LBL-40297
UC-1600

ENERGY DATA SOURCEBOOK FOR THE U.S. RESIDENTIAL SECTOR

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September 1997

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http://enduse.lbl.gov/Projects/RED.html

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, State, and Community Programs of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

ABSTRACT

Analysts assessing policies and programs to improve energy efficiency in the residential sector require disparate input data from a variety of sources. This sourcebook, which updates a previous report, compiles these input data into a single location. The data provided include information on end-use unit energy consumption (UEC) values of appliances and equipment; historical and current appliance and equipment market shares; appliance and equipment efficiency and sales trends; appliance and equipment efficiency standards; cost vs. efficiency data for appliances and equipment; product lifetime estimates; thermal shell characteristics of buildings; heating and cooling loads; shell measure cost data for new and retrofit buildings; baseline housing stocks; forecasts of housing starts; and forecasts of energy prices and other economic drivers. This report is the essential sourcebook for policy analysts interested in residential sector energy use. The report can be downloaded from the Web at http://enduse.lbl.gov/Projects/RED.html. Future updates to the report, errata, and related links, will also be posted at this address.

FOREWARD AND ACKNOWLEDGMENTS

This report is an updated version of Hanford et al (1994). Much of the data from the earlier report have been updated to 1995, and corrections have been made where necessary. We did not update the thermal shell and heating and cooling loads (Chapter 3) because of the difficulty of recalculating these parameters within the timeframe and funding constraints for the revisions.

We would like to thank the members of the Market Technologies Assessment Group in the Energy Analysis Program at LBNL for their time spent gathering data and explaining the technical details of appliance efficiency improvements. In particular, we thank James McMahon, Peter Chan, Isaac Turiel, and James Lutz, as well as Mithra Moezzi of the End-Use Forecasting Group.

We would also like to thank the analysts who reviewed this report, including Alan Meier, Robert Richey, and Richard Brown of the Energy Analysis Program at LBNL, John Cymbalsky of the Energy Information Administration, and Jordan Kelso and Bill Zwack of D&R International.

We are grateful for the support and insights of Dick Jones and Bill Raup of the Office of Building Technology, State, and Community Programs, U.S. Department of Energy, who funded this work.

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1. INTRODUCTION

This sourcebook is designed to support improved energy demand forecasting at Lawrence Berkeley National Laboratory (LBNL) and within the U.S. Department of Energy (US DOE). It is the most extensive compilation of the major data elements necessary for end-use energy demand forecasting in the residential sector. The work represents an attempt to systematically assess and document these data, and to provide them in a format readily usable to energy analysts. This report describes the methodology used in collecting and assessing these data, the sources used, and presents the major pieces of data in graphical or tabular form. The sourcebook includes the following model input data:

- Unit energy consumption (UECs) of appliances and equipment;
- Historical and current appliance and equipment market shares;
- Appliance and equipment efficiency and sales trends;
- Cost vs. efficiency data for appliances and equipment;
- Product lifetime estimates;
- Thermal shell characteristics of buildings and heating and cooling loads;
- Shell measure cost data for new and retrofit buildings;
- Baseline housing stocks;
- Forecasts of housing starts; and
- Forecasts of energy prices and other economic drivers.

The sourcebook serves as the source of input data for the residential forecasting models used in the Energy Analysis Program at LBNL.

In Chapter 2, we describe the major elements of the sourcebook and the methodology and sources used in developing the estimates. In Chapter 3, we describe the data for the heating and cooling end-uses. In Chapters 4 through 13, we discuss the data for typical household appliances. In Chapter 14, we describe general data, such as fuel prices, housing starts, etc., that are used in forecasting residential energy demand by end-use. In Chapter 15, we provide suggestions for areas where we feel forecasting data could still be improved. Appendix A contains a description and analysis of a database of over 1300 UEC estimates from a variety of studies.

2. *METHODOLOGY*

This sourcebook provides input data for detailed characterizations of the residential energy sector. Several major data sources, as well as a number of smaller studies, were used to compile the sourcebook. This section describes how the data were developed. The actual data are presented in Chapters 3 through 14. Primary data sources include:

- Residential sector characteristics and consumption surveys, referred to as the Residential Energy Consumption Survey, or RECS (US DOE 1982a, 1986, 1989a, 1993b, 1995b);
- Appliance efficiency standards analyses (US DOE 1988, 1989b, 1989c, 1990b, 1993c, 1995c, 1996a, 1996b);
- Appliance and equipment manufacturer data (AHAM 1996; ARI 1997; GAMA 1996);
- Surveys of current housing and construction (US Bureau of the Census 1988, 1990a, 1990b, 1992, 1996; NAHB 1989);
- Surveys of sector energy use (US DOE 1990a; AGA 1991; EEI 1983; LBNL-REM 1991);
- UEC estimating studies (various utility studies; US DOE 1988; US DOE 1989b; US DOE 1989c; US DOE 1990a; US DOE 1993a; AGA 1996; Cohen et al. 1991);
- Building characterization projects (Ritschard et al. 1992a; NAHB 1986; NAHB 1989; MHI 1991); and
- Building heating and cooling simulation databases (LBNL 1987; Huang et al. 1987b).

2.1. Unit Energy Consumptions

Data on end-use unit energy consumptions (UECs) were collected to verify the accuracy of UECs used in engineering models that estimate energy savings from conservation improvements, and also to forecast baseline energy consumption. We collected data from metered studies and other estimates based on measurements of actual field usage of a particular appliance or house. From these data, we developed a database of over 1300 records for all major residential end-uses. Because of the large variability in estimates for any particular value, we selectively aggregated the data based on the quality of the study and the methodology used to derive the estimate. The method we used was: 1) collect information on the estimate concerning its representation, including region of the country, specific house type studied, specific appliance type studied, etc., to ensure we were comparing like values, 2) assign a subjective quality rating (1-5) to each estimate based on the sample size or other measure of the quality of the estimate, and 3) record the type of methodology ("study type") used to calculate the estimate (e.g. measurement, statistical or "conditional demand", an aggregate of other estimates, etc.), and 4) calculate averages of the UEC estimates based on quality and study type to determine the best estimate from the available data. This UEC database, which is summarized in Appendix A, was used as guidance in developing the final UEC estimates.

Appliance End-Uses

UECs for appliance end-uses in the existing housing stock were derived from analyses performed on the UEC database. For new appliances entering the market, we relied upon engineering estimates developed for the U.S. DOE appliance standards analysis (US DOE 1988, 1989b, 1989c, 1990b, 1993c, 1995c, 1996a, 1996b), as well as manufacturer data (AHAM 1996, ARI

1997, GAMA 1996). These engineering estimates represent test data rather than field data, however, and should be used with care.

Heating and Cooling End-Uses

For heating and cooling end-uses, we used a North/South region division of the U.S. to better describe the variation in energy use across climates. Federal regions 1, 2, 3, 5, 7, and 10 make up the North region, and federal regions 4, 6, and 9 make up the South region. The UEC database did not provide readily usable values for heating and cooling UECs, since the estimates were typically averages for the entire nation or regionally-specific estimates for small climatic regions. Therefore, we relied on a combination of data, including RECS conditional demand estimates (US DOE 1982a, 1986, 1989a, 1993b, 1995b), estimates in the LBNL-REM forecasting model (LBNLREM 1991), American Gas Association (AGA) gas space heating survey data (AGA 1996), some regional data from the UEC database, and the BECA-B database compiled at LBNL (Cohen et al. 1991) for heating and cooling UECs in existing buildings in the North and South regions of the U.S. In some cases, we also used the heating and cooling loads from prototype buildings defined for the database to estimate UECs.

Determining UECs for typical new buildings is even more difficult than for existing buildings since there are few data on the energy usage of new buildings, particularly across large parts of the country (the 1993 RECS began to address this concern, by increasing the sample of new homes surveyed to about 1200). Therefore, for new building heating and cooling UECs, we adjusted the UECs for existing buildings based on: 1) different heating and cooling loads between the existing buildings and new buildings entering the stock, and 2) different heating and cooling equipment efficiencies of new vs. existing equipment.

2.2. Market Shares

Appliance Market Shares

We compared appliance market shares from the RECS surveys (US DOE 1982a, 1986, 1989a, 1993b, 1995b), LBNL-REM forecast estimates (LBNL-REM 1991), data from the American Housing Survey (US Bureau of the Census 1988, 1990b, 1992), and industry estimates (AHAM 1996, ARI 1997, GAMA 1996). The sources are in agreement for appliance market shares in the existing housing stock for the major end-uses. Appliance market shares for existing buildings by housing type from the RECS surveys are included in the sourcebook. We also include estimates from the RECS survey for new construction by segmenting the RECS data to include only buildings built in the previous 5 to 7 years (market shares in new construction in 1993 are derived from the 1993 RECS data for buildings built between 1988 and 1993; the 1988 RECS is used for market shares for new construction between 1980 and 1987). Since this is a relatively small sample, these estimates have a larger error. These estimates also represent devices present in homes after several years of occupancy, rather than the appliances in homes at the time of sale.

Heating and Cooling Equipment Market Shares

The sourcebook includes RECS data on heating and cooling equipment market shares from 1981-1993 for existing buildings (US DOE 1982a, 1986, 1989a, 1993b, 1995b). Heating and cooling equipment market shares for new construction are taken from U.S. Department of Census Reports Series C25 on new construction characteristics, and are included for 1980-95 (US Bureau of the Census 1996). Data on the market shares of heating and cooling equipment combinations (HVAC market shares) are also included. These were developed for the year 1995 from the RECS data for existing buildings and by combining estimates from the Census C25 data and RECS data for new buildings.

2.3. Appliance Technology Characteristics

Historical Sales, Efficiencies, and Sizes of Appliances and Equipment

Data on shipments of appliances and equipment from 1950 to the present were compiled for the major end-uses. These data also show the evolution of appliance efficiencies over time starting from the early 1970s. Furthermore, the shipments (or sales) data allow the user to estimate product lifetimes and the average efficiency of the current appliance stock. These data are from industry reports produced by the major trade associations (AHAM 1996; ARI 1997; and GAMA 1996) as well as data derived for the U.S. DOE appliance standards analysis and incorporated in the LBNL Residential Energy Model (LBNL-REM 1991). These data are not adjusted for any imports, exports, or use in buildings other than residences (e.g. a residential-type water heater in a commercial establishment), and thus may introduce some error into the analysis.

Equipment Cost vs. Efficiency Data

Equipment cost vs. efficiency data were gathered primarily from the U.S. DOE appliance standard analyses (US DOE 1988, 1989b, 1989c, 1990b, 1993c, 1995c, 1996a, 1996b) as well as other documents for appliances not yet analyzed under this process. Data for all of the major residential end-uses have been compiled to be used to derive forecasting model inputs.

2.4. Building Characteristics, Building Prototypes, and Building Loads

Building characteristics data for both the existing stock and for typical new construction were compiled from previous LBNL work on prototype development for GRI, U.S. DOE, and the U.S. EPA as well as more recent data from RECS (US DOE 1982a, 1986, 1989a, 1992a, 1995a) and the C25 surveys (US Bureau of the Census 1996a). There are two regional prototypes for existing single-family and multi-family buildings (representing average uninsulated buildings and insulated buildings) and single regional prototypes for manufactured homes and new single-family and multi-family buildings. The prototypes are also segmented by heating fuel to account for the differences in thermal efficiency between fuel-heated and electrically-heated buildings. Populations of each type are included, and each prototype building is linked to an HVAC system type.

Heating and cooling loads for the prototype buildings are calculated based on the building component characteristics (wall area and R-value, etc.) using a database developed at LBNL in support of the ASHRAE Special Project 53 (Huang et al. 1987b). This database provides heating and cooling loads for each building component based on the component area and the thermal characteristics. These component loads can also be used to estimate changes in the loads with improved components.

2.5. Building Component Costs

Costs for increasing levels of thermal integrity in new buildings have been derived from an NAHB cost database (NAHB 1986). Costs for retrofitting single-family buildings with improved levels of thermal integrity were also derived from previous LBNL work (Boghosian 1991). Cost estimates for retrofitting existing multi-family or manufactured home buildings have not been estimated.

2.6. Electronic Data

All of the data are stored in Excel spreadsheets that allow the user to display and manipulate the data, or input the data into forecasting models. The report itself can be downloaded from the Web at http://enduse.lbl.gov/Projects/RED. Future updates to the report, errata, and related links, will also be posted at this address.

3. HEATING AND COOLING END-USE DATA

Heating and cooling together account for about 30% of electricity consumption, 70% of gas consumption, and 90% of oil consumption in the U.S. residential sector. These end-uses are a major source of conservation potential as well as energy demand growth (see Koomey et al. 1991a). In this section, we present data for UECs, heating and cooling equipment characteristics, and building thermal characteristics. Energy consumption for heating and cooling is a function of many variables, including HVAC equipment characteristics, building shell characteristics, occupant behavior, climate (both across regions and year to year within the same region), microclimates, and regional energy prices. For heating and cooling, we use a regional disaggregation to segment the housing population to capture the major variations in climate and building characteristics across the country. As shown in Figure 3.1, we use a North and South regional breakdown similar to that used in earlier LBNL work (e.g. Koomey et al. 1991a). We provide UECs and building prototype characteristics for these two regions.

3.1. UECs

The UECs for heating and cooling are important since the current level of energy consumption determines potential energy savings from improvements in building thermal shell characteristics as well as equipment. We show these estimates in Tables 3.1 and 3.2. The sources used in developing UECs include national data sources as well as regional data from utilities and weatherization studies. These include the U.S. Residential Energy Consumption Survey (RECS) data sets (US DOE 1982a, 1986, 1989a, 1990a, 1993b, 1995b), LBNL-REM estimates (LBNL-REM 1991), the American Gas Association Gas Househeating Survey (AGA 1996), the BECA-B data set (Cohen et al. 1991) and many different regional utility estimates compiled as part of the UEC database (Appendix A).

Generalized UEC equations

The generalized equations for calculating heating and cooling UECs are given below. In the generalized equation, the efficiency is the combined heating or cooling *system* efficiency, where the system efficiency includes effects of both the equipment and the thermal distribution system. These are discussed in a following section.

Fuel heating: $$\text{UEC (MMBtu/yr)} = \frac{\text{Load}}{(\text{Efficiency}/100)}$$

where: Load is building heating load (MMBtu/yr)

Efficiency is heating AFUE (%) plus a factor to account for distribution efficiency

Electric heating: $$\text{UEC (kWh/yr)} = \frac{\text{Load}}{(\text{Efficiency}/100) * 0.003413}$$

where: Load is building heating load (MMBtu/yr)

Efficiency for electric resistance heating is assumed to be 100%
0.003413 converts units (MMBtu/kWh)

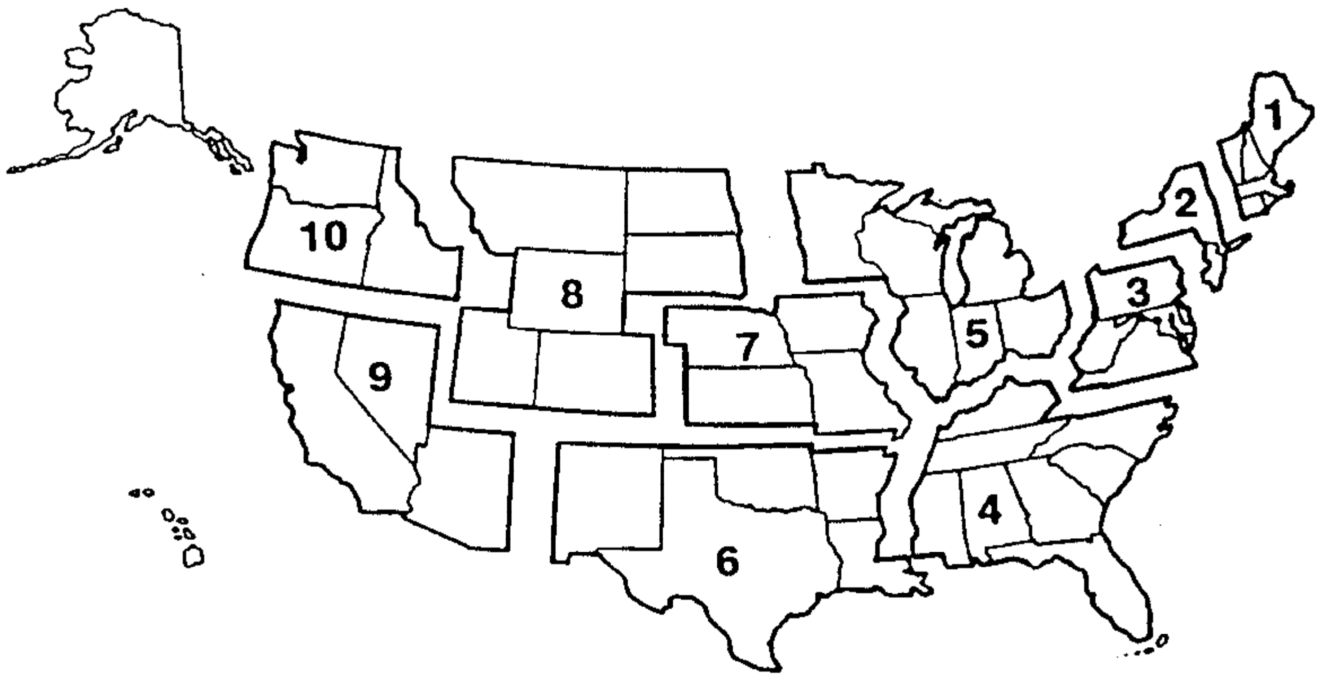
Air Conditioning, Ht Pump Heating: $$\text{UEC (kWh/yr)} = \frac{\text{Load}}{\text{Efficiency} * 0.001}$$

where: Load is building heating or cooling load (MMBtu/yr)

Efficiency is EER, SEER, or HSPF (kBtu/kWh) plus a factor to account for distribution efficiency

0.001 converts units (MMBtu/1000kBtu)

Figure 3.1. Federal Regions and North/South regional breakdown



Region 1
New England
Connecticut (CT)
Maine (ME)
Massachusetts (MA)
New Hampshire (NH)
Rhode Island (RI)
Vermont (VT)

Region 2
New York/
New Jersey
New Jersey (NJ)
New York (NY)

Region 3
Mid Atlantic
Delaware (DE)
District of Columbia (DC)
Maryland (MD)
Pennsylvania (PA)
Virginia (VA)
West Virginia (WV)

Region 4
South Atlantic
Alabama (AL)
Florida (FL)
Georgia (GA)
Kentucky (KY)
Mississippi (MS)
North Carolina (NC)
South Carolina (SC)
Tennessee (TN)

Region 5
Midwest
Illinois (IL)
Indiana (IN)
Michigan (MI)
Minnesota (MN)
Ohio (OH)
Wisconsin (WI)

Region 6
Southwest
Arkansas (AR)
Louisiana (LA)
New Mexico (NM)
Oklahoma (OK)
Texas (TX)

Region 7
Central
Iowa (IA)
Kansas (KS)
Missouri (MO)
Nebraska (NE)

Region 8
North Central
Colorado (CO)
Montana (MT)
North Dakota (ND)
South Dakota (SD)
Utah (UT)
Wyoming (WY)

Region 9
West
Arizona (AZ)
California (CA)
Hawaii (HI)
Nevada (NV)

Region 10
Northwest
Alaska (AK)
Idaho (ID)
Oregon (OR)
Washington (WA)

South Region is defined as Federal Regions 4, 6, and 9.

