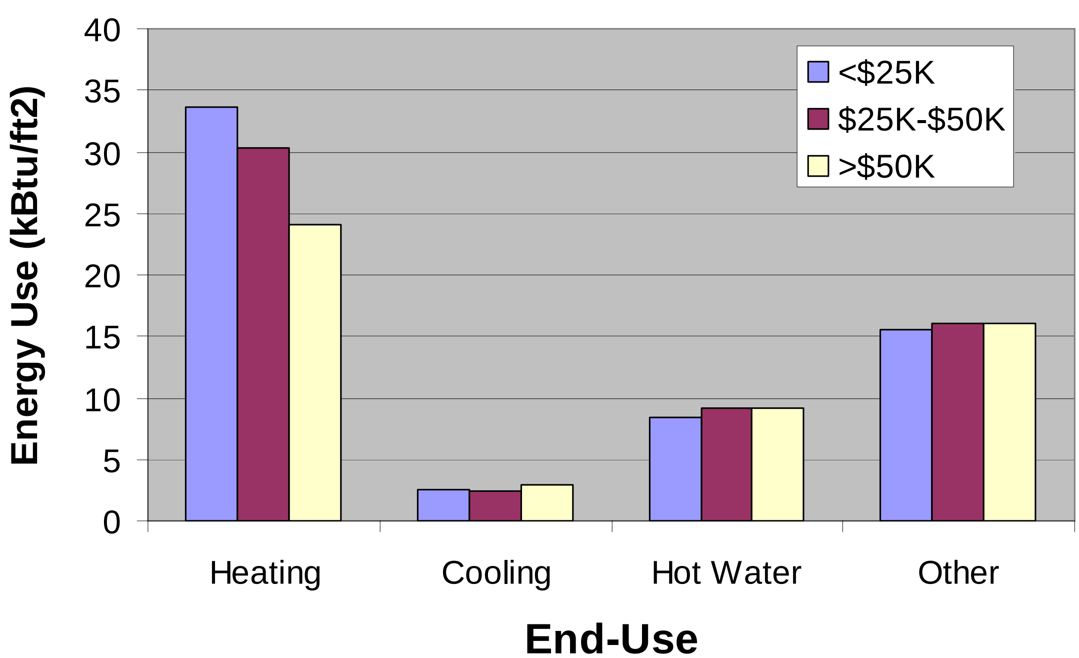


Figure 12. Normalized energy consumption by household income (EIA, 1999)

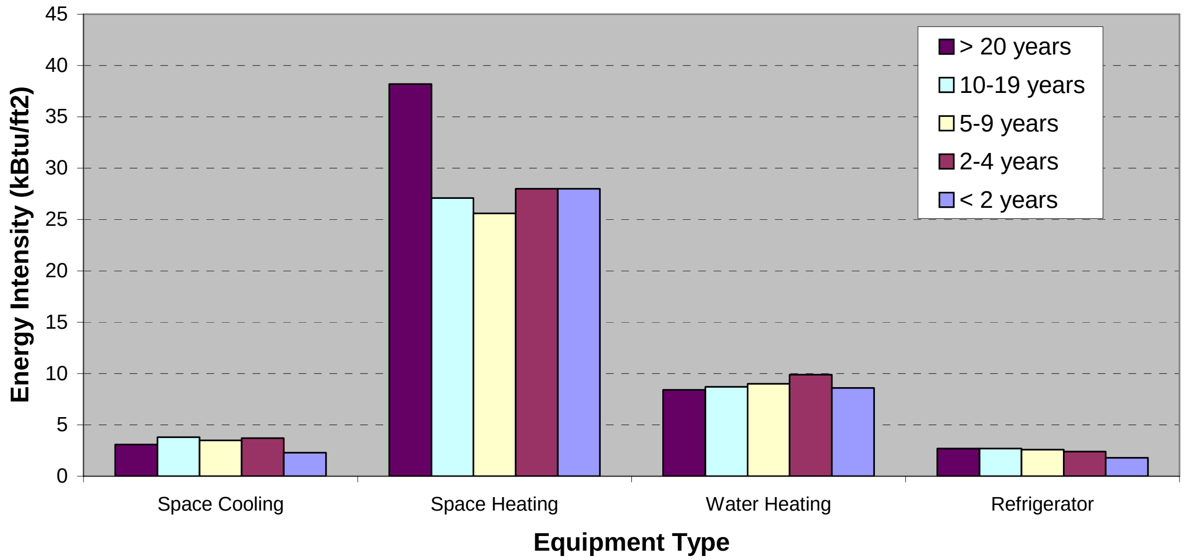


Figure 13. Normalized end-use site energy consumption by age of equipment for single-family, detached, owner-occupied homes. (EIA, 1999)

In an attempt to better characterize predictors of energy use in existing homes, the U.S. Environmental Protection Agency (EPA) and Oak Ridge National Laboratory (ORNL) conducted a statistical analysis of the 1997 RECS data (Hoffmeyer, 2002). The analysis identified 31 variables that helped to predict whole-house energy consumption to a degree that was statistically significant to a 95% confidence level (see Table 1). These variables are listed in order of the percentage of uncertainty explained by that variable (R-Square). The R-Square should not be confused with statistical significance, because a variable may be highly significant even though it explains less than 1% of the variation in energy use. The last column indicates whether this variable is within the immediate control of the occupants, and therefore more appropriately addressed through education or marketing rather than energy efficient retrofits. The most consistent predictors of energy use appear to be heated floor space, climate, and number of occupants (which is presumably correlated with quantity of televisions, refrigerators and lights on).

It is important to note that these variables are predictors of high or low energy consumption, and not necessarily indicators of inefficient energy consumption. For example, a 4000 ft^2 house may be very energy efficient, yet still use more energy than an inefficient 1000 ft^2 house, simply because the building envelope is larger and more occupants are likely to be present. The variables listed in Table 1 suggest which houses tend to have the greatest potential for energy savings in absolute terms, but not necessarily the greatest number of cost-effective retrofit opportunities.

Table 1. Key predictors of energy consumption based on 1997 RECS. (Hoffmeyer, 2002)

Variable	Sign of Regression Coefficient	R-Square	Controlled by Occupants
Heated floor space	+	0.2718	No
California	-	0.0486	No
Number of televisions	+	0.0373	Yes
Number of lights on >12 hrs/day	+	0.0163	Yes
1 household member	-	0.0147	Yes
2 household members	-	0.0090	Yes
East-South Central Census Division	+	0.0086	No
Number of windows	+	0.0075	No
Use dryer every time clothes washed	+	0.0074	Yes
Home built between 1990-1997	-	0.0073	No
Hot tub, spa, or Jacuzzi	+	0.0071	Yes
Chest freezer	-	0.0061	No
Heating degree days	+	0.0055	No
Use central A/C all summer	+	0.0051	Yes
West-South Central Census Division	+	0.0047	No
Home built before 1940	+	0.0024	No
Oregon or Washington	+	0.0022	No
One refrigerator	-	0.0019	No
Electric well pump	+	0.0018	No
Home built between 1940-1949	+	0.0017	No
Upright freezer	-	0.0017	No
More than 20 showers per week	+	0.0016	Yes
East-North Central Census Division	+	0.0013	No
Home built between 1980-1989	-	0.0013	No
6 or more household members	+	0.0011	Yes
Use dryer for some but not all loads	+	0.0011	Yes
Three or more refrigerators	+	0.0011	No
Mid-Atlantic States (DE, DC, GA, MD, NC)	+	0.0010	No
3 household members	-	0.0006	Yes
Use central A/C quite a bit	+	0.0006	Yes
No crawlspace	-	0.0005	No

Geographic Predictors of High Energy Use and Inefficiency

As shown in Figure 14, certain climate zones contribute a larger share of nationwide energy expenditures than others, but the difference is not large enough to warrant narrowing the target market based on climate zone (as defined in the 1997 Residential Energy Consumption Survey (RECS) study). In fact the differences are largely a result of how the climate zones are defined (resulting in a different number of households in each region), not of any real difference in household energy usage or efficiency. Though these characteristics provide some interesting information, there are no clear opportunities to further narrow the set of houses to be investigated.

Switching to energy intensity as the basis of comparison, the five RECS climate zones are again shown in Figure 15. It is more evident that houses in warmer climate zones use more source energy once an adjustment is made for differences in floor area and number of houses in each climate zone. Increases in air conditioning energy and other end-uses more than compensate for the reduction in heating energy. However, the difference in energy intensity between climate zones is relatively small, and no strong target markets are evident based on this coarse level of climate differentiation.

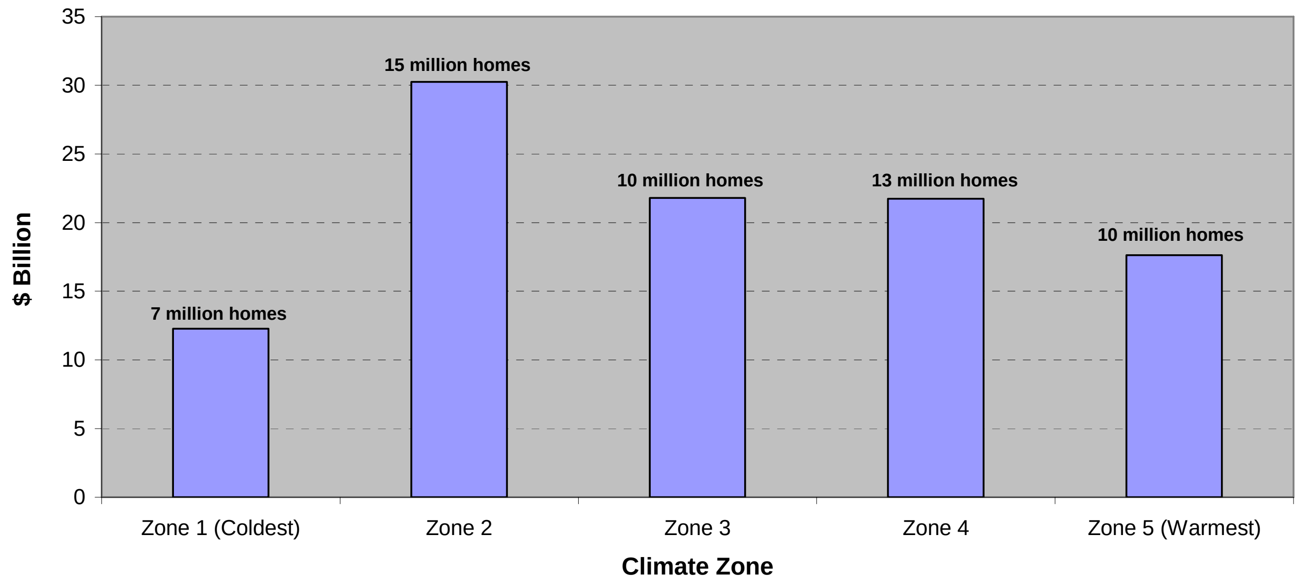


Figure 14. Nationwide energy expenditures by climate zone (EIA, 1999).