North Region is defined as Federal Regions 1, 2, 3, 5, 7, 8, and 10

Table 3.1. Calibrated Database UEC Estimates for Heating, 1990

			UEC by Housing Type					
Location	Fuel	Technology	Existing Single-Family	Existing Multi-Family	Existing Manufactured	New Single-Family	New Multi-Family	New Manufactured
North								
	Electric	Furnace	14000	8700	8000	11301	4320	6488
	(kWh)	Room	14000	8700	8000	11301	4320	6488
		HP	9000	4000	6300	9648	2614	-
	Gas	Furnace	93	69	65	64	27	56
	(MMBtu)	H2O	111	65	-	74	24	-
		Room	83	63	63	-	-	61
	Oil	Furnace	83	66	59	62	-	56
	(MMBtu)	H2O	112	66	-	79	26	-
		Room	79	60	-	-	-	-
South								
	Electric	Furnace	6000	3700	4500	4903	1940	3391
	(kWh)	Room	6000	3700	4500	4903	1940	-
		HP	5000	2100	1500	3935	948	1947
	Gas	Furnace	52	31	36	26	11	29
	(MMBtu)	H2O	79	35	-	39	12	22
		Room	38	19	28	-	8	-
	Oil	Furnace	55	-	61	30	-	24
	(MMBtu)	H2O	86	68	-	-	25	-
		Room	46	11	18	-	-	10
US weighted average								
	Electric	Furnace	10417	6708	6282	7661	2967	4616
	(kWh)	Room	10417	6708	6282	7661	2967	6488
		HP	7209	3243	3944	6398	1667	-
	Gas	Furnace	75	54	51	42	18	40
	(MMBtu)	H2O	97	53	-	54	17	22
		Room	63	45	46	-	8	61
	Oil	Furnace	70	66	60	44	-	37
	(MMBtu)	H2O	100	67	-	79	25	-
		Room	64	40	18	-	-	10
Weighting factors		*North*	*55%*	*60%*	*51%*	*43%*	*43%*	*40%*
		South	*45%*	*40%*	*49%*	*57%*	*57%*	*60%*

Source: Table 3.20.
US weighted average calculated using weighting factors at bottom of table. Factors for existing homes calculated using data in Table 3.19. Factors for new homes represent housing starts for north and south regions averaged over 1980-1988 for single family, 1985-88 for multifamily, and 1988 alone for mobile homes. Source of starts for SF and MF is Statistical Abstract of the US. Source of starts for mobile homes is Manufactured Housing Institute -- Summary of Manufactured Housing by States, which takes data from "National Conference of States on Building Codes and Standards, 1988".

Table 3.2. Calibrated Database UEC Estimates for Cooling, 1990

			UEC by Housing Type					
Location	Fuel	Technology	Existing Single-Family	Existing Multi-Family	Existing Manufactured	New Single-Family	New Multi-Family	New Manufactured
North								
	Electric	Central	1160	515	1443	1132	307	1630
	(kWh)	Room	375	160	447	352	89	499
		HP	1176	517	1544	1425	342	-
South								
	Electric	Central	3821	1366	2988	2297	928	2702
	(kWh)	Room	1358	424	1007	756	273	886
		HP	4077	1371	3175	3316	808	3463
US weighted average								
	Electric	Central	2352	854	2201	1795	660	2278
	(kWh)	Room	815	265	722	582	194	733
		HP	2475	857	2345	2501	607	3463
Weighting factors		*North*	*55%*	*60%*	*51%*	*43%*	*43%*	*40%*
		South	*45%*	*40%*	*49%*	*57%*	*57%*	*60%*

Source: Table 3.21.

US weighted average calculated using weighting factors at bottom of table. Factors for existing homes calculated using data in Table 3.19. Factors for new homes represent housing starts for north and south regions averaged over 1980-1988 for single family, 1985-88 for multifamily, and 1988 alone for mobile homes. Source of starts for SF and MF is Statistical Abstract of the US. Source of starts for mobile homes is Manufactured Housing Institute -- Summary of Manufactured Housing by States, which takes data from "National Conference of States on Building Codes and Standards, 1988".

Existing Building UECs

For natural gas space heating, the American Gas Association's (AGA's) Gas Househeating Survey provides estimates of average space heating and "other" consumption for single-family and multi-family buildings. The survey also provides an average across the two building types on a national level and across the four census regions (AGA 1991). As of the 1995 survey, now called the Residential Natural Gas Market Survey, AGA only reports average space heating consumption for single-family homes, both nationally and for the nine census regions (AGA 1995). These data are derived from surveys of gas utilities, and are shown over the period 1980 through 1995 in Figures 3.2 and 3.3. Also shown are end-use estimates of gas space heating consumption from RECS (US DOE 1982a, 1986, 1989a, 1993b, 1995b) which are estimated from utility bill data using a statistical regression analysis model. The figures also show national gas heat UECs from the most recent runs of the LBNL Residential Energy Model (LBNL-REM 1996), which is calibrated to RECS data for certain end-uses.

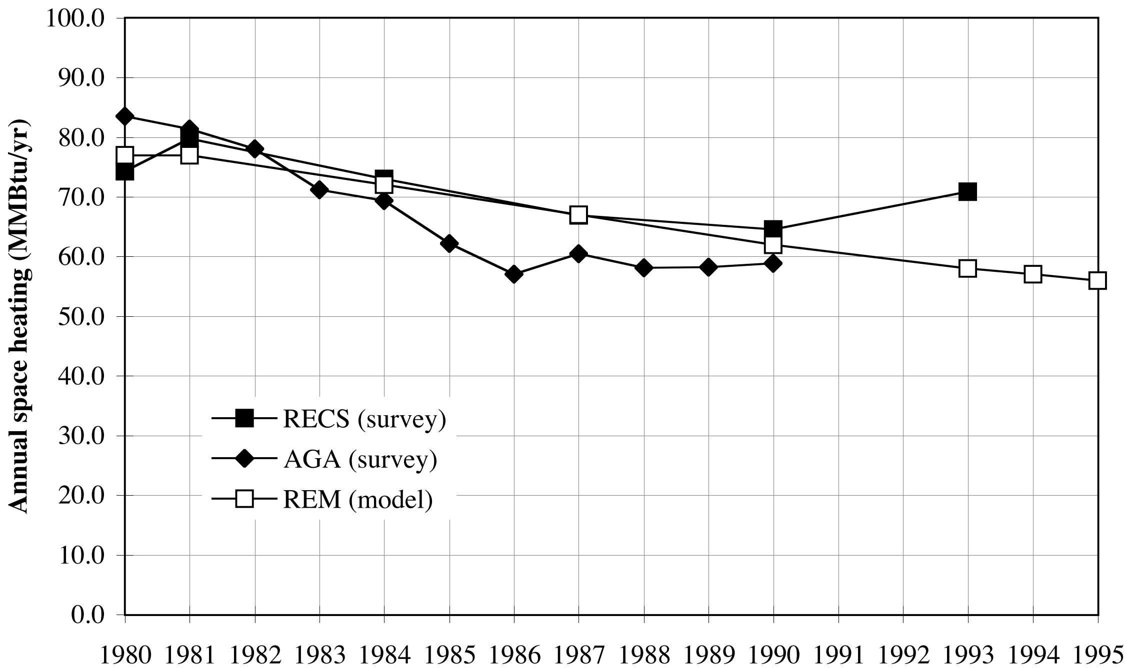
Since all sources are in fairly close agreement for national average natural gas space heating UECs, we developed the UECs for natural gas using the RECS data. At the same time, we used the RECS data for estimating all fuel space heating UECs. The RECS format allows easy stratification of the data by house type, region, and heating technology, and is thus more flexible. The RECS also is a representative survey of the national building stock.

Electric space heating consumption for all house types and single-family houses are shown in Figures 3.4 and 3.5. For electric space heat, there are no utility surveys that provide national average electricity space heating consumption analogous to the AGA data for natural gas. The two primary sources, the RECS end-use estimates and the LBNL-REM forecasts, are in wide disagreement on electric heat UECs. Two studies comparing the conditional demand estimates in RECS with utility sub-metering data have found that RECS overestimates electric space-heating and -cooling UECs, and underestimates electric water heating UECs (Battles 1990, Battles 1994). The UEC database contains almost 250 estimates of electric heating UECs for different regions, technologies, house types vintages, etc. In general, electric heat UECs show wide variations across regions and even within regions (see Appendix A).

Regional utility estimates for electric heating from the UEC database are shown in Figure 3.6 for resistance heat and Figure 3.7 for heat pump heating, with the estimate plotted against heating degree days for the federal region incorporating the utility service area. The BECA-B database of single-family retrofit programs and savings contains several entries with end-use estimates of electric space heating UECs (primarily electric resistance) (Cohen et al. 1991). These data are plotted in Figure 3.8. All of these data are from the Pacific Northwest region (except for three data points from the Tennessee Valley Authority), and thus may not be representative of the rest of the U.S.

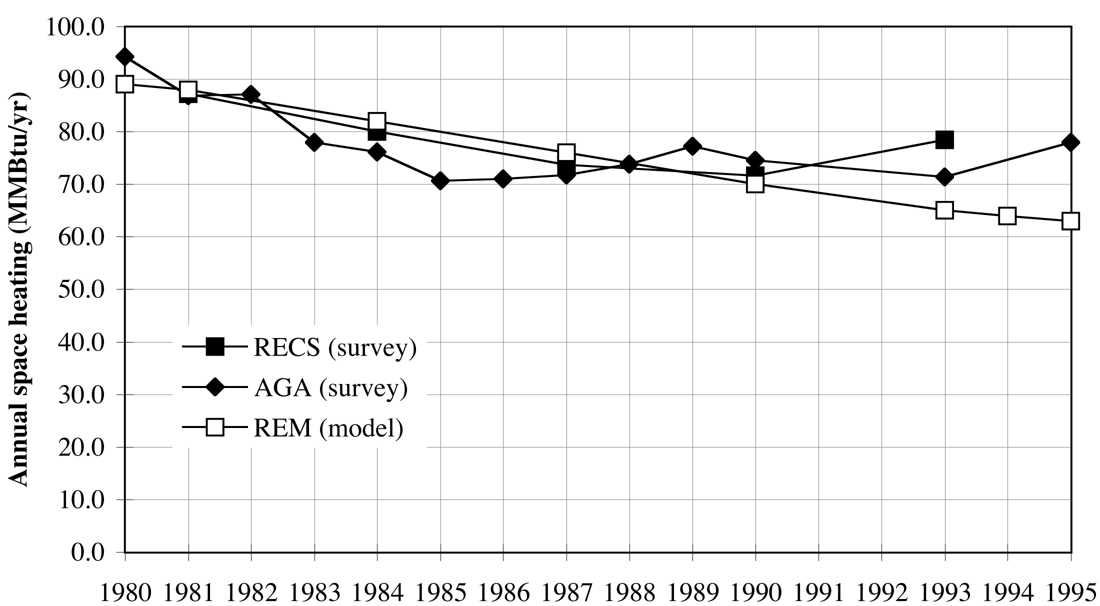
We use the BECA-B data to develop electric resistance space heat UECs for the North region and the regional utility data to estimate UECs for resistance heat in the South and heat pump UECs in both regions since these sources provide data best for single-family dwellings. The single-family estimates are used to estimate UECs for the other building types. Furnace fan energy consumption is not included in the natural gas heating data, but is included in the electric space heating data. Table 13.1 in the Miscellaneous End-Use Data section of this report provides an estimate of furnace fan UECs.

Figure 3.2. National Average Gas Space Heating Consumption -- All House Types



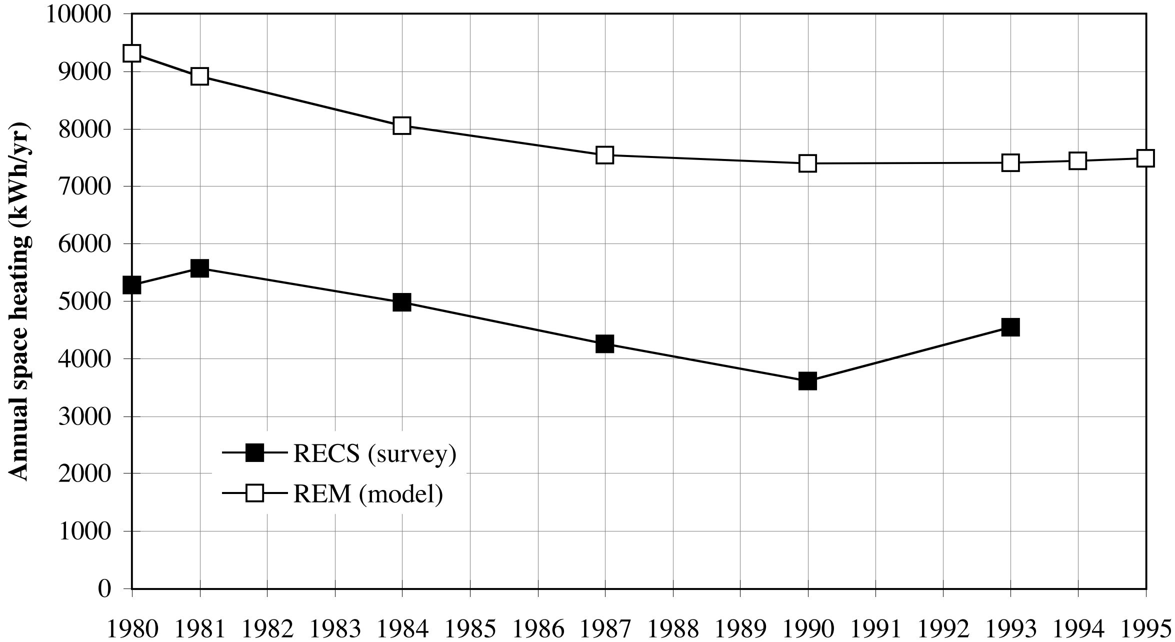
Source: US DOE 1982a, 1986, 1989a, 1993a, 1995a; AGA 1996; LBNL-REM 1996.