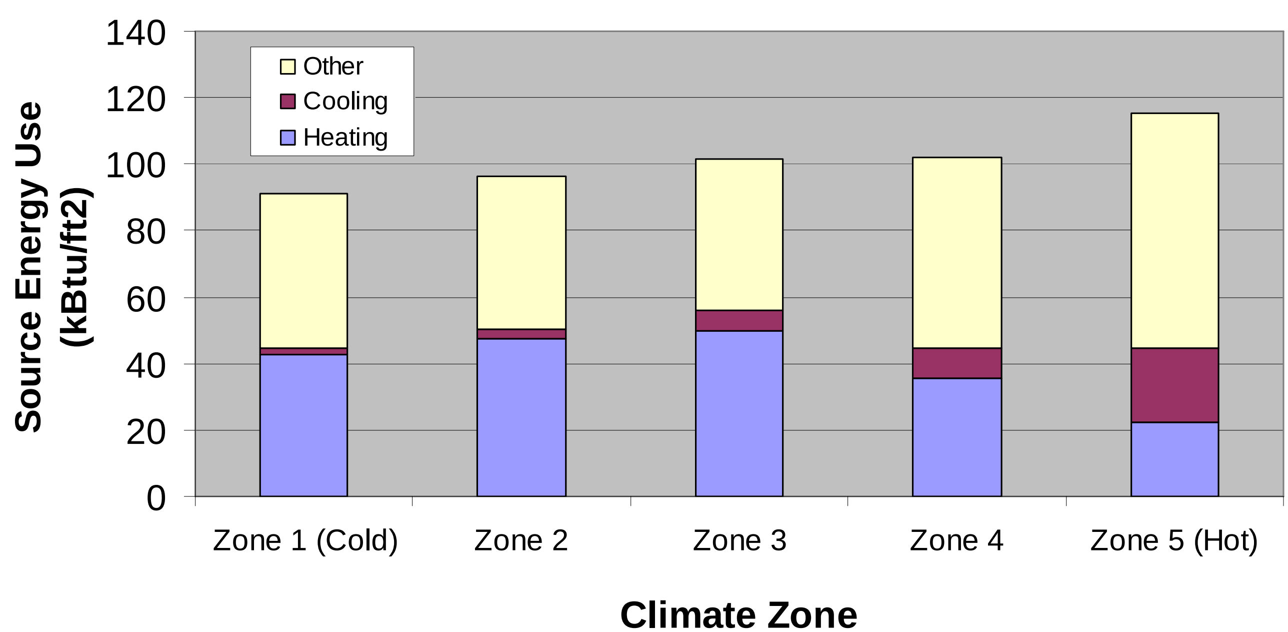


Figure 15. Normalized source energy consumption of existing homes sorted by RECS climate zone. (EIA, 1999)

More specific information about geographical differences can be found by examining state-level energy usage. Because the RECS survey conducted by EIA does not provide this level of detail, it is necessary to combine several data sources to estimate average energy expenditures for single-family detached homes. Table 2 summarizes the results of this analysis, taken from the 2000 EIA State Energy Data and the 2000 U.S. Census. Although the New England states (where fuel costs are high and the weather is cold) stand out as the region with the greatest energy expenditures per household, when these expenditures are normalized as a fraction of income, the poorest states seem to be hit hardest by high energy costs. Table 2 also indicates whether each state has adopted a residential energy code based on information published by the Building Codes Assistance Project (BCAP). However, there seems to be no strong correlation between high residential energy costs and the presence of a statewide energy code.

Table 2. Residential energy expenditures as percent of income ranked by state. (EIA, 2000) (U.S Census, 2002) (BCAP, 2003)

Rank	State	Average Energy Expenditures as % of Household Income	Annual Energy Expenditures per Household (2000)	Mean Household Income	Annual Source Energy per Household (Million Btu)	State-wide Residential Energy Code
1	Maine	4.2%	$1,984	$47,383	177	No
2	Vermont	4.1%	$2,083	$51,270	182	Yes
3	Mississippi	3.7%	$1,554	$42,315	196	No
4	Louisiana	3.6%	$1,617	$44,833	194	Yes
5	Arkansas	3.5%	$1,506	$42,785	186	Yes
6	North Dakota	3.5%	$1,508	$43,560	209	Yes
7	Alabama	3.4%	$1,576	$45,923	195	Yes
8	Oklahoma	3.3%	$1,481	$44,438	195	Yes
9	South Dakota	3.3%	$1,477	$44,746	185	No
10	South Carolina	3.2%	$1,556	$48,349	186	Yes
11	West Virginia	3.2%	$1,284	$40,030	184	Yes
12	Pennsylvania	3.2%	$1,690	$52,682	179	Yes
13	Iowa	3.2%	$1,571	$49,079	186	Yes
14	New Hampshire	3.2%	$1,936	$61,083	166	Yes
15	North Carolina	3.1%	$1,599	$51,225	181	Yes
16	Rhode Island	3.1%	$1,688	$54,767	162	Yes
17	Ohio	3.1%	$1,613	$52,836	190	Yes
18	Missouri	3.0%	$1,489	$49,956	194	No
19	Kansas	3.0%	$1,547	$52,080	194	Yes
20	New York	2.9%	$1,815	$61,856	160	Yes
21	Georgia	2.9%	$1,621	$56,612	196	Yes
22	Texas	2.8%	$1,535	$54,412	180	Yes
23	Montana	2.8%	$1,194	$42,471	176	Yes
24	Tennessee	2.8%	$1,369	$48,688	194	Yes
25	Delaware	2.7%	$1,655	$60,185	181	Yes
26	Connecticut	2.7%	$2,021	$74,196	187	Yes
27	Kentucky	2.7%	$1,232	$45,246	192	Yes
28	Indiana	2.7%	$1,421	$52,229	198	Yes
29	Nebraska	2.7%	$1,329	$49,556	194	No
30	Idaho	2.6%	$1,275	$48,114	203	Yes
31	Wisconsin	2.6%	$1,420	$53,863	177	Yes
32	Massachusetts	2.6%	$1,735	$66,365	171	Yes
33	Illinois	2.6%	$1,578	$61,544	193	No