Figure 3.3. National Average Gas Space Heating Consumption -- Single-Family Houses



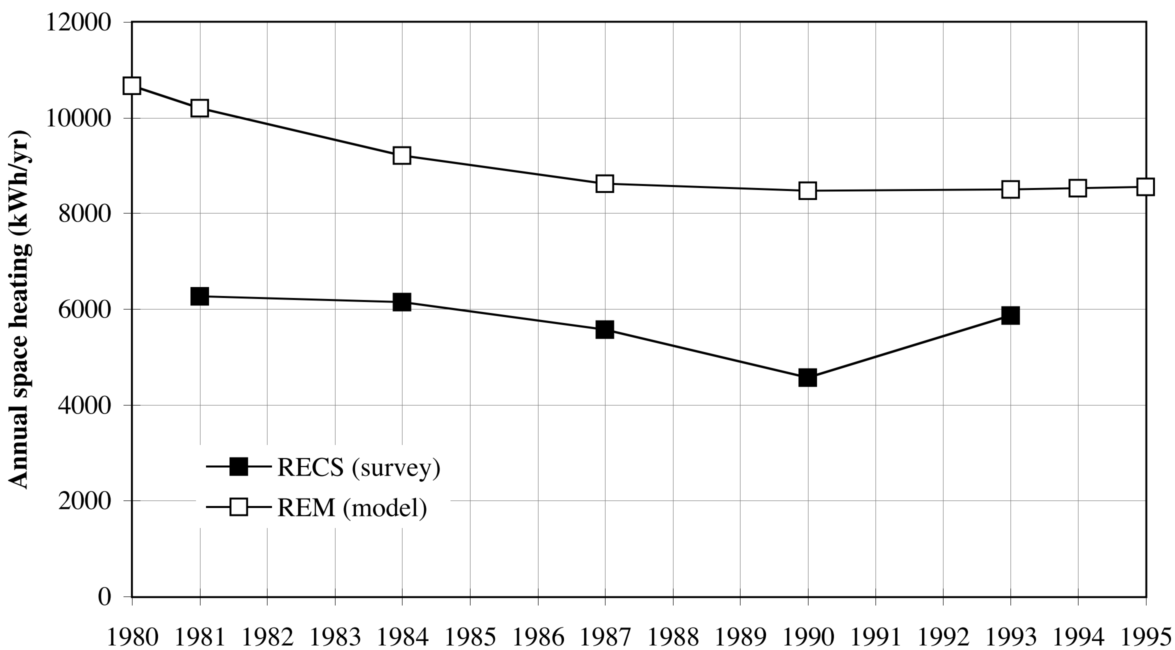
Sourece: US DOE 1982a, 1986, 1989a, 1993a, 1995a; AGA 1996; LBNL-REM 1996.

Figure 3.4. National Average Electric Space Heating Consumption -- All House Types



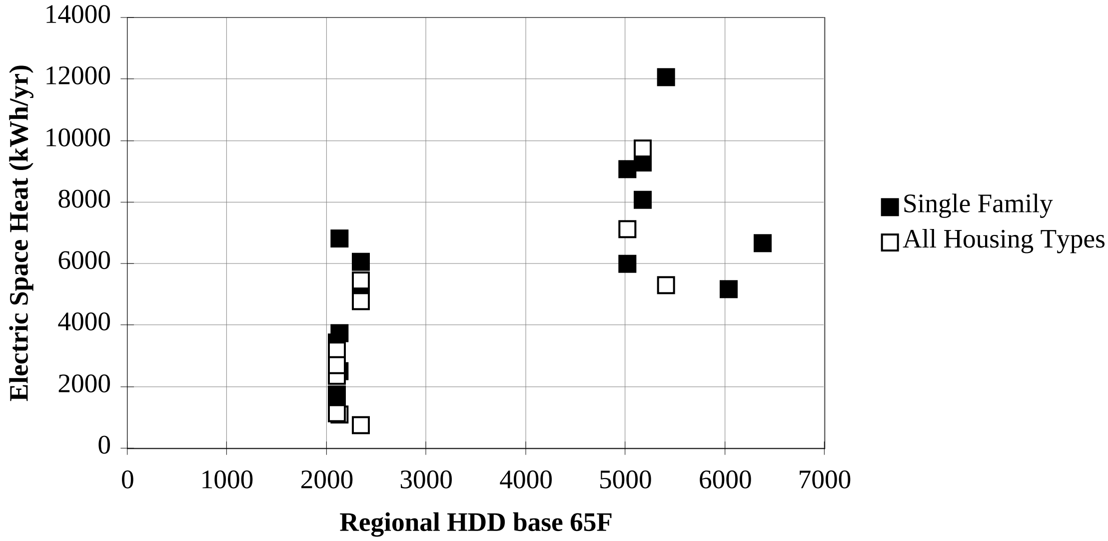
Source: US DOE 1982a, 1986, 1989a, 1993a, 1995a; LBNL-REM 1996.

Figure 3.5. National Average Electric Space Heating Consumption -- Single-Family Houses



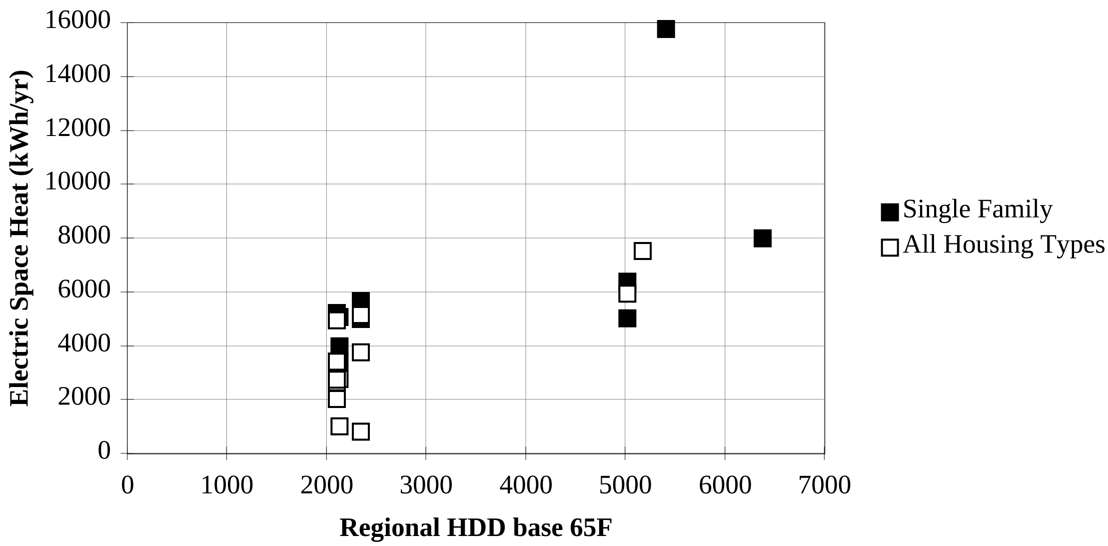
Source: US DOE 1982a, 1986, 1989a, 1993a, 1995a; LBNL-REM 1996.

Figure 3.6. Electric Resistance Space Heat UECs from Utility Studies



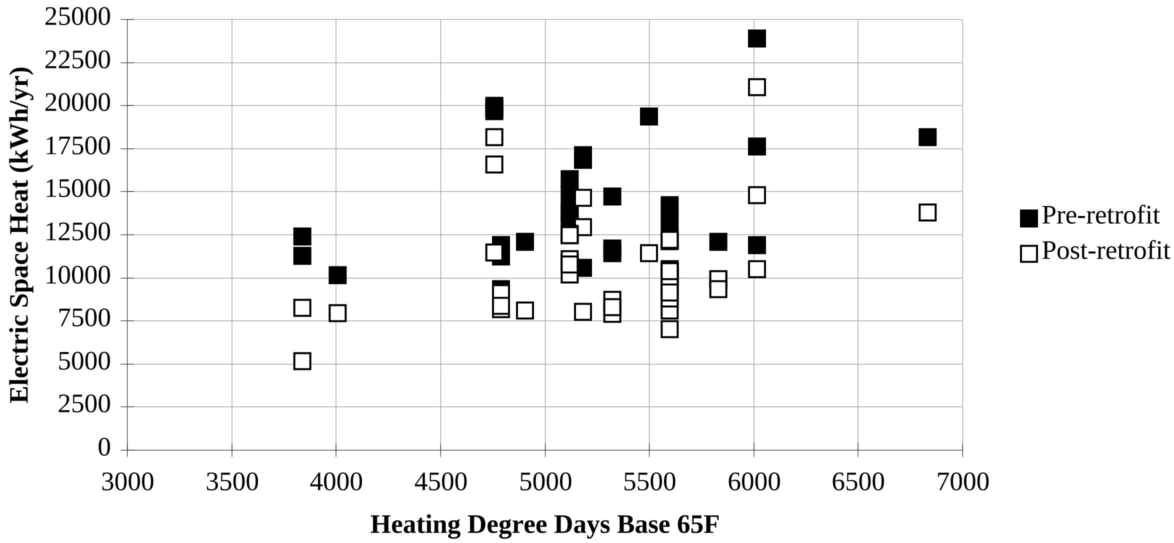
Source: Data in Residential UEC Database (Appendix B).

Figure 3.7. Electric Heat Pump Space Heat UECs from Utility Studies



Source: Data in Residential UEC Database (Appendix B).

Figure 3.8. Average Electric Space Heat Use from Retrofit Programs in BECA-B Database



Source: Cohen et al. 1991.

For cooling, UEC estimates show wide variation across sources, as shown in Figures 3.9 and 3.10. In addition, the values from year to year derived from the RECS data are more variable than are the heating data. Records in the UEC database also show wide variation, even within the same North/South regions we have defined (e.g. California locations are in the same region as Florida locations). We use values derived during an earlier LBNL study (Koomey et al. 1991a), which are in reasonable agreement with the data in the UEC database (Appendix A). Central air conditioning fan energy use is included in the Seasonal Energy Efficiency Ratio (SEER) and thus in the UECs.

New Building UECs

We estimate UECs for space heating and cooling in new buildings by first calibrating the UECs for existing buildings with UECs estimates from building descriptions, a building loads model, and equipment efficiencies for existing buildings, and then applying the calibration multiplier to the model for new buildings and equipment. This ensures that the UECs for new buildings, which are not well represented in available measured data, are calculated in a consistent manner to UECs for existing buildings. This process is discussed further in Section 3.5 (below).

3.2. Technology Data for HVAC Equipment and Distribution Systems

Historical Efficiency of Equipment

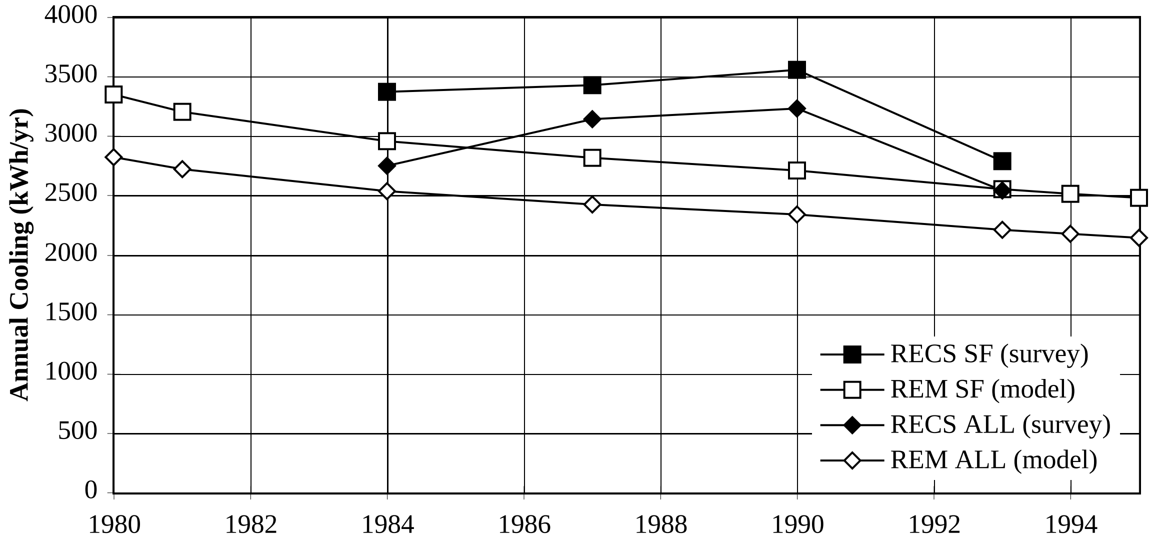
Efficiencies of heating and cooling equipment have been generally rising since the early 1970s, when data are first available. The sources of data on HVAC equipment efficiency trends include appliance manufacturers trade associations (AHAM 1996; ARI 1997; GAMA 1996). Fuel-fired furnace and boiler efficiencies are determined from standardized testing procedures which simulate seasonal performance. The measure of efficiency for this equipment is the Annual Fuel Utilization Efficiency (AFUE), which is expressed as a percent. Electric resistance heating equipment, both furnaces and room heating, is assumed to have an AFUE of 100%. Electric equipment that uses a compressor, including heat pumps for heating and cooling and electric air-conditioners, have unique measures of efficiency which are also derived from standardized testing procedures.

The measure of efficiency for central air conditioning (CAC) and the cooling mode for electric heat pumps (HP) is the Seasonal Energy Efficiency Ratio (SEER), while the efficiency for heat pumps in heating mode is the Heating Seasonal Performance Factor (HSPF). Each of these measures is a ratio of the useful cooling or heating provided, in kBtu, to the electrical energy required, in kWh. Both the SEER and HSPF account for seasonally induced part-load operation. For room air conditioners, the efficiency measure is the Energy Efficiency Ratio (EER), which is based on full load operation of the equipment.

The average efficiency of new residential heating and cooling equipment sold each year, sometimes called the SWEF (shipment-weighted energy factor), is shown with the shipments data in Figures 3.11 through 3.16. Shipments of equipment include both new construction markets and replacement markets.

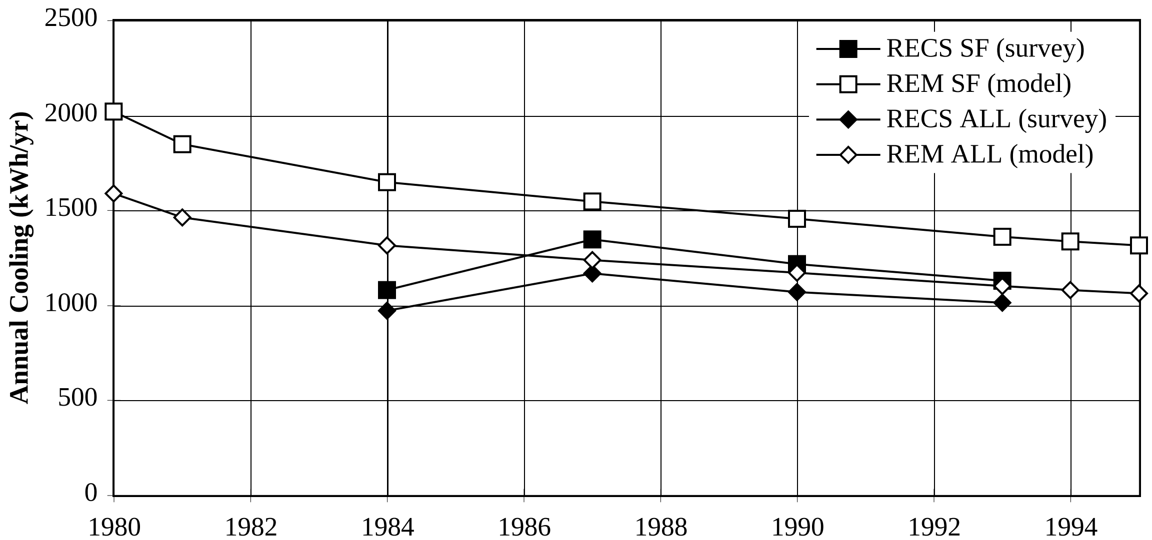
Gas furnaces represent the major portion of the residential heating equipment market, with current sales around 2 million units per year. Heat pumps are the major central heating competition for gas furnaces, with current sales of about 0.75 million units per year. Since 1972, average furnace efficiency (AFUE) has increased from 63% to 83% in 1995 (the legal minimum under the NAECA appliance standards is 78%). The average oil furnace now has a slightly lower efficiency. Changes, if any, in residential boiler efficiencies are not well known. Air conditioning equipment efficiency has also risen dramatically over the last 20 years, as have shipments of residential cooling equipment. Note the increase in unvented room heaters in Figure 3.14. This presents a potential health and safety problem, as well as an indoor moisture problem.

Figure 3.9. National Average Central Air Conditioner (CAC) UEC



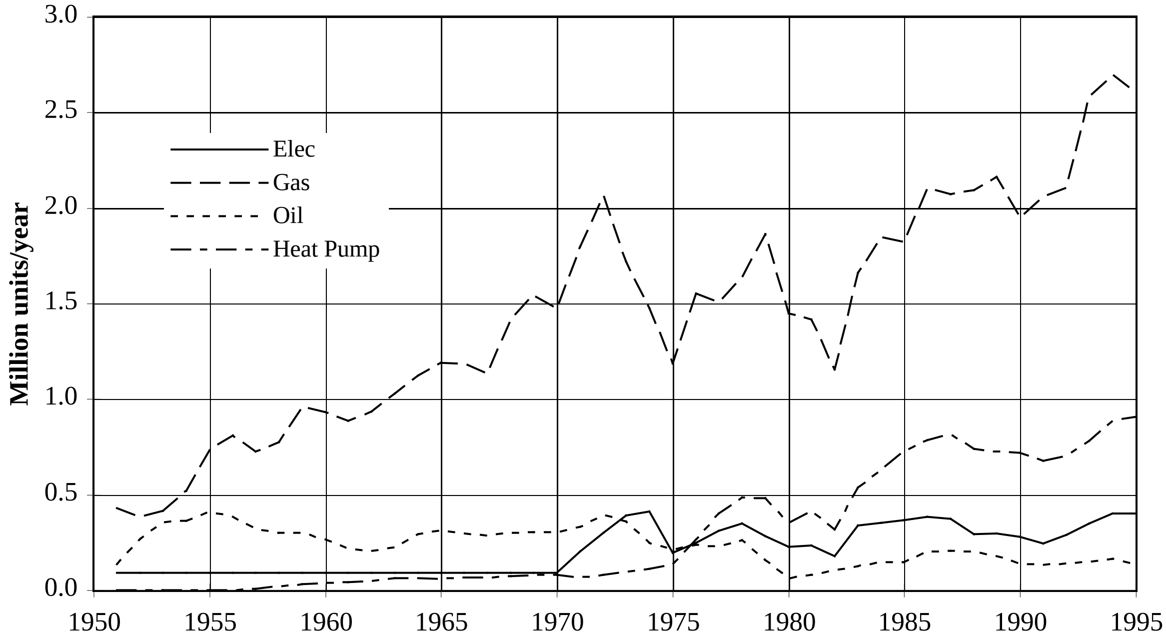
Source: US DOE 1982a, 1986, 1989a, 1993a, 1995a; LBNL-REM 1996.