34	Alaska	2.6%	$1,597	$62,475	191	Yes
35	Wyoming	2.6%	$1,222	$47,801	184	No
36	Virginia	2.5%	$1,569	$61,618	184	Yes
37	Arizona	2.5%	$1,325	$53,926	149	No
38	Florida	2.4%	$1,296	$53,504	156	Yes
39	New Mexico	2.4%	$1,092	$45,589	136	Yes
40	Michigan	2.4%	$1,371	$57,400	194	No
41	Minnesota	2.4%	$1,415	$59,348	182	Yes
42	Maryland	2.3%	$1,581	$67,454	178	Yes
43	New Jersey	2.2%	$1,599	$73,260	173	Yes
44	Nevada	2.2%	$1,240	$57,469	166	No
45	Oregon	2.1%	$1,114	$52,816	169	Yes
46	Hawaii	2.0%	$1,269	$63,065	59	Yes
47	Utah	2.0%	$1,138	$57,052	179	Yes
48	District of Columbia	2.0%	$1,256	$64,355	134	Yes
49	Colorado	1.9%	$1,142	$61,437	161	No
50	Washington	1.8%	$1,073	$58,653	181	Yes
51	California	1.8%	$1,156	$65,628	114	Yes

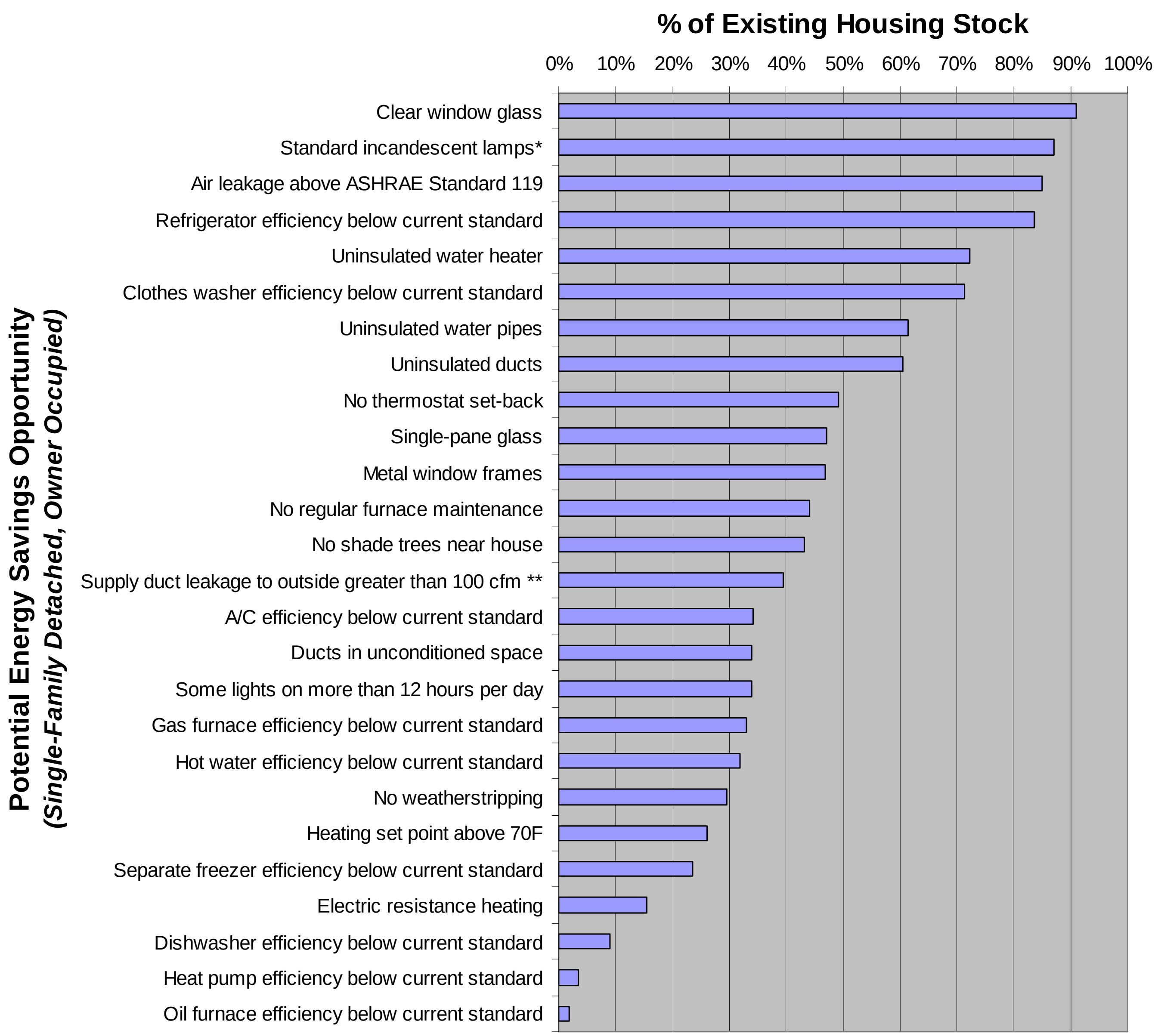
Other Indicators of Energy Inefficiency

The last approach used to identify priority houses for EERE was to examine housing data from the American Housing Survey (U.S. Census, 2001), the Residential Energy Consumption Survey (EIA, 1993, 1997, 2001), the 2003 DOE Buildings Energy Databook, EERE analysis of proposed appliance standards (EERE, 2000), a study by the California Energy Commission (CEC, 1995) and four LBNL studies (Huang, 2002; Wenzel, 1997; Sherman, 1995) to identify housing characteristics that generally lead to inefficient use of energy, and then to estimate their prevalence (or lack thereof) in the stock of existing homes nationwide. The results are summarized in Figure 16. The graph illustrates some common features of existing homes that suggest opportunities for energy savings. Table 3 provides an estimate of the associated energy savings potential for upgrading each of these features to the best commercially available technology.

Although these features are suggestive of energy efficiency improvement opportunities, there are a number of other factors that can affect whether such improvements are cost-effective. In particular, climate, occupant behavior, and equipment cost play a significant role in whether energy efficiency improvements are warranted. For example, the following considerations should factor into any decision whether to replace clear glass windows with low-E and/or low solar heat gain windows:

- First cost (usually the major barrier to window replacement)
- Utility rates
- Weather conditions (temperature, sunlight)
- Window area and orientation
- Satisfaction with current windows (style, damage, radiative exchange, cold drafts, etc)
- State or local financial incentives (tax credits, rebates)
- Use of curtains or blinds by occupants

Unfortunately, these effects are extremely variable and it is difficult to make generalizations about the types of retrofit measures that should be recommended. Typically, building energy simulations are necessary to evaluate the specifics of a retrofit or remodeling opportunity, and quantify the potential energy cost savings in comparison to the initial investment required. Some conclusions about the cost-effectiveness of specific measures may be possible on a state-by-state basis, but it would be necessary to obtain more detailed regional information about housing characteristics, material and equipment costs, and energy prices.



* Percentage of lighting energy consumption in residential sector.
** Sample of California houses with duct in the attic

Figure 16. Features of existing homes nationwide that represent potential opportunities for improvements in energy efficiency. Note the dominant presence of sub-optimal window glass, light bulbs, air leakage, water heaters, and refrigerators.

Table 3. Energy savings potential for retrofits using best commercially available products. (Navigant, 2003; Energy Star Web Site; EnergyGauge analysis)

Feature Indicating Energy Savings Opportunity	Possible Retrofit	Achievable End-Use Energy Savings[3]
Clear window glass (single or double pane)	Low-emissivity, low solar heat gain windows	28-39% space heating 32-56% space cooling
Standard incandescent lamps	Compact fluorescent lamps in high use areas	50-70% lighting
Air leakage above ASHRAE Standard 119	Tighten envelope	36-60% space heating
Refrigerator efficiency below current standard	Energy Star refrigerator	~37% refrigerator
Uninsulated water heater	Add R-16 insulation	~6% water heating
Clothes washer efficiency below current standard	Energy Star clothes washer	~53% clothes washer & dryer
Uninsulated water pipes	Add R-6 insulation	~3% water heating
Uninsulated ducts	Add R-6 insulation	0-27% space heating 0-15% space cooling
No thermostat set-back	Programmable thermostat with 5ºF offset	10-40% space heating 6-12% space cooling
Single-pane glass	Storm windows	25-40% space heating
Metal window frames (no thermal break assumed)	Vinyl frame windows	8-13% space heating
No regular furnace maintenance	Replace filter, clean chamber, adjust burner	~2% space heating
No shade trees near house	Plant trees on east/west	20-35% space cooling
Supply duct leakage to outside over 100 ft^3/min	Seal ducts	5-10% space heating 5-10% space cooling
Air conditioner efficiency below current standard	Replace w/ SEER[4] 18 A/C	~46% space cooling
Ducts in unconditioned space	Move to interior space	15-20% space heating 10-15% space cooling
Some lights on more than 12 hours per day	Occupancy sensors	0-50% lighting
Gas furnace efficiency below current standard	Condensing furnace	~19% space heating
Hot water efficiency below current standard	Condensing water heater	~40% water heating
No weatherstripping	Add weatherstripping	5-10% space heating
Heating set point above 70ºF	Increase mean radiant temperature in winter (reduce drafts, minimize cold surfaces)	15-30% space heating
Separate freezer efficiency below current standard	Energy Star freezer	~17% freezer
Electric resistance heating	Replace w/ 9.8 HSPF[5] heat pump	~65% space heating
Dishwasher efficiency below current standard	Energy Star dishwasher	~64% dishwasher
Heat pump efficiency below current standard	Replace w/ 9.8 HSPF heat pump	~21% space heating ~21% space cooling
Oil furnace efficiency below current standard	Condensing gas furnace	~19% space heating

[3] If best commercially available technology is used. Savings for different measures should not be added together because interactive effects must be considered. Space conditioning energy savings are a strong function of climate and house geometry; results are based on typical IECC compliant houses in Chicago and Houston. Many of the measures (such as lighting and appliance improvements) have indirect effects on space conditioning energy, which may be higher or lower depending on climate, equipment efficiency, and other factors.