Figure 3.10. National Average Room Air Conditioner (RAC) UEC (per household)



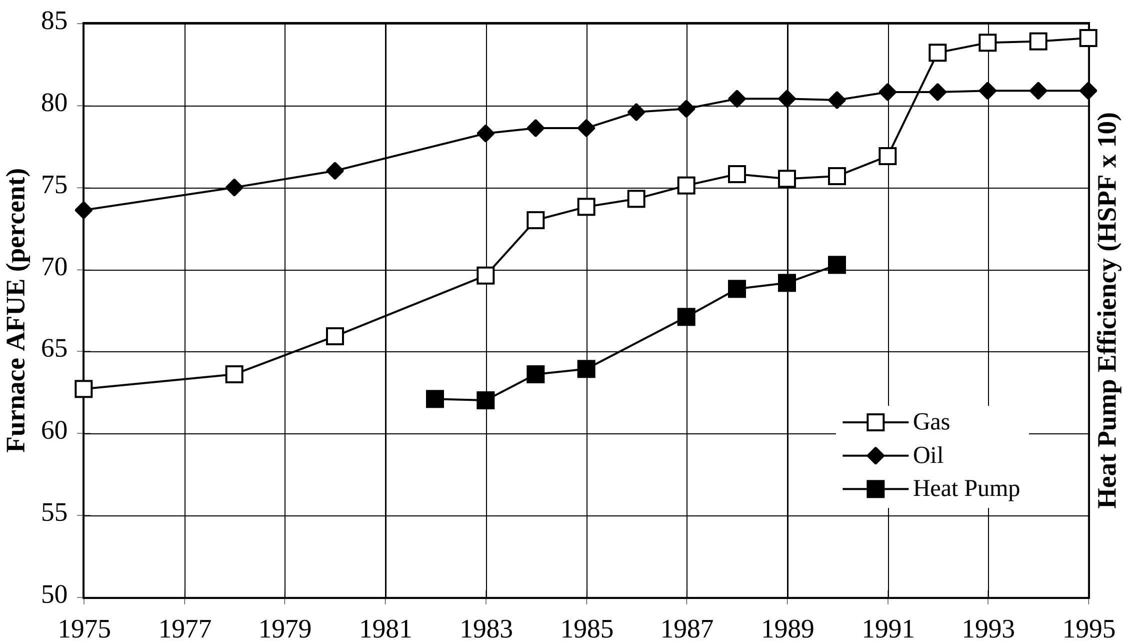
Source: US DOE 1982a, 1986, 1989a, 1993a, 1995a; LBNL-REM 1996.

Figure 3.11. Annual Residential Furnace and Heat Pump Shipments, 1951-1995



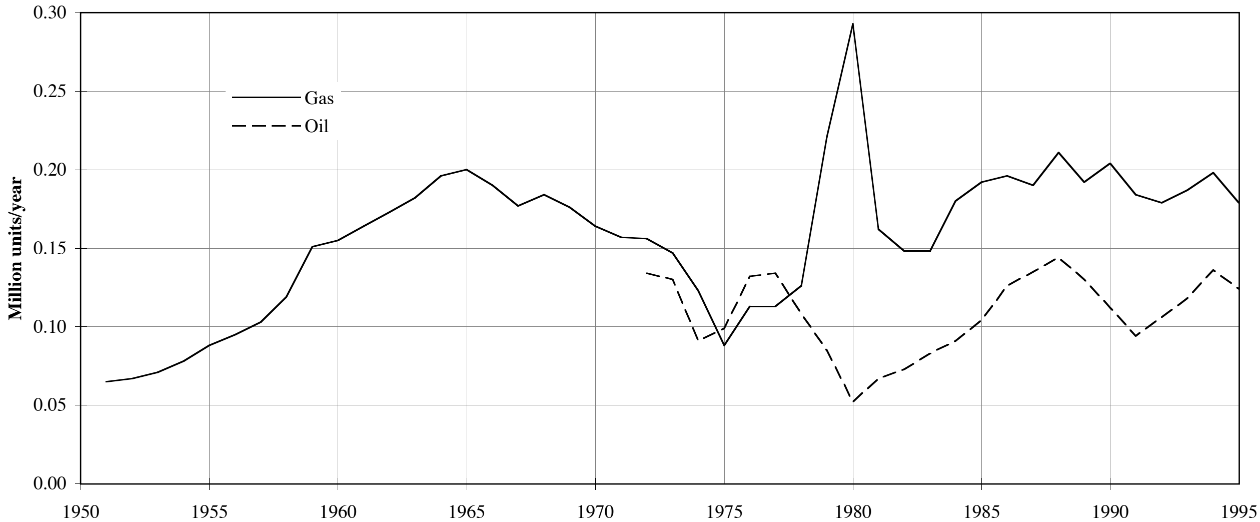
Source: Fechtel et al. 1980, LBLREM 1991, GAMA 1996 for Furnaces (not adjusted for imports, exports or non-residential uses); ARI 1991 for Heat Pumps (1991-95 based on 1986-90 residential share of 1991-95 total).

Figure 3.12. Shipment-Weighted Efficiencies for Residential Furnaces and Heat Pumps, 1975-1995



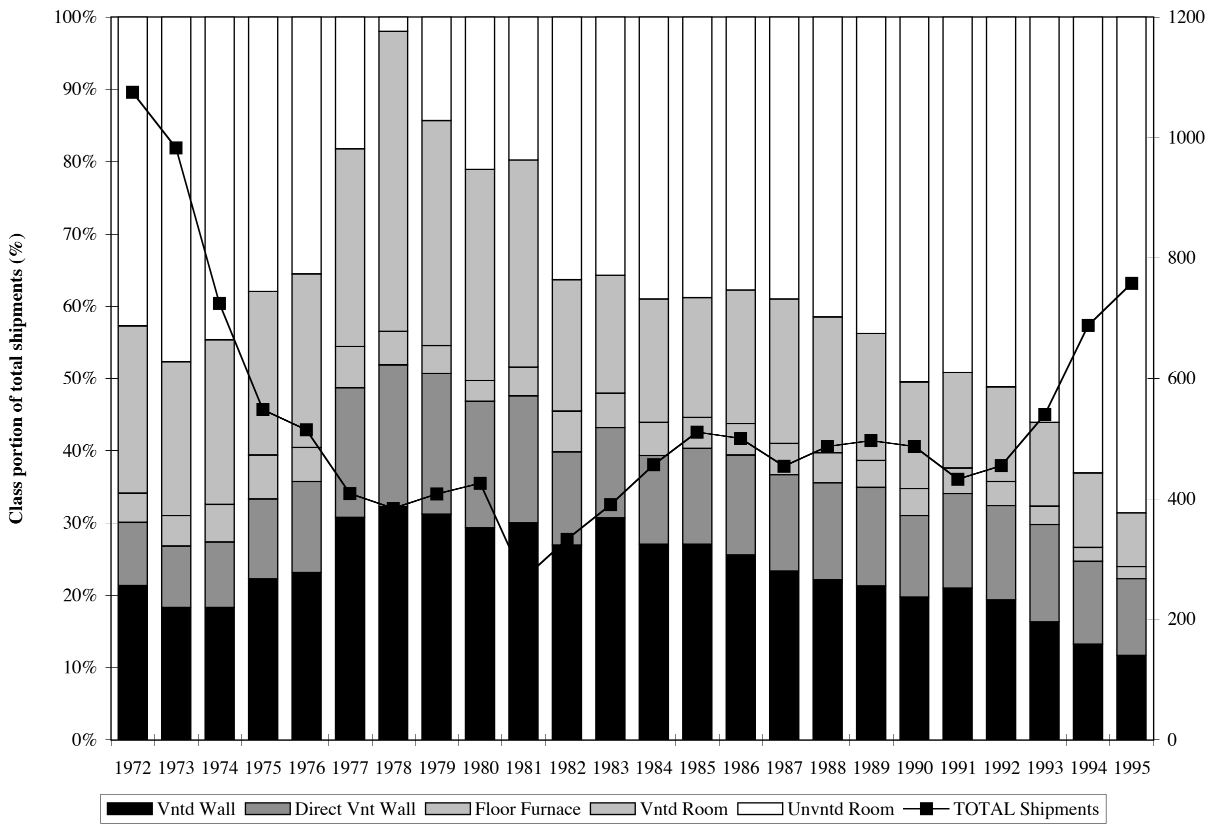
Source: US DOE 1982b; LBNL calculations from ACHR News 1996 for Furnaces; ARI 1991 for Heat Pumps; Electric Furnaces assumed to be 100% efficient.

Figure 3.13. Annual Boiler Shipments for Residential Size Boilers, 1951-1995



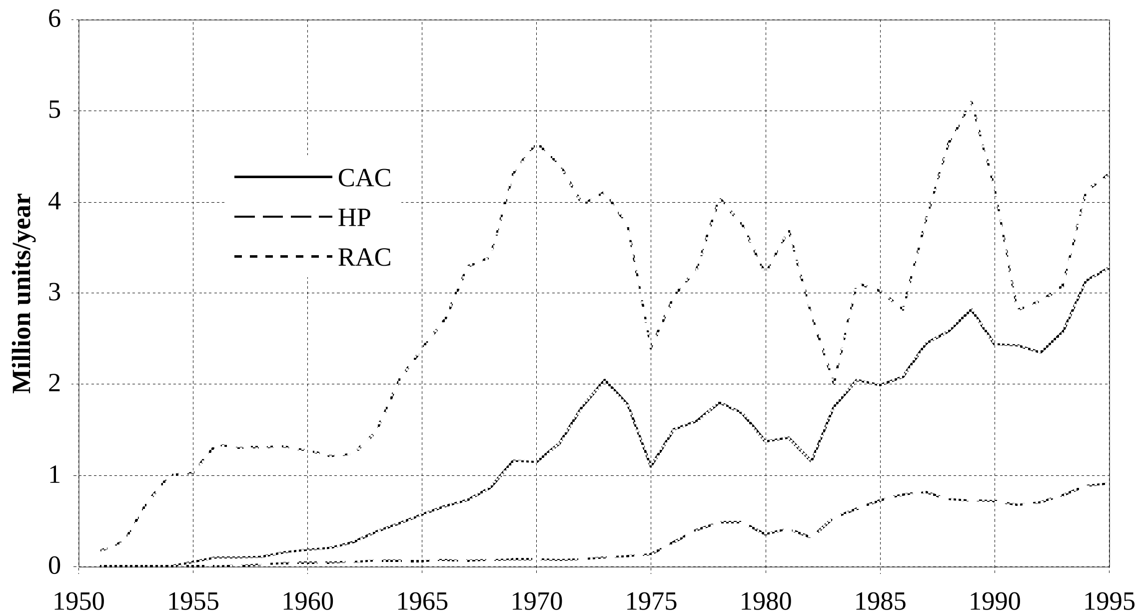
Source: GAMA 1996; Fechtel et al. 1980.
Residential size defined as up to 300 kBtu per hour. Shipments not adjusted for imports, exports, or non-residential uses.

Figure 3.14. Shipments of Direct Heating Equipment for Gas and LPG



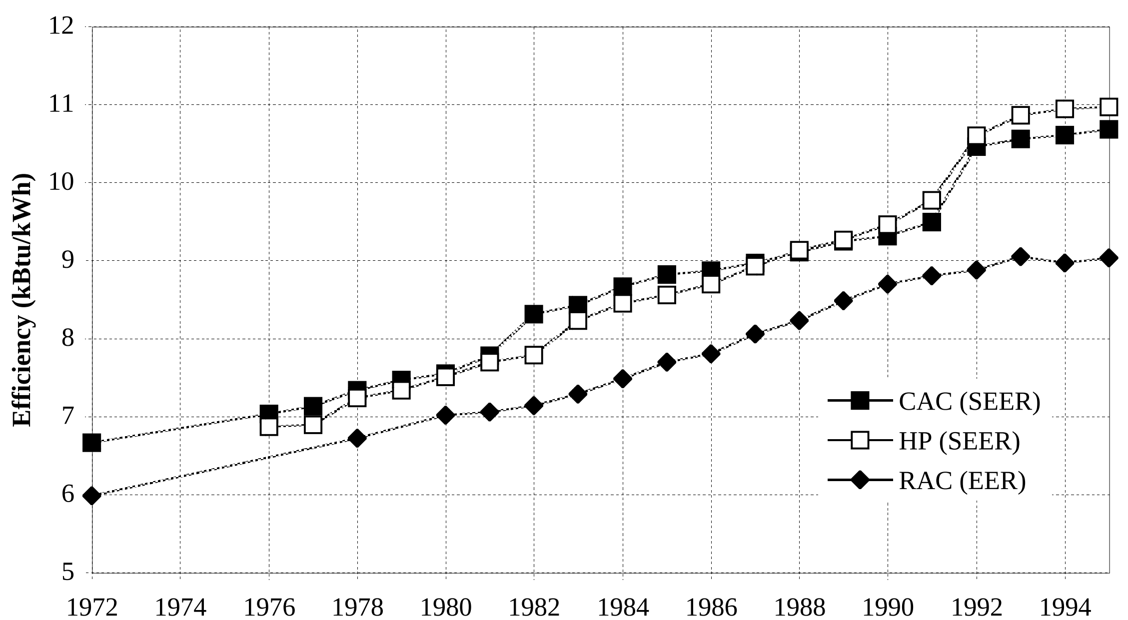
Note: Legend items read from left to right correspond on a one-to-one basis with columns read from bottom to top.
Source: GAMA 1996.

Figure 3.15. Annual Residential Cooling Equipment Shipments, 1951-1995



Source: ARI 1996 (CAC and HP); AHAM 1996; Fechtel et al. 1980 (RAC). CAC and HP shipments exclude imports, exports and non-residential uses (post-90 data extrapolated from 86-90). Data are for CACs of <65 kBtuh and HPs of <65 kBtuh.

Figure 3.16. Shipment-Weighted Efficiencies for Cooling Equipment, 1972-1995



Source: ARI 1996 (CAC and HP); AHAM 1996 (RAC). CAC and HP efficiencies not adjusted for imports, exports or non-residential uses. Prior to 1981, CAC and HP ratings are EER, not SEER.

Distribution System Efficiency

Over the last decade heating and cooling distribution systems have been shown to be major sources of inefficiency in overall heating and cooling performance in residential buildings (Modera 1993). The inefficiency was found in both air distribution through ducting systems and hydronic distribution through piping. Inefficiencies in ducts occur through several paths: 1) air leakage resulting in conditioned air being lost from the supply ducts and unconditioned air entering the return ducts; 2) conduction of heat through the duct wals; 3) excess air infiltration caused by unbalanced supply and return air flows to zones; and 4) poor equipment efficiency due to reduced air flow and increased loads. Thus, duct system performance is based on the quality of the construction in addition to the duct location and design.

Andrews and Modera (1991) estimate that ducts in unconditioned spaces (e.g. attics and crawl spaces) are 70% efficient, and ducts in partially conditioned spaces (e.g. basements) are 80% efficient since not all of the energy lost by ducts is wasted when the ducts are in partially conditioned spaces. About one-half of the heat losses in ducts are attributable to air leakage, and half are due to conduction. They also estimate that hydronic systems are typically 90% efficient in single-family buildings and approximately 70% efficient in multi-family buildings.

Modera (1993) estimates that distribution system performance in new construction is of the same level as that in existing buildings. Proctor (1992a) suggests that in California, at least, air distribution system performance may actually be worse in new buildings than in existing buildings due to poor construction quality. We assume that existing and new distribution systems have the same performance characteristics.

We set distribution system efficiency for forced air systems at 80% in the North region, where basements are the predominant foundation type and thus the most likely location for duct systems, and 70% in the South region where crawl spaces and attics are the most likely location for duct systems. For hydronic systems, we use a baseline efficiency of 90% for all locations (hydronic systems are typically in partly-conditioned spaces). These data are specified in the cost vs. efficiency database for distribution systems, described below, and are assumed to be applicable for both existing buildings and new construction.

Cost vs. Efficiency and Cost vs. Capacity for Equipment and Distribution Systems in Single-Family Homes

We developed coefficients that can be used to estimate the installed cost of heating and cooling equipment, based on several sources: typical unit costs and the cost vs. heating or cooling capacity found in the MEANS construction estimator (1992), and cost vs. efficiency data from an analysis of energy conservation potential for new equipment (ADM 1987). The coefficients that are used in the equation are shown in Table 3.3.