[4] Seasonal Energy Efficiency Ratio

[5] Heating Seasonal Performance Factor

Fortunately, a number of important insights can be gained by looking at past and present trends in the DOE Weatherization Assistance Program (WAP). Table 4 summarizes the most common measures implemented by weatherization agencies for the specific category of low-income, high-energy use households addressed by WAP. Air leakage (including envelope and duct leakage) measures were by far the most common improvement at the time this study was conducted in 1989 (Brown, 1994). Such air sealing measures usually involved weatherstripping and caulking. Additional insulation was also a frequent improvement, usually in the attic because it is the most accessible and often the most important location. Water heater improvements usually included insulating the tank or pipes, and lowering the supply temperature set point. Window and door improvements (addition of storm windows or replacement of broken windows and doors) were also common, along with space heating improvements (usually tune-ups and filter replacements). It should be noted that WAP providers often do not use a rigorous method of determining cost effectiveness of various measures for each house, and weatherized houses are not likely to be representative of the existing housing stock. Although the WAP program recommends the NEAT software for evaluating energy saving opportunities, other important considerations play a role in the choice of a retrofit package, such as health, comfort, safety, and security.

Table 4. Common improvements in weatherized homes in 1989. (Brown, 1994)

Energy Efficiency Improvement	Percent of Homes
Air leakage control	95%
Insulation	62%
Water heater measures	56%
Windows & doors	42%
Space heating measures	30%

WAP has demonstrated very high return on investment according to a 1996 evaluation by Oak Ridge National Laboratory (Berry et al, 1997), returning $2.40 in benefits for each dollar invested by the government. But despite the relatively long history of this program, a large portion of the low-income market remains untapped. As of 1997, only about 15% of eligible households had received weatherization assistance during the 21-year lifetime of the program.

Another key target market is homeowners who are making major equipment purchases or upgrades to their homes. Figure 17 summarizes the most common home improvement measures based on total nationwide expenditures. The repairs or improvements that offer the best opportunities for energy efficiency upgrades are designated with an asterisk. A recent ACEEE study (Thorne, 2003) identifies southern and western cities as the most likely to see large investments in home improvements over the next decade, because of the large amount of construction occurring in these regions throughout the 1970s. The lifetimes of many major building systems range from 25-30 years and will soon be in need of significant upgrades and/or renovations. The ACEEE study provides a very good survey of other opportunities and barriers associated with the existing homes market, and the approaches taken by various organizations to transform both the market and the delivery infrastructure.

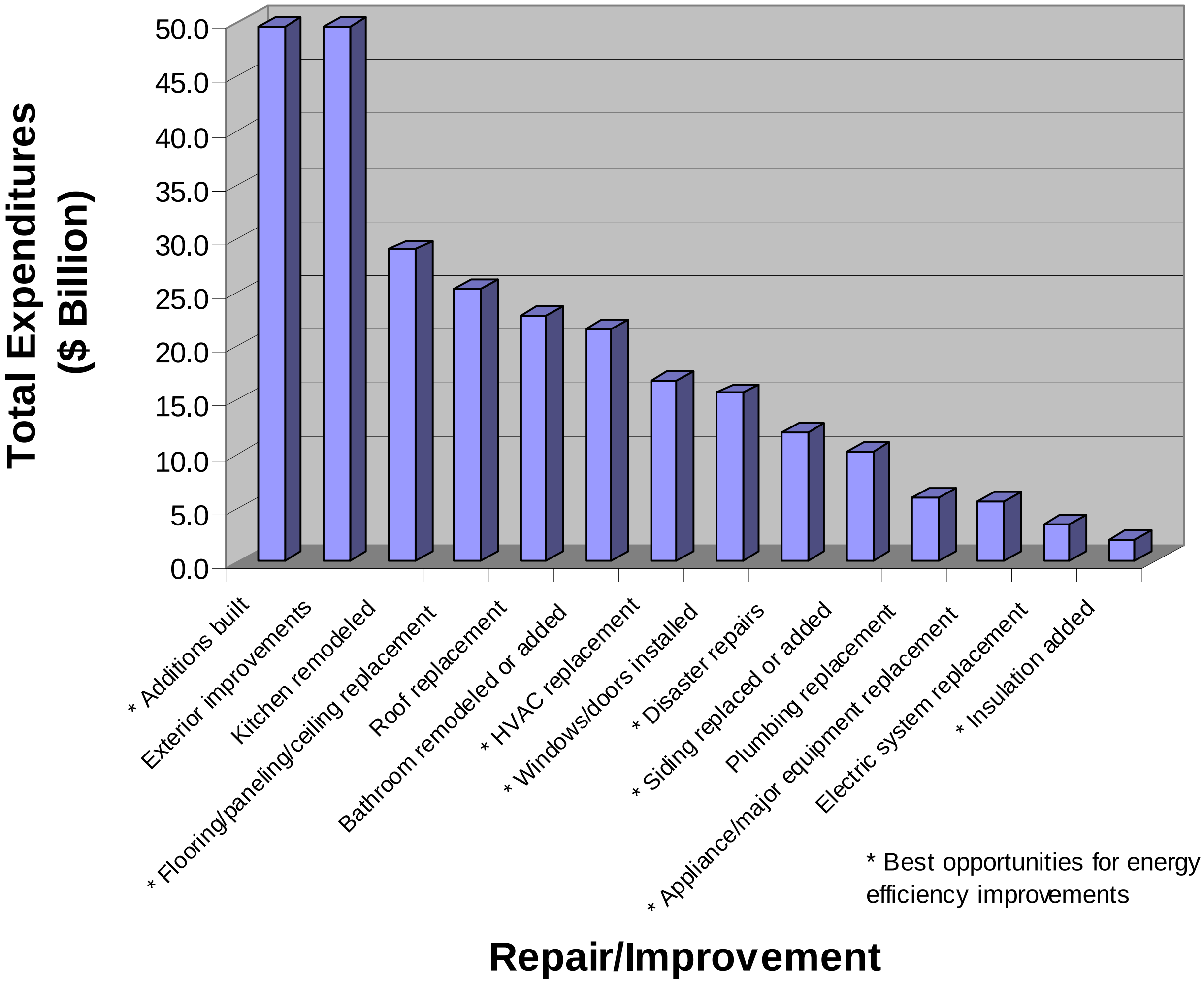


Figure 17. Major categories of renovations and improvements in existing homes (EERE, 2003)

Occupant Behavior

Finally, one must be cautious when estimating the potential energy savings in actual homes following retrofits. Occupant behavior plays a very important role, both in terms of variability from one set of occupants to another, and in terms of take-back effect by the same occupants after energy efficiency improvements have been made. One analytical study examined the effects of variations in weather (year-to-year), building construction (for similar houses), and occupant behavior on energy consumption in typical Norwegian houses. Reasonable probability distributions were identified for each variable based on data published in the literature. The report calculates uncertainties for the effects of occupants, building construction, and climate, as shown in Table 5.

Table 5. Importance of occupants, year-to-year weather differences, and building construction on predicted energy use in similar houses in Norway.

Variable	**Standard Deviation of Energy Consumption for Similar Houses in Norway (Simulated)**	
	Total Energy	**Heating Only**
Occupants	7.8%	11.8%
Building	4.0%	7.0%
Climate	4.0%	N/A
Combined Total	9.6%	13.8%*

* Occupant and building effects only

Another study by LBNL (Sonderegger, 1978) estimated that the standard deviation of heating energy for similar homes in a New Jersey community caused by differences in occupant behavior was 9.1%. A third study in Sweden measured energy consumption in 87 similar houses, and estimated the standard deviation of total energy usage to be roughly 10% (9% due to occupant behavior alone). The results from all three studies are fairly consistent, and indicate that occupant behavior causes approximately 10% standard deviation in heating energy use, and roughly 8% standard deviation in whole-house energy use. Of course this uncertainty can be greatly amplified in leaky, inefficient homes.

The take-back or rebound effect is another complicating factor when considering occupant behavior. This change in behavior can occur because energy efficiency improvements have reduced the penalty for operating the home in an inefficient manner. For example, an occupant may increase the thermostat set point in winter because the furnace is more efficient, or leave lights on in unoccupied rooms because compact fluorescent lamps are used. A study by the Congressional Research Service estimated these take-back effects to be in the range of 0-50% of expected energy savings for the particular end-use that has been made more efficient (see Table 6).

Table 6. Measured take-back effects for various residential end-uses, expressed as a percentage of expected energy savings with no change in behavior. (Gottron, 2001)

End-Use	**Size of Take-Back Effect**	**Number of Studies**
Space Heating	10-30%	26
Space Cooling	0-50%	9
Water Heating	10-40%	5
Residential Lighting	5-12%	4
Home Appliances	0%	2

Conclusions

Based on the literature search and supplementary analysis described in this report, several conclusions can be drawn about logical target markets for EERE existing homes activities:

1. Owner-occupied, single-family detached homes are the dominant category of existing homes, accounting for over 60% of energy expenditures. This market has not been heavily addressed by current or past DOE programs, and represents a large potential for reduction in nationwide energy consumption. Rented homes and apartments account for another 18%, but this market is difficult to address because the decision maker for retrofits usually does not receive the direct benefits of lower energy bills (owner vs. tenant).
2. Plug loads or miscellaneous end-uses (including clothes washers, dryers, dishwashers, and small electronic devices such as televisions and personal computers) are a rapidly increasing energy end-use in both new and existing homes. Many of the contributing appliances (e.g. home entertainment systems, computers) are not currently covered by appliance standards. Water heating and lighting are also important end-uses, followed by space cooling and refrigeration. Electricity is expected to constitute a larger fraction of home energy use over the next two decades.
3. Based on the ORNL statistical analysis of RECS data, none of the common demographic variables appear to be particularly strong or consistent predictors of <u>total</u> household energy use, except for conditioned floor area. Climate and number of occupants provide some information, but explain no more than 5% of the total variation among households ($R\text{-Square} < 0.05$). Occupant behavior and specific housing characteristics dominate the variability in whole-house energy use.
4. Older houses with older equipment and low-income occupants use more energy on a per square foot basis. These three household characteristics are also strongly correlated with each other. The same trend for this market sector is not apparent when looking at total household energy use, because conditioned floor area tends to be smaller in older homes with low-income occupants.
5. Homeowners in the northeastern states have larger energy bills than anywhere else in the U.S., despite the fact that average source energy consumption is fairly uniform throughout the country. This trend is caused by a combination of relatively high energy prices, a very cold climate that causes large heating loads, and houses that are older and larger on average than in other parts of the U.S. This may indicate that the northeastern states should be a priority market for EERE.
6. As a fraction of income, the poorest states tend to spend the most for household energy. The average income is $46,000 for the top ten states, and $62,000 for the ten states paying the least for their energy bills as a percent of total income. This trend is not surprising because of the inelasticity of the demand for household energy.
7. A large number of inefficient housing characteristics still dominate the existing housing stock, including clear glass windows, incandescent lamps, poorly insulated water tanks and pipes, and excessive envelope and duct leakage. This does not necessarily mean that retrofits of these features would be cost-effective, but it provides an indication of which elements of existing homes should be pursued further, perhaps on a state-by-state basis.
8. Over a hundred billion dollars are invested every year on home repairs and improvements in the U.S., offering opportunities to improve home energy efficiency at the same key decision point that other home performance and quality issues are addressed. Home additions, envelope measures, and equipment replacements provide the best leveraging opportunities.