Table 3.4 provides estimates of distribution system costs. These are based on typical systems from the MEANS construction estimator. In addition, we also include variations in the system cost based on the thermal efficiency of the system. The cost/efficiency data is based on Andrews and Modera (1991) estimates of efficiency for different types of construction, costs for insulation from MEANS (1992), and costs for duct leak sealing from Proctor (1992b).

Table 3.3. Parameters for New Single-Family HVAC Equipment Cost Functions

End-use	Technology		Fuel		Base Cost ($1990)	Base Capacity (Output) (kBtu/hr)	Base Efficiency	Efficiency Units	Cost Slope ($/kBtuh)	Efficiency Elasticity
Heating	Furnace	FRN	Electric	E	1165	65	100	AFUE	7.6	n/a
Heating	Furnace	FRN	Gas	G	1280	80	77.2	AFUE	7.9	1.44
Heating	Furnace	FRN	Oil	O	1837	100	80.3	AFUE	7.4	3.91
Heating	Hydronic	H2O	Gas	G	2102	120	79.6	AFUE	8.1	2.73
Heating	Hydronic	H2O	Oil	O	2735	120	84.6	AFUE	9.1	3.14
Heating	Room	RM	Electric	E	1085	20	100	AFUE	35.8	n/a
Heating	Room	RM	Gas	G	822	30	70.0	AFUE	14.8	0.15
Heating	Room	RM	Oil	O	1837	100	75.0	AFUE	7.4	1.95
Cooling	Central Air	CAC	Electric	E	2097	36	9.24	SEER	31.8	0.76
Cooling	Heat Pump	HP	Electric	E	3449	36	9.41	SEER	60.0	0.46
Cooling	Room AC	RAC	Electric	E	522	12	8.73	EER	27.9	1.50

The Purchase Cost of Equipment is a function of Capacity and Efficiency according to the following equation:

Cost = (b + m*[C-C1])*(E/E1)^eff

where:

b = Cost at Base Capacity and Efficiency ($)
m = Cost Slope ($/kBtu/hr)
C = Equipment Capacity (Output, kBtu/hr)
C1 = Base Capacity (Output, kBtu/hr)
E = Equipment Efficiency
E1 = Base Efficiency
eff = Elasticity of cost with respect to efficiency

(1) Heat pump (HP) costs are based on data for split systems. Hydronic (H2O) costs are based on data for hot water boilers. Electric room (E RM) costs are based on data for electric baseboards, with increasing capacity from adding additional baseboards.
(2) Base cost, capacity, and cost vs. capacity relationship from MEANS 1992 residential cost data (MEANS 1992). Converted to 1990$ using the producer price index. Costs include installation but not thermal distribution system.
(3) Cost vs efficiency relationship from ADM 1987. Converted to 1990$ using the producer price index.
(4) Base efficiency and capacity are not necessarily the typical efficiency and capacity of current units, and are only used as a reference point for cost purposes.
(5) HP base unit HSPF is 7, and HP base unit heating capacity is 36 kBtuh. To first approximation, HSPF and heating capacity scale more or less linearly with their cooling counterparts.

Valid Ranges for Equipment Cost Functions

End-use	System	Technology	Heating Fuel	Output Capacity (kBtuh) Lower	Output Capacity (kBtuh) Upper	Efficiency Lower	Efficiency Upper	Efficiency Units
Heating	Forced Air	Furnace	Electric	30	131	n/a	n/a	n/a
Heating	Forced Air	Furnace	Gas	42	160	62	92	AFUE
Heating	Forced Air	Furnace	Oil	55	200	80	91	AFUE
Heating	Hydronic	HW Boiler	Gas	80	203	68	90	AFUE
Heating	Hydronic	HW Boiler	Oil	109	236	82	89	AFUE
Heating	Room	Baseboard	Electric	8	38	n/a	n/a	n/a
Heating	Room	Furnace	Gas	18	50	73	80	AFUE
Heating	Room	Heater	Oil	24	94	64	87	AFUE
Cooling	Forced Air	Central Air	Electric	24	60	7.0	14.1	SEER
Cooling	Forced Air	Heat Pump	Electric	18	60	6.8	14.7	SEER
Cooling	Room	Room Air	Electric	6	21	9.3	13.5	EER

Table 3.4. Distribution System Cost, Size, and Efficiency Relationships for Single-Family Housing

Single-Family Distribution System Description	Incremental Insulation Level (R-val)	Incremental Insulation Cost (1990$)	Air Leakage Sealing Level (% sealed)	Air Leakage Sealing Cost (1990$)	Total Cost (1990$)	Total Cost/ Floor Area (1990$/ sqft)	Increm. Cost/ Floor Slope ($/sqft)	Efficiency by System Location: Uncon-ditioned Space	Efficiency by System Location: Partly Cond. Space
FORCED AIR DUCTING									
Base Case	R0	0	0%	0	2361	1.35	0.97	0.70	0.80
65% Tighter	R0	0	65%	300	2661	1.52	0.97	0.78	0.84
R5-8, 65% Tighter	R6	798	65%	300	3459	1.98	1.47	0.84	0.87
R12, 80% Tighter	R12	1596	80%	400	4357	2.49	1.47	0.96	0.98
HYDRONIC PIPING SYSTEM									
Base Case	R0	0	n/a	n/a	3591	2.05	1.52	n/a	0.90
Insulated Piping	insulated	627	n/a	n/a	4218	2.41	1.63	n/a	0.95

Notes: Costs are installed costs to consumer including all contractor markups.
Base costs calculated for 1750 square foot house.
Unconditioned spaces include attics and crawl spaces.
Partly conditioned spaces are basements.
Forced air (duct) data primarily derived from single family construction data.

Source: Base case efficiencies for forced air systems from Modera 1993, Treidler and Modera 1993, and Jansky and Modera 1994.
Base case efficiencies for hydronic systems from Andrews and Modera 1991.
Savings estimates from Andrews and Modera 1991. We calculate efficiency from their energy savings data as efficiency = base efficiency/(1-savings (%)).
Duct leak repair costs from Proctor 1992b, $300 ($200 labor, $100 materials) for 65% tighter duct system. We assume 80% tighter than the base can be achieved using the aerosol duct sealing method described in Modera et al 1996. We assume 5.5 hours of labor at $70/hour, plus $15 for materials, for a total cost of $400. More discussion and analysis of this method can be found in Modera and Jump 1994, Lucas et al 1995, Modera and Triedler 1995, Consol 1996, Jump et al 1996, Modera et al 1996, Triedler et al 1996, Triedler and Modera 1996.
Duct insulation costs estimated at $798 for R5-8 from MEANS 1992 for 1750 sqft house.
Piping insulation estimated at $627 from MEANS 1992 for 1750 sqft house.

Product Lifetimes

Several sources give estimated lifetimes of heating and cooling equipment, as shown in Tables 3.5 and 3.6.

Table 3.5. Estimates of Residential Heating Equipment Lifetimes

Source		Heat Pump	Gas Furnace	Oil Furnace	Electric Furnace	Gas Boiler	Oil Boiler	Gas Room Heater
		Lifetime in Years						
Appliance*	Low	8	13	11	13	13	12	13
	Avg	13	18	16	17	17	15	16
	High	18	24	20	20	22	19	20
ASHRAE	Median	n/a	18	18	n/a	30	30	n/a
Lewis/Clark	Low	10	15	15	20	20	20	15
	Point	12	18	17	20	20	20	18
	High	15	20	20	25	25	25	20
LBNL/REM	Low	7	14	15	18	n/a	n/a	10
	Avg	15	19	20	23	n/a	n/a	15
	High	19	25	25	29	n/a	n/a	20

*Heat pump and furnace lifetimes from Appliance 1996;
boiler and room heater lifetimes from Appliance 1992.
Sources: Appliance 1992, 1996 (first owner lifetime only); ASHRAE 1987; Lewis and Clarke 1990; LBNL-REM 1991.

Table 3.6. Estimates of Residential Cooling Equipment Lifetimes

Source		Room Air Cond.	Central Air Cond.	Heat Pump
		Lifetime in Years		
Appliance	Low	6	10	8
	Avg	10	14	13
	High	14	19	18
ASHRAE	Median	10	15	n/a
Lewis/Clarke	Low	10	11	10
	Point	11	14	12
	High	15	16	15
LBNL/REM	Low	9	7	7
	Avg	13	15	15
	High	16	19	19

Sources: Appliance 1996 (first owner lifetime only); ASHRAE 1987; Lewis and Clarke 1990; LBNL-REM from Fechtel et al 1980.

3.3. Technology Data for Shell Measures

We developed costs for various levels of efficiency of the major building heat loss and heat gain components. The costs for new buildings are the incremental costs from a certain base case level, and represent the incremental costs at the time of original construction. For existing buildings (or retrofit cases) we only have costs for single-family buildings.

We developed a series of cost estimates, both as national averages and by regions, based on data from NAHB (NAHB 1986). These estimates include shell measure costs for new single-family, multi-family, and manufactured home building types on a cost per square foot of component basis for roofs, walls, underfloor insulation, and windows; cost per linear foot of foundation for slab and heated basement foundations, and a cost per house basis for infiltration measures. Using the forecasting prototypes, these costs can be converted into cost per floor area data. The costs for new single-family buildings are shown in Table 3.7.

We developed retrofit measure costs derived from previous LBNL work which relied on a variety of regional studies of building retrofit costs (Boghosian 1991). These costs are available for single-family building types only. The cost units are the same as for new buildings. These data are provided by region and as national averages, and are shown in Table 3.8.

3.4. Fuel and Equipment Market Shares

Market shares of heating and cooling equipment are included in the sourcebook in two places. First, market shares of heating and cooling equipment by region and for the national average are included in the appliance market shares section. Second, we have constructed a data set which estimates HVAC system type market shares (combinations of heating and cooling equipment) for both existing buildings and new construction in 1990. The primary sources used for these data are RECS (US DOE 1982a, 1986, 1989a, 1993b, 1995b) and the U.S. Census Bureau Current Construction Reports, Series C25 (US Bureau of the Census 1996).

Stock Market Shares

Market shares of main heating fuels and cooling equipment in the existing building stock are taken from the RECS data sets by building type and region (US DOE 1982a, 1986, 1989a, 1993b, 1995b). We also use HVAC system market shares for existing buildings from the 1990 RECS data (US DOE 1995b). We present some of these data in a series of figures that follow.

Figure 3.17 shows the heating fuel market shares for 1981 through 1993. The data highlight the slowness of changes in housing stock for a major element such as fuel market shares. Figure 3.18 shows the breakdown of fuel and equipment market shares for the year 1993 on a national level. It shows that central gas furnaces are the heating technology of choice for almost 40% of the residential sector. Heat pumps comprise only about 8% of the heating systems; there are more than twice as many electric resistance heaters (EFRN and ERM) than heat pumps.

Table 3.7. Shell Measure Costs for New Single-Family Buildings

Level	Component Unit Cost (1990$) North Region	Component Unit Cost (1990$) South Region	Component Unit Cost (1990$) US Region	Cost/sqft of Conditioned Floor Area ($1990/sqft) for different prototypes: North Region 1 Story	North Region 2 Story	South Region 1 Story	South Region 2 Story	US Region 1 Story	US Region 2 Story
Roof Insulation (per sqft of Roof)									
R0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R11	0.35	0.31	0.33	0.35	0.17	0.31	0.15	0.33	0.16
R19	0.49	0.46	0.47	0.49	0.24	0.46	0.23	0.47	0.24
R30	0.67	0.64	0.65	0.67	0.33	0.64	0.32	0.65	0.33
R38	0.83	0.84	0.83	0.83	0.41	0.84	0.42	0.83	0.42
R49	1.04	1.02	1.03	1.04	0.52	1.02	0.51	1.03	0.51
R60	1.22	1.21	1.21	1.22	0.61	1.21	0.61	1.21	0.61
Wall Insulation (per sqft of Net Wall)									
R0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R11	0.38	0.37	0.38	0.29	0.33	0.27	0.31	0.28	0.32
R19	0.64	0.62	0.63	0.48	0.55	0.46	0.53	0.47	0.54
R27	1.39	1.39	1.39	1.03	1.18	1.03	1.18	1.03	1.18
Floor Insulation (per sqft of Foundation)									
R0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R11	0.42	0.39	0.41	0.42	0.21	0.39	0.19	0.41	0.20
R19	0.65	0.60	0.63	0.65	0.32	0.60	0.30	0.63	0.31
R30	0.80	0.73	0.77	0.80	0.40	0.73	0.36	0.77	0.39
Slab Insulation (per lin. ft of Foundation)									
R0	n/a	0.00	0.00	n/a	n/a	0.00	0.00	0.00	0.00
R5 2ft	n/a	2.66	2.66	n/a	n/a	0.29	0.15	0.29	0.15
R10 4ft	n/a	6.85	6.85	n/a	n/a	0.74	0.38	0.74	0.38
Infiltration Reduction (per House)									
0.7 ach	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.4 ach	592	560	575	0.38	0.26	0.36	0.25	0.37	0.26
Windows (per sqft of Window)									
1 Pane	0.00	0.00	0.00	0.00		0.00		0.00	
2 Pane	4.07	3.55	3.84	0.49		0.43		0.46	
2 Pane w/ LowE	6.13	5.34	5.78	0.74		0.64		0.69	
2 Pane w/ LowE and Argon fill	6.77	5.90	6.38	0.81		0.71		0.77	
2 Pane w/ LowE, Spect. Select.	6.72	5.85	6.32	0.81		0.70		0.76	
Superwindow	9.42	8.21	8.87	1.13		0.99		1.06	
Heat Mirror	9.70	8.45	9.14	1.16		1.01		1.10	

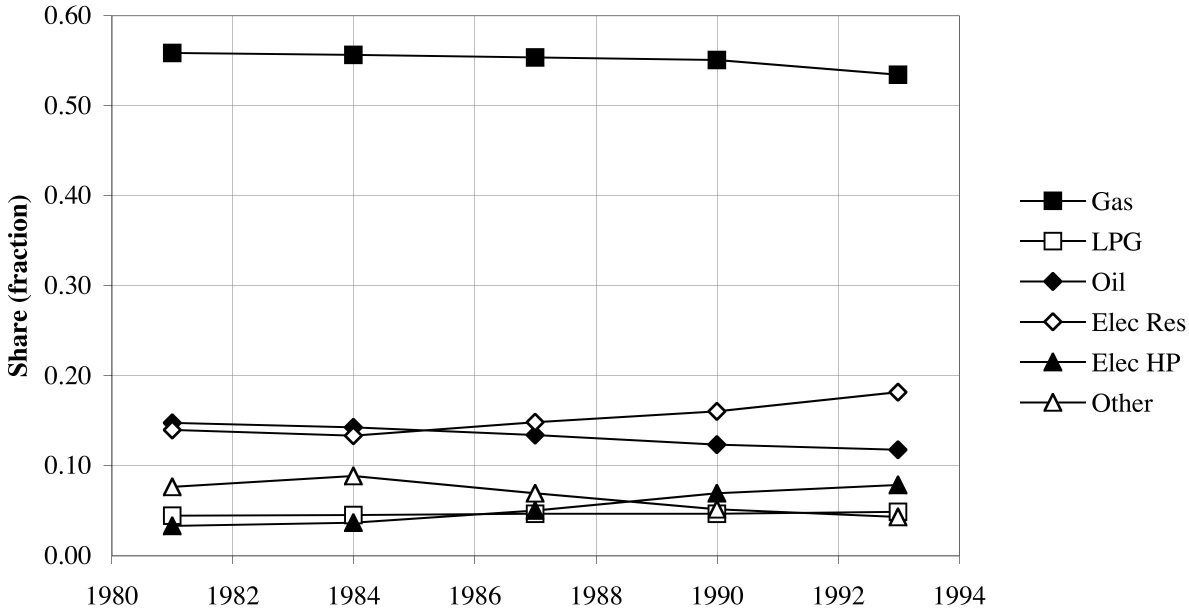
Sources: 1) Insulation and infiltration measures from Koomey et al. 1991b. Data originally from NAHB 1986. Adjusted to Regional costs using MEANS 1989 data. Adjusted from $1988 to $1990 using CPI inflator of 1.102.
2) Window measure costs from Koomey et al. 1994a. Costs for base windows taken from NAHB 1986. Costs premia for other window technologies from Eley Associates 1991. Adjusted to Regional costs using MEANS 1989 data. Adjusted from $1989 to $1990 using CPI inflator of 1.054. Costs shown are incremental window costs for wood-framed windows.
3) Two Story Prototype: 2240 sqft, dimensions 28x40 ft, window area = 12% of floor area. One Story Prototype: 1540 sqft, dimensions 28x55 ft, window area = 12% of floor area.

Table 3.8. Shell Measure Costs for Existing Single-Family Buildings (Retrofit Costs)

	Component Unit Cost (1990$)			Cost/sqft of Conditioned Floor Area ($1990/sqft) for different prototypes					
	North	South	US	North Region		South Region		US Region	
Level	Region	Region	Region	1 Story	2 Story	1 Story	2 Story	1 Story	2 Story
Roof Insulation (per sqft of Roof)									
add R8	0.49	0.42	0.46	0.49	0.25	0.42	0.21	0.46	0.23
add R11	0.49	0.42	0.46	0.49	0.25	0.42	0.21	0.46	0.23
add R19	0.49	0.42	0.46	0.49	0.25	0.42	0.21	0.46	0.23
add R27	0.57	0.49	0.53	0.57	0.29	0.49	0.25	0.53	0.27
add R30	0.65	0.56	0.61	0.65	0.33	0.56	0.28	0.61	0.30
add R38	0.93	0.80	0.87	0.93	0.47	0.80	0.40	0.87	0.44
add R49	1.26	1.09	1.18	1.26	0.63	1.09	0.54	1.18	0.59
add R60	1.47	1.27	1.38	1.47	0.74	1.27	0.63	1.38	0.69
Wall Insulation (per sqft of Net Wall)									
upgrade to R-11 (blown-in)	0.79	0.68	0.74	0.59	0.67	0.59	0.67	0.55	0.63
add R-5 (exterior sheathing)	1.89	1.63	1.77	1.40	1.61	1.40	1.61	1.32	1.51
Slab Insulation (per lin. ft of Foundation)									
add R5 2ft	13.68	11.79	12.81	1.47	0.83	1.27	0.72	1.38	0.78
add R10 2ft	14.74	12.71	13.81	1.59	0.89	1.37	0.77	1.49	0.84
add R5 4ft	19.19	16.55	17.98	2.07	1.17	1.78	1.00	1.94	1.09
add R10 4ft	21.87	18.85	20.49	2.36	1.33	2.03	1.14	2.21	1.24
Floor Insulation (per sqft of Foundation)									
add R11	0.65	0.56	0.61	0.65	0.33	0.56	0.28	0.61	0.30
add R19	0.85	0.73	0.80	0.85	0.43	0.73	0.37	0.80	0.40
add R30	1.11	0.96	1.04	1.11	0.56	0.96	0.48	1.04	0.52
Infiltration Reduction (per House)									
reduce ACH by 25%	258	223	242	0.17	0.12	0.14	0.10	0.16	0.11
Windows (per sqft of Window)									
1 Pane	13.10	11.41	12.33	1.57	1.57	1.37	1.37	1.48	1.48
2 Pane	17.17	14.96	16.17	2.06	2.06	1.79	1.79	1.94	1.94
2 Pane w/ LowE	19.23	16.75	18.11	2.31	2.31	2.01	2.01	2.17	2.17
2 Pane w/ LowE and Argon fill	19.87	17.31	18.71	2.38	2.38	2.08	2.08	2.25	2.25
2 Pane w/ LowE, Spect. Select.	19.81	17.26	18.66	2.38	2.38	2.07	2.07	2.24	2.24
Superwindow	22.52	19.62	21.21	2.70	2.70	2.35	2.35	2.54	2.54
Heat Mirror	22.80	19.86	21.47	2.74	2.74	2.38	2.38	2.58	2.58

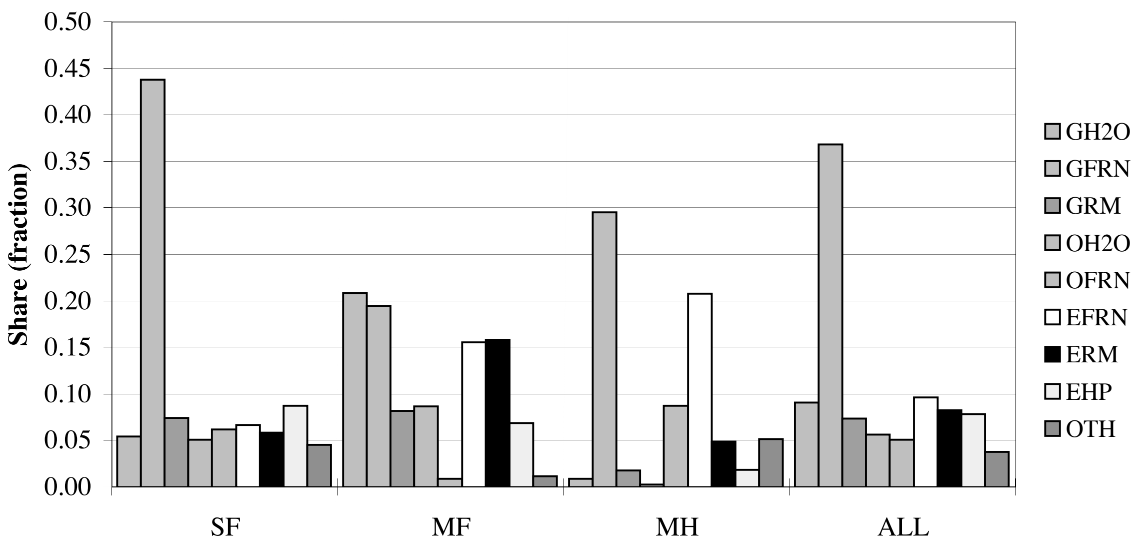
Sources: 1) Insulation and infiltration measures from Boghosian 1991. Adjusted to Regional costs using MEANS 1989 data. Adjusted from $1989 to $1990 using CPI inflator of 1.054.
2) Window measure costs from Koomey et al. 1994a. Costs for base windows taken from NAHB 1986. Costs premia for other window technologies from Eley Associates 1991. Adjusted to Regional costs using MEANS 1989 data. Adjusted from $1989 to $1990 using CPI inflator of 1.054. Costs shown are total window costs. Costs shown are total window costs for wood-framed windows.
3) Two Story Prototype: 2240 sqft, dimensions 28x40 ft, window area = 12% of floor area. One Story Prototype: 1540 sqft, dimensions 28x55 ft, window area = 12% of floor area.

Figure 3.17. Space Heating Fuel Shares in Total Housing Stock, National, 1981-1993



Source: US DOE 1982a, 1986, 1989a, 1993b, 1995b. Oil includes kerosene. Elec Res = electric resistance heating, Elec HP = electric heat pump heating. Other is primarily wood. Values are "primary heating fuel" from US DOE 1982a, 1986, 1989a, 1993b, and 1995b.

Figure 3.18. Space Heating Fuel/Technology Shares by House Type, National, 1993



Legend items read from top to bottom correspond on a one-to-one basis with columns read from left to right.

Source: US DOE 1995b. G = natural gas, O = oil (includes kerosene), E = electricity. Other is primarily wood. H2O = steam or hot water systems, FRN = furnace, RM = room heating. Values are "primary heating fuel" from US DOE 1995b.

Air conditioning market shares have experienced large changes during the last decade. As shown in Figure 3.19, the share of central air conditioning (not including heat pumps) rose from about 22% in 1981 to about 37% of the stock in 1993. Heat pump market shares grew from 3% to 9% over this same period. The percentage of buildings with room air conditioners dropped during this period. Overall, the increasing saturation of cooling has leveled off since 1990 (noted in the figure by the end to the decrease in homes with no cooling equipment). It appears that the increasing saturation of central air and heat pumps is due to conversions of room air and evaporative cooler equipment, rather than installations in homes with no cooling. Figure 3.20 shows that the 1993 market shares for air conditioning are relatively consistent across housing types, except that most multi-family units have no air conditioning, and manufactured homes have a much larger percentage of evaporative coolers.

Figures 3.21, 3.22, and 3.23 show HVAC system market shares (combined heating and cooling) for the three housing types by region and for the national average. These figures highlight: 1) the dominance of the gas furnace/central air conditioning HVAC system in single-family buildings in all regions (23% nationally; slightly less in the north, slightly more in the south); 2) the greater percentage of electrically-heated single- and multi-family homes in the south; 3) the high portion of hydronic heating systems in multi-family buildings in the north (and electric furnace and heat pumps in the south); 4) the use of LPG as a heating fuel in manufactured houses; and 5) greater diversity of system types in multi-family homes, particularly by region.

New Home Market Shares

Market shares of heating and cooling equipment for new buildings are derived from new housing construction data from the Census C25 survey (US Bureau of the Census 1996) and RECS fuel/technology market shares by housetype for new construction (1987 RECS market shares for buildings built between 1980 and 1987, and 1993 RECS market shares for buildings built between 1988 and 1995; US DOE 1989a and 1995b).[1] We have also developed HVAC system market shares using these same data sets. Some of these data are shown in Figures 3.24 through 3.29.

Figures 3.24 and 3.25 show the heating fuel market shares and central air conditioning market shares in new construction for single-family buildings. Figures 3.26 and 3.27 show the same for multi-family, while Figures 3.28 and 3.29 show similar data for manufactured homes (time-series data were not available for manufactured homes, so RECS 1988-93 data are used). The striking observation from these data is the large decrease in the use of electricity as a heating fuel, particularly for electric resistance heating, between 1985 and 1995 (although in recent years the share of electric heating has been increasing in multi-family units). At the same time, the percentage of new buildings with central air conditioning has been rising dramatically, so that 80% of new single-family homes and 70% of new multi-family units have central air conditioning installed at the time of construction.

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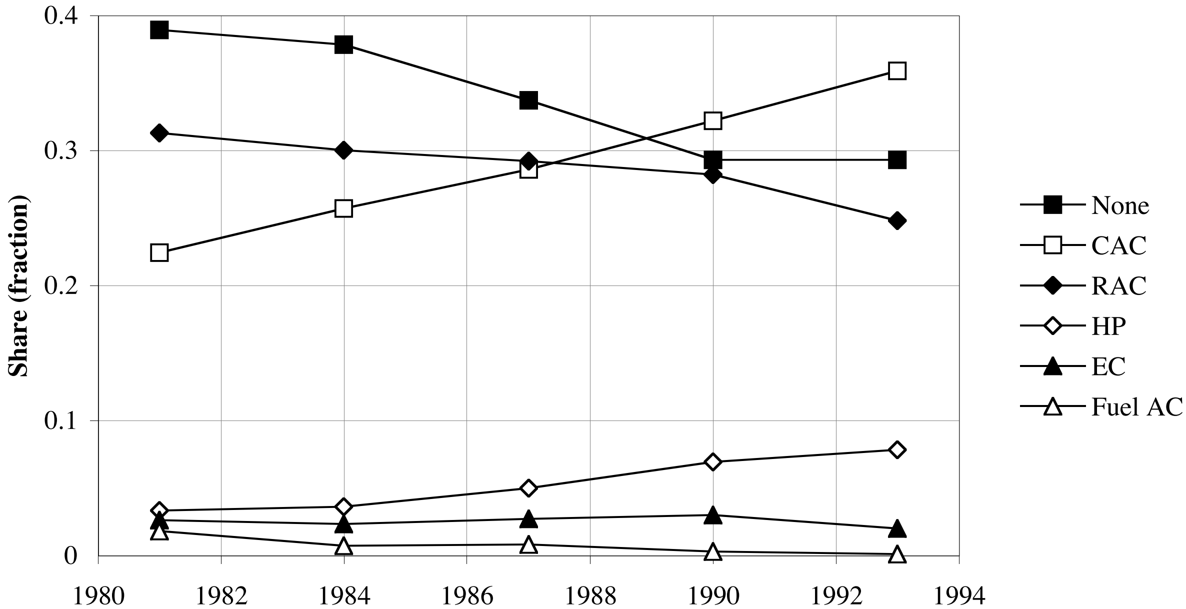
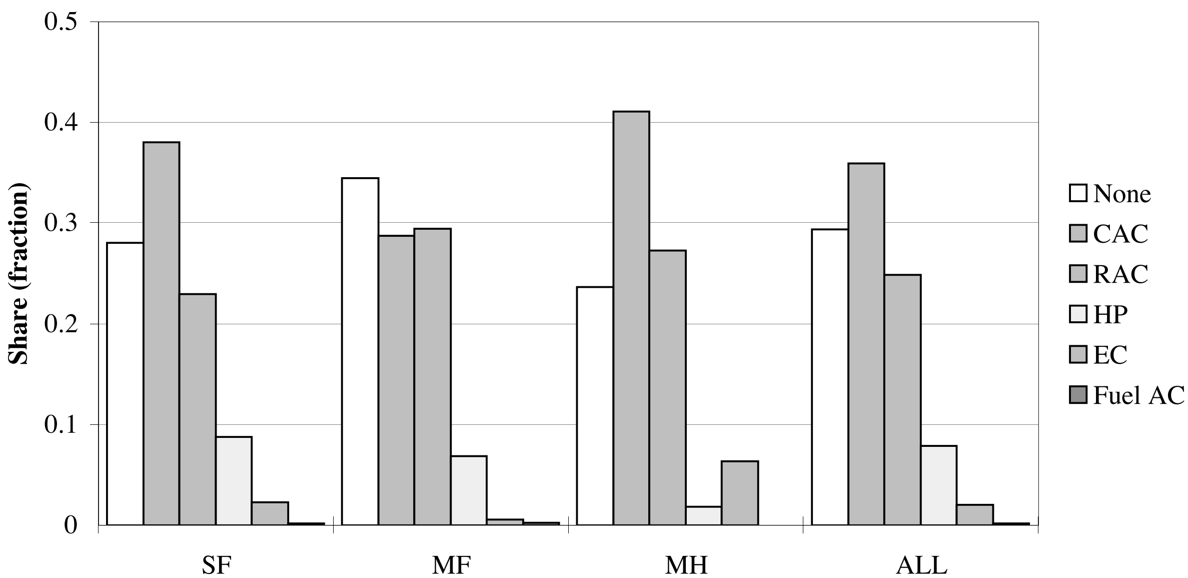
1. Beginning in 1991, C25 reports electric room heating shares in its "other" category. We pulled out estimated electric room heating shares from "other" based on historical trends.

Figure 3.19. Air Conditioning Shares in Total Housing Stock, National, 1981-1993



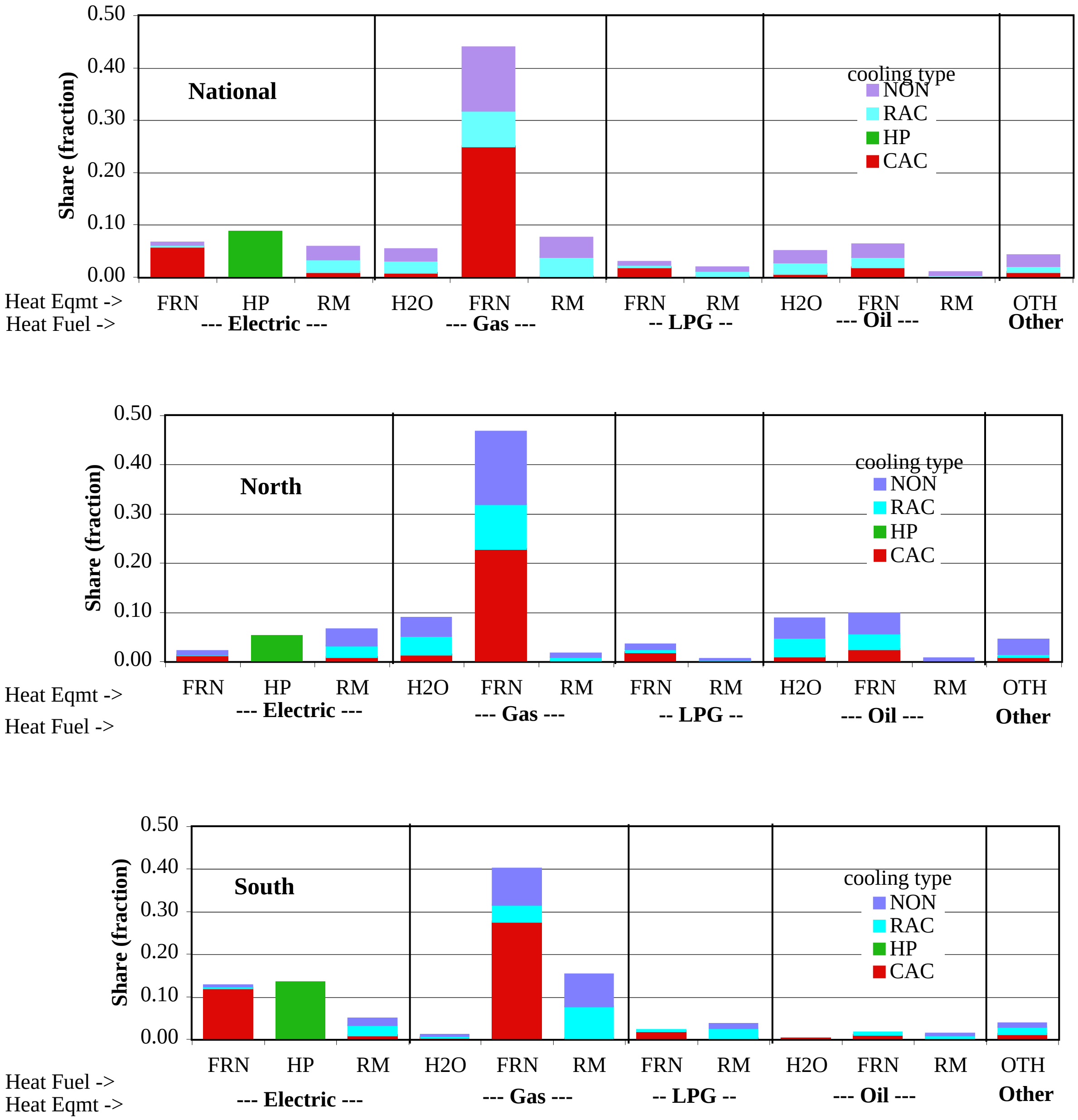
Source: US DOE 1982a, 1986, 1989a, 1993b, 1995b.
CAC = electric central air conditioning, HP = heat pump, RAC = room air conditioning, EC = evaporative cooler, Fuel AC = gas driven air conditioning. In 1993, RAC homes averaged 1.47 units.