Recommendations for Future Study

1. Locate or develop more detailed information about housing characteristics in different states or regions of the country, and identify which of those characteristics are important from an energy efficiency standpoint. The lack of useful data in this area has been one of the more widely recognized problems with segmenting the existing homes market (Thorne, 2003; PATH, 2002). Some individual states may have collected this information for houses within their state borders, but there appears to be no nationwide set of housing characteristics broken down by state. The information could be helpful to states and local partners as a tool to more quickly identify high priority categories of housing in their region.
2. Evaluate a sampling of common house designs in different regions of the U.S., or different parts of a state, using typical cost data and occupant behavior to determine the likely cost-effectiveness, maximum market penetration, and potential long-term energy savings of specific retrofit measures.
3. Examine advanced energy retrofit technologies and their potential impacts on existing homes in the future. Any target markets identified today may shift as new technologies and products arrive in the marketplace, and manufacturing improvements lower the price of existing products that currently do not offer homeowners an adequate return on their investment.
4. Conduct a thorough analysis of the housing stock of selected states to gain a better understanding of what causes the difference in total costs. For example, California is an important variable listed by ORNL as a key predictor of low energy consumption. Is this result largely due to favorable climate or is it significantly impacted by codes and incentives? Conversely, other regions of the country consume more energy on a per household basis. Is this due to climate or housing characteristics, or do those states offer fewer incentives for energy efficiency?

References

Berry, L., et al. 1997. *Progress Report of the National Weatherization Assistance Program.* Oak Ridge National Laboratory, Oak Ridge, TN.

Building Codes Assistance Project (BCAP). 2003. *Residential Energy Code Status as of October 2003.* Building Codes Assistance Project, Washington, DC.

California Energy Commission (CEC). 1995. *Treatment of Residential Duct Leakage in Title-24 Energy Efficiency Standards -- Section Six of Energy Characteristics, Code Compliance and Occupancy of California's 1993 Title 24 Houses (1993 Residential Field Data Project).* California Energy Commission, Sacramento, CA.

DOE Office of Energy Efficiency and Renewable Energy (EERE). 2000. Final Rule Technical Support Document (TSD): Energy Efficiency Standards for Consumer Products: Clothes Washers. U.S. Department of Energy, Washington, DC.

Energy Information Administration (EIA). 1999. *Residential Energy Consumption Survey (RECS) 1997*. U.S. Department of Energy, Washington, DC.

Energy Information Administration (EIA). 2000. *State Energy Data 2000*. U.S. Department of Energy, Washington, DC.

Energy Information Administration (EIA). 2001. *Residential Energy Consumption Survey 2001*. U.S. Department of Energy, Washington, DC.

Energy Information Administration (EIA). 2002. *Annual Energy Review 2002.* U.S. Department of Energy, Washington, DC.

Energy Information Administration (EIA). 2003. *Annual Energy Outlook 2003*. U.S. Department of Energy, Washington, DC.

Gottron, F. 2001. *Energy Efficiency and the Rebound Effect: Does Increasing Efficiency Decrease Demand?* CRS Report RS20981. Congressional Research Service, Washington, DC.

Hoffmeyer, D.A. 2002. *A Yardstick Consumers Use to Measure Home Energy Performance*. U.S. Environmental Protection Agency, Washington, DC.

Nadel, S., et al. 2003. *Market Transformation: Substantial Progress from a Decade of Work.* American Council for an Energy Efficient Economy, Washington, DC.

Navigant Consulting. 2003. *Zero Energy Homes' Opportunities for Energy Savings: Defining the Technology Pathways Through Optimization Analysis.* Navigant Consulting, Inc., Washington, DC.

Office of Energy Efficiency and Renewable Energy (EERE). 2003. *2003 Buildings Energy Databook*. U.S. Department of Energy, Washington, DC.

Partnership for Advanced Technology in Housing (PATH). 2002. *Technology Roadmap: Energy Efficiency in Existing Homes, Volume Two: Strategies Defined*. U.S. Department of Housing and Urban Development, Washington, DC.

Pettersen, T. 1995. *Variation of Energy Consumption in Dwellings Due to Climate, Building and Inhabitants.* Energy and Buildings 21. Narvik Institute of Technology, Norway.

Sherman, M.; Matson, N. 1995. *Residential Ventilation and Energy Characteristics.* LBL-39036. Lawrence Berkeley National Laboratory, Berkeley, CA.

Sonderegger, R. 1978. *Movers and Stayers: The Resident's Contribution to Variation Across Houses in Energy Consumption for Space Heating*. Lawrence Berkeley National Laboratory, Berkeley, CA.

Thorne, J. 2003. *Residential Retrofits: Directions in Market Transformation.* American Council for an Energy Efficient Economy, Washington, DC.

U.S. Census Bureau. 2001. *American Housing Survey for the United States: 2001*. U.S. Department of Commerce, Washington, DC.

U.S. Census Bureau, Population Division. 2002. *State Housing Unit Estimates: April 1, 2000 to July 1, 2002*. U.S. Department of Commerce, Washington, DC.