Figure 3.20. Air Conditioning Shares in Housing Stock by House Type, National, 1993



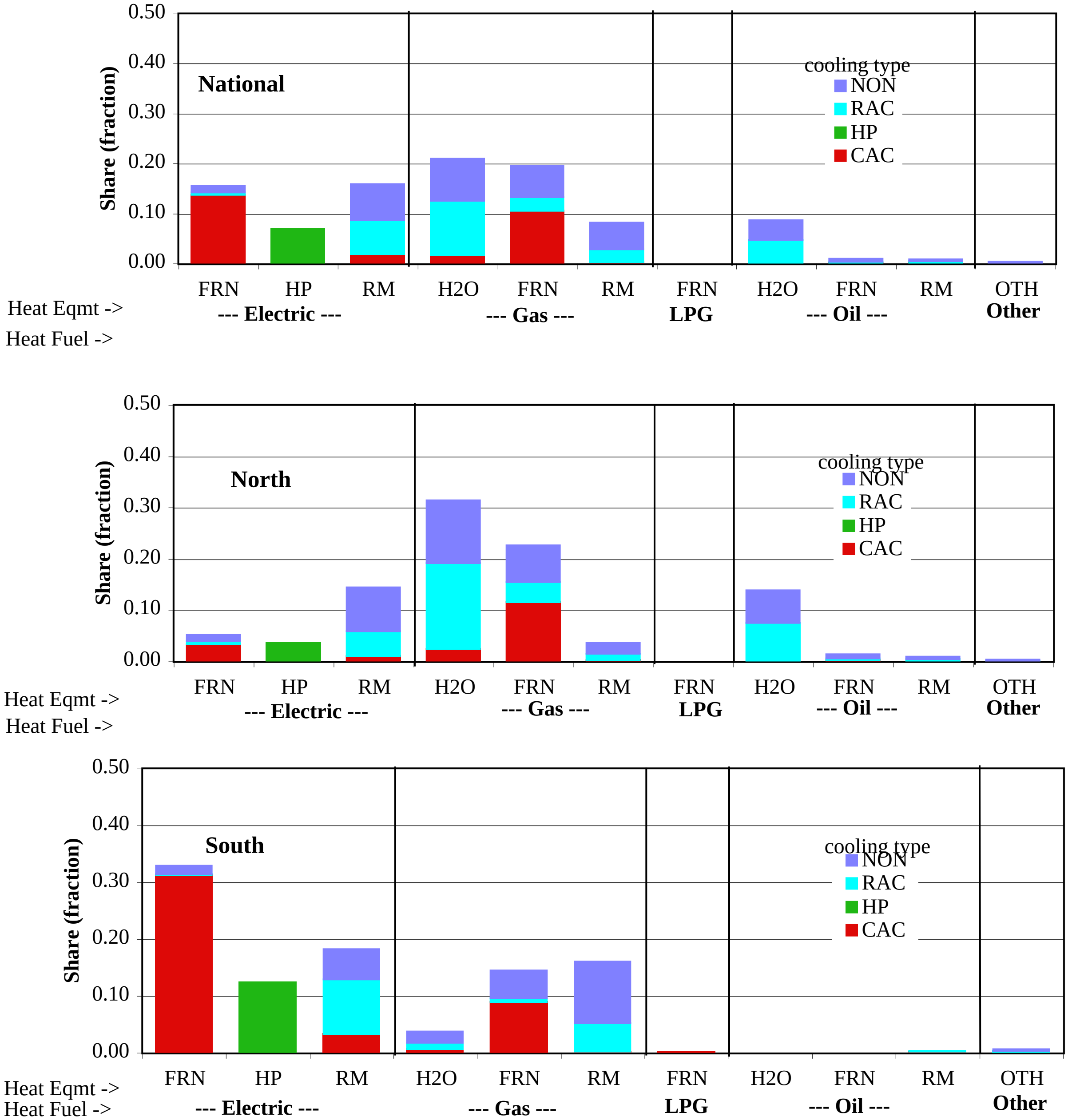
Note: Legend items read from top to bottom correspond on a one-to-one basis with columns read from left to right.
Source: US DOE 1995b.
CAC = electric central air conditioning, HP = heat pump, RAC = room air conditioning, EC = evaporative cooler, Fuel AC = gas driven air conditioning.

Figure 3.21. Existing Stock HVAC System Shares for Single-Family Homes: National and Regional



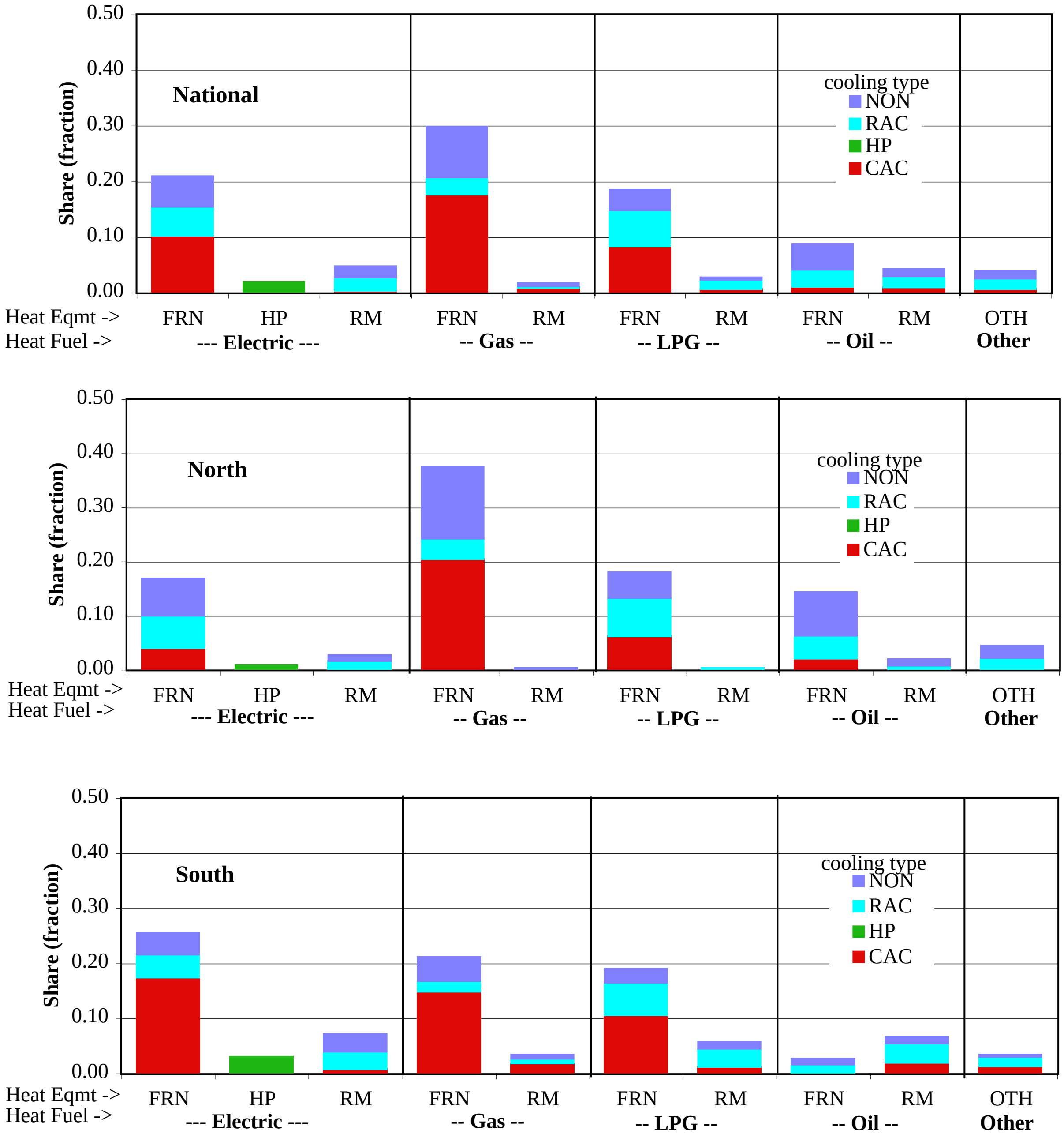
Source: US DOE 1995b. Oil heating fuel category includes kerosene. Other heating fuel is primarily wood. H2O = steam or hot water, FRN = furnace, HP = heat pump, RM = room heating, OTH is all other heating technologies. US DOE 1995b data converted to north and south using census divisions and HDD to approximate the federal region breakdown.

Figure 3.22. Existing Stock HVAC System Shares for Multi-Family Homes: National and Regional



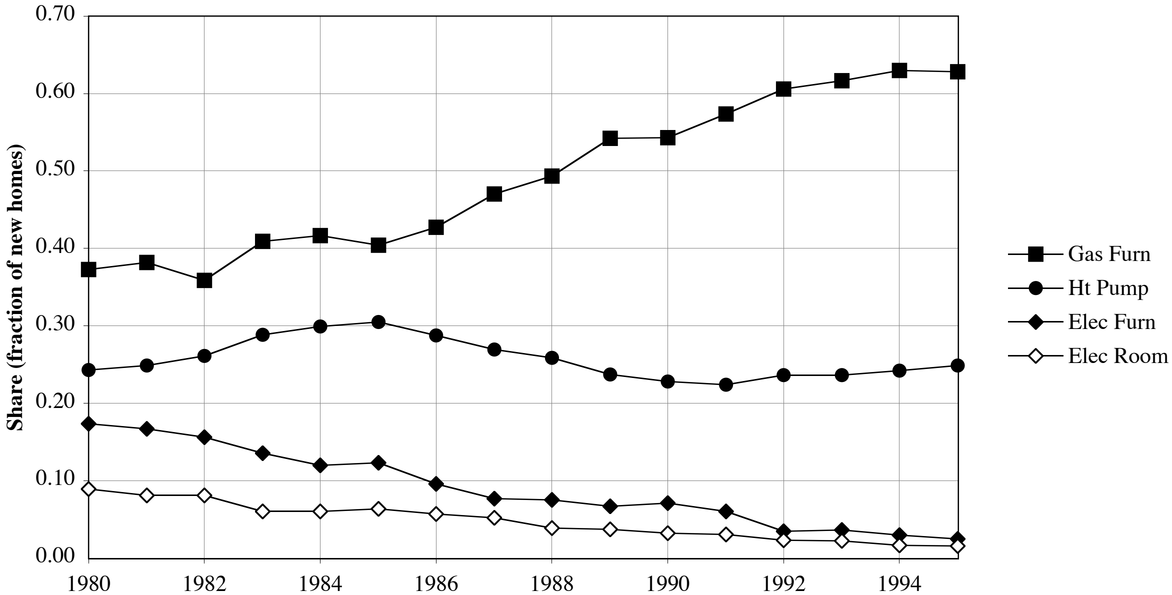
Source: US DOE 1995b. Oil heating fuel includes kerosene. Other heating fuel is primarily wood. H2O = steam or hot water, FRN = furnace, HP = heat pump, RM = room heating, OTH = all other heating technologies. US DOE 1995b data converted to north and south using census divisions and HDD to approximate the federal region breakdown.

Figure 3.23. Existing Stock HVAC System Shares for Manufactured Homes: National and Regional



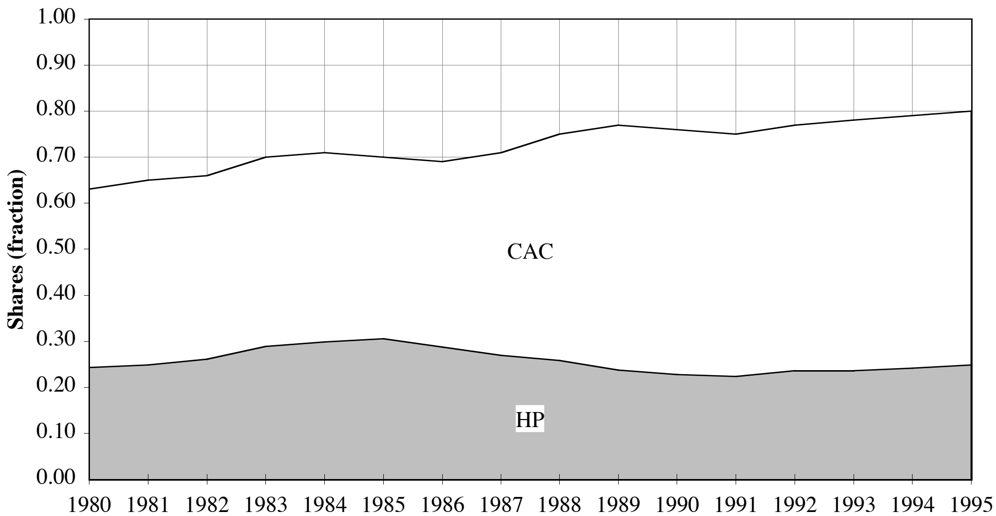
Source: US DOE 1995b. Oil heating fuel category includes kerosene. Other heating fuel is primarily wood. FRN = furnace, HP = heat pump, RM = room heating, OTH is all other heating technologies. US DOE 1995b data converted to north and south using census divisions and HDD to approximate the federal region breakdown.

Figure 3.24. Selected Space Heat Fuel/Technology Shares in New Construction, Single-Family, National



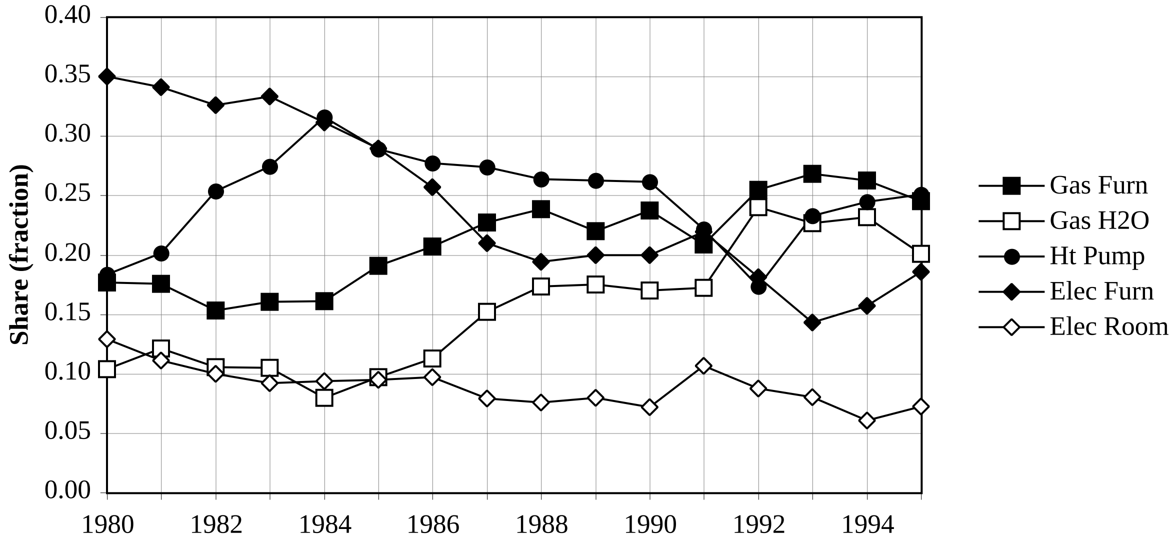
Source: US Bureau of the Census 1996; US DOE 1989a (for 1980-87) and 1995b (for 1988-95).

Figure 3.25. Total Central AC Shares (CAC+HP) in New Construction, Single-Family, National



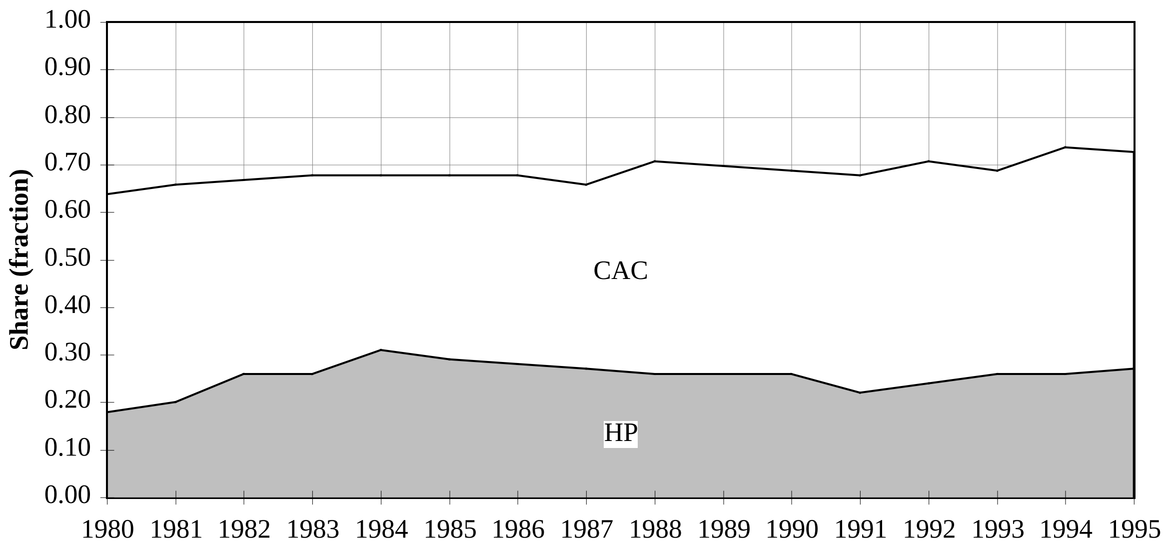
Source: US Bureau of the Census 1996.
HP data is from heating equipment and subtracted from total central AC to get CAC.

Figure 3.26. Selected Space Heat Fuel/Technology Shares in New Construction, Multi-Family, National



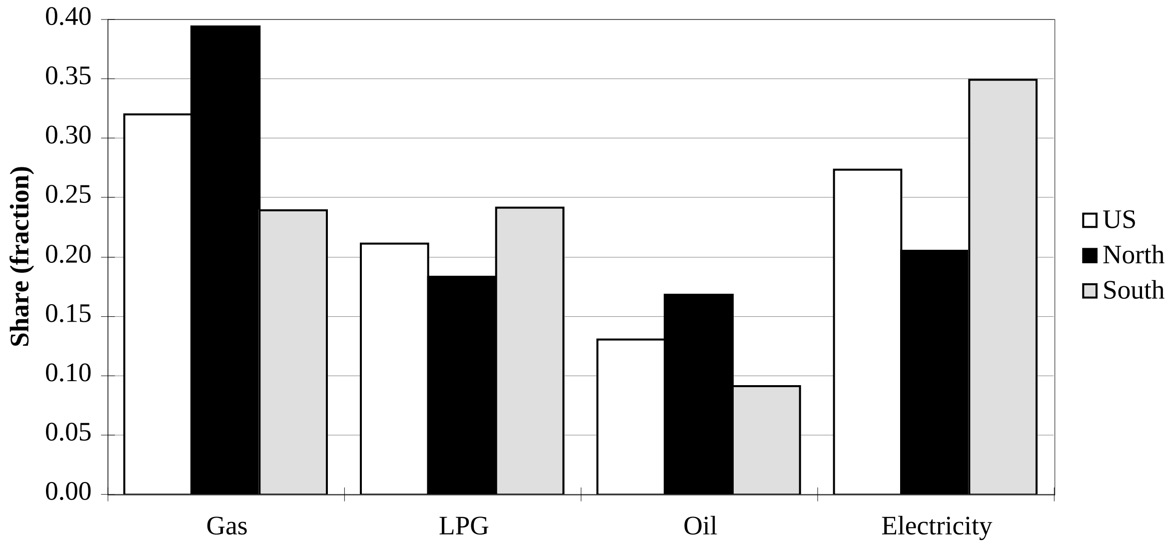
Source: US Bureau of the Census 1996; US DOE 1989a (for 1980-87) and 1995b (for 1988-93).

Figure 3.27. Total Central AC Shares (CAC+HP) in New Construction, Multi-Family, National



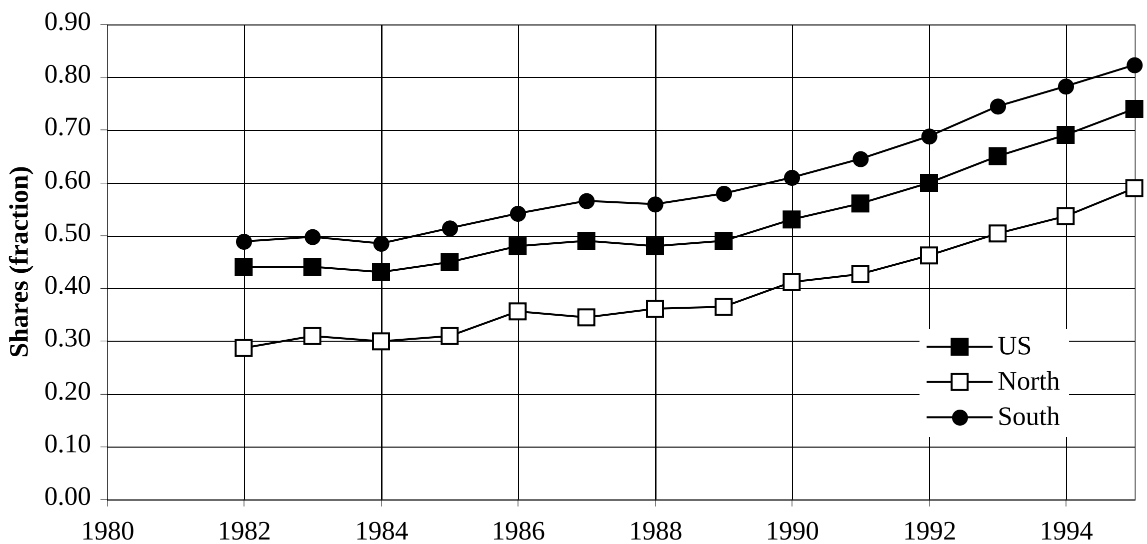
Source: US Bureau of the Census 1996.
HP data is from heating equipment and subtracted from total central AC to get CAC.

Figure 3.28. Space Heating Fuel Shares in New Construction, Manufactured Homes



Source: US DOE 1995 for buildings built 1988-93. Oil includes kerosene.

Figure 3.29. Central Air Conditioning Shares (includes HP) in New Construction, Manufactured Homes



Source: US Bureau of the Census 1996. Census Region data converted to North/South by housing starts by state.

3.5. Forecasting Prototypes

For the analysis of conservation potential from building envelope measures, we use the same methodology and data from the previous version of this report (Hanford et al. 1994). We first define a set of building prototypes that represent the major characteristics of the residential building population. The important parameters include the component areas of the building (roof, wall, floor, etc.) and the thermal characteristics of those components. The prototypes are characterized from data taken from surveys of either the building stock or recently constructed buildings. Once defined, the heating and cooling energy consumption of these buildings can be assessed with improved building components to estimate potential energy savings from improvements to the building envelopes.

We define building prototypes that represent the *existing* building stock and average *new* construction patterns for three building types (single-family, multi-family, and manufactured homes), two regions (North and South), and three different heating fuel types (electric resistance, heat pump, and other fuels (mostly gas)). The specification of different prototypes for different fuels is an attempt on our part to account for the fact that buildings with electric heating, and heat pumps in particular, are generally newer and therefore have greater thermal integrity.

Because the existing building stock includes a diverse building population in terms of age, building size, and insulation levels, we also segmented the prototypes for the existing building stock for single-family and multi-family into older uninsulated ("loose") buildings and newer insulated ("tight") buildings. Each prototype is associated with a particular fraction of the existing stock in that heating fuel category. We call this fraction the "shell share." The population of any specific building prototype is thus the product of total stock, heating fuel share, and shell share.

Existing Single-Family

For existing single-family buildings, we developed prototypes using the 1987 RECS data (US DOE 1989a); later RECS surveys do not provide as detailed information on insulation levels, and so were not used in developing the prototypes. Other existing single-family prototypes have been defined previously by the Gas Research Institute (GRI) (Ritschard et al. 1992b) and by LBNL (Boghosian 1991), but these are not readily usable in the residential energy demand forecasting models at LBNL. The GRI prototypes are highly region-specific (9 census divisions, 16 base cities) and are not related to specific heating or cooling system types. For example, we expect that buildings heated by electricity will, in general, be newer and better insulated than those heated by natural gas or oil. Therefore, we use the RECS data to define the prototypes, supplemented by data from the GRI and LBNL prototypes where the RECS data are either not complete or have missing data for individual houses. Ultimately, the prototypes defined in this work provide similar results in terms of component specifications and baseline heating and cooling loads to those from the other studies, with the advantage of varying by heating system type.

To develop single-family prototypes, we first stratified the RECS data by region, and for each sample building we characterized: 1) thermal parameters based on the RECS data and other estimates (Koomey et al. 1991a, Koomey et al. 1991b, Boghosian 1991, Huang et al. 1987b), 2) conditioned floor areas and number of stories, 3) foundation types, and 4) heating fuel. We then stratified the sample into partially insulated, or "tight", buildings and virtually uninsulated, or "loose" buildings, based on combinations of roof and wall insulation and average number of glazing layers across all windows in the house. Loose buildings are assumed to be easily and cost-effectively insulated, whereas tight buildings are already somewhat insulated. Buildings representing new construction in the period 1987-1990 are added to the data set as "tight" buildings (see the New Single Family prototypes) to fully characterize the housing stock in 1990. Finally, for each heating fuel type and "tight" and "loose" thermal shell package in each region, we calculate the number of buildings represented, average building conditioned floor area, typical foundation type and number of stories, and average component insulation level. The component R-values are converted to U-values, then averaged, and then converted back to R-values to more accurately characterize overall building heat loss. All buildings are assumed to be wood-frame walls and roof systems. The final specifications are given in Table 3.9.

Table 3.9 shows that across the different heating fuels within either the North or South region, the average thermal characteristics of the “tight” prototypes are similar. Note, however, that for electrically heated buildings, both with resistance heat and heat pumps, the “tight” buildings represent a greater portion of the stock than for the fuel heated buildings. The fuel heated buildings tend to be older, and thus, less well insulated.

New Single-Family

The new single-family prototypes for the North and South regions are taken directly from the LBNL electricity conservation supply curve study (Koomey et al. 1991a). These prototypes were originally derived from data in the 1987 National Association of Home Builder Annual Builder Survey (NAHB 1989) as described elsewhere (Koomey et al. 1991b). These buildings are significantly better insulated than the existing buildings, with ceilings up to R30, walls above R11, and double-glazed windows with foundation insulation, yet also have significantly larger conditioned floor areas. The specifications are found in Table 3.9.

Existing and New Multi-Family

Existing and new multi-family prototypes are taken from the GRI multi-family residential database (Ritschard and Huang 1989). The GRI database includes 16 different prototypes defined for four census regions, with three to five prototypes per census region, and simulated in sixteen base cities, with two to five cities per census region. The combination produces 60 different combinations of cities and building prototypes.

For the prototypes defined here, we updated the building populations to 1987 populations based on the RECS data (US DOE 1993b), extrapolated the prototypes to represent the entire sector (as described in Hanford and Huang 1992), and applied heating types to the prototypes. We then segmented the prototypes into North and South regions using the same strategy as for single-family buildings, and averaged the building component areas and thermal values as in the existing single-family analysis.

We also segment two prototypes for existing buildings based on building vintage. The thermal characteristics of the GRI prototypes showed that insulation levels for pre-1980 buildings were significantly different than post-1980 buildings, with pre-1980 buildings being typically uninsulated or not well insulated. Therefore, we create a pre-1980 and post-1980 vintage in the existing stock for each region and heating fuel type. The pre-1980 and post-1980 buildings are similar across heating fuels, but electrically heated buildings generally have a larger proportion of the better insulated buildings than the fuel heated buildings. The post-1980 prototypes are also used as the new multi-family prototypes. This assumes that new multi-family buildings in 1990 are similar to 1980 vintage buildings. The specifications are given in Table 3.10.

Existing and New Manufactured Homes

Existing and new manufactured home prototypes are taken directly from the previous LBNL electricity conservation supply curve study (Koomey et al. 1991a). As with single-family buildings, the new prototypes are better insulated than existing buildings but are larger. These are listed in Table 3.11.

Table 3.9. Building and Thermal Characteristics of Single-Family Building Prototypes

Heat Type	Shell Group	Regional Popln. (% of stock)	Fndn Type	Cond. Floor Area (sqft)	No. of Stories	Roof (R)	Wall (R)	Glazing Layers	Infiltration ELF	Infiltration ACH	Foundation Insulation Floor (R)	Foundation Insulation Perim. Config.
EXISTING BUILDINGS (Population is percent of existing stock in 1990)												
North Region		99.3%										
Electric	Tight	7.2%	Bsmt	1560	1	21	8	2.0	0.00036	0.47	R06	n/a
Electric	Loose	2.1%	Bsmt	1220	1	7	2	1.6	0.00046	0.59	R03	n/a
HPump	Tight	2.1%	Bsmt	1830	2	25	11	2.0	0.00035	0.43	R08	n/a
HPump	Loose	0.1%	Slab	2470	1	11	7	1.0	0.00027	0.36	n/a	R1 for 2'
Fuel	Tight	45.0%	Bsmt	1700	2	22	5	1.9	0.00044	0.57	R06	n/a
Fuel	Loose	42.8%	Bsmt	1420	2	6	1	1.7	0.00059	0.76	R05	n/a
South Region		99.9%										
Electric	Tight	10.3%	Slab	1640	1	19	7	1.4	0.00065	0.67	n/a	R2 for 2'
Electric	Loose	4.2%	Slab	1170	1	6	2	1.3	0.00065	0.67	n/a	R1 for 2'
HPump	Tight	11.0%	Slab	1650	1	21	8	1.7	0.00069	0.70	n/a	R2 for 2'
HPump	Loose	1.8%	Slab	1480	1	6	1	1.2	0.00062	0.64	n/a	R1 for 2'
Fuel	Tight	32.2%	Crawl	1650	1	20	5	1.5	0.00070	0.71	R03	n/a
Fuel	Loose	40.4%	Crawl	1370	1	5	1	1.2	0.00068	0.69	R02	n/a
NEW BUILDINGS (Population is percent of new construction)												
North Region		99%										
Electric	All	8%	Bsmt	1860	2	29	15	2.0	0.00031	0.40	R15	n/a
HPump	All	13%	Bsmt	2220	2	28	14	1.9	0.00031	0.40	R13	n/a
Fuel	All	78%	Bsmt	2180	2	28	14	1.7	0.00044	0.56	R12	n/a
South Region		100%										
Electric	All	13%	Slab	1890	1	28	10	1.5	0.00060	0.62	n/a	R4 for 2'
HPump	All	31%	Slab	1820	1	25	11	1.7	0.00061	0.63	n/a	R2 for 2'
Fuel	All	56%	Slab	2070	1	25	12	1.7	0.00061	0.63	n/a	R2 for 2'

Existing Single Family:
1) Building areas, shell group populations, ceiling R-values and window glazing layers from 1987 RECS data, updated to 1990 populations using new prototypes from Koomey et. al. 1991a. Populations by heating type from US DOE 1992a.
2) Data from Boghosian 1991 and Ritschard et al. 1992a for roof, wall, foundation, and window measures are used where data not available in US DOE 1992a.
3) Breakdown between "Tight" and "Loose" determined approximately as follows (see writeup):
North: "Loose" has roof R-value<10 or wall R-value<4 and average glazing layers<1.7. All others "Tight".
South: "Loose" has roof R-value<10 or wall R-value<4 or wall R-value=<7 and average window layers<1.4.
New Single Family:
4) Prototype descriptions from Koomey et al. 1991b, as presented in Koomey et al. 1991a. Original data source is the 1987 NAHB Builders Survey data (NAHB 1989). Populations by heating type from US Bureau of the Census 1990 series heating fuel shares in new construction.
Existing and New:
5) Window area assumed as 12% of floor area.
6) Wall height assumed to be 8 feet per story in all locations.
7) Infiltration air changes per hour (ACH) from Boghosian 1991. Equivalent leakage fraction (ELF) calculated from ACH using simulated ACH in Huang et al. 1987b assuming ACH is for heating season.
8) Number of stories are above-grade (excludes basements).
9) Perimeter configuration insulation distances are vertical distances.

Table 3.10. Building and Thermal Characteristics of Multi-Family Building Prototypes

Heat Type	Shell Group	Regional Popln. (% of stock)	Fndn Type	Cond. Floor Area (sqft)	Roof (R)	Wall (R)	Glazing Layers	Infiltration ELF	Infiltration ACH	Foundation Insulation Floor (R)	Foundation Insulation Perim. Config.
EXISTING BUILDINGS (Population is percent of existing stock in 1990)											
North Region		99.8%									
Electric	pre-80s	16.7%	Bsmt	903	2	1	1.2	0.00047	0.62	n/a	n/a
Electric	1980s	3.0%	Bsmt	1017	23	13	2.0	0.00035	0.47	n/a	R5 for 4'
HPump	pre-80s	1.1%	Bsmt	914	4	3	1.2	0.00043	0.57	n/a	n/a
HPump	1980s	0.8%	Bsmt	1020	22	13	2.0	0.00035	0.47	n/a	R5 for 4'
Fuel	pre-80s	74.9%	Bsmt	1054	2	2	1.7	0.00047	0.62	n/a	n/a
Fuel	1980s	3.3%	Bsmt	1115	27	13	2.0	0.00035	0.47	n/a	R5 for 4'
South Region		100.2%									
Electric	pre-80s	24.4%	Slab	1038	4	1	1.0	0.00046	0.49	n/a	n/a
Electric	1980s	11.4%	Slab	1084	22	13	2.0	0.00035	0.37	n/a	R5 for 2'
HPump	pre-80s	4.8%	Slab	1036	4	1	1.0	0.00047	0.50	n/a	n/a
HPump	1980s	8.8%	Slab	983	22	13	2.0	0.00035	0.37	n/a	R5 for 4'
Fuel	pre-80s	45.7%	Slab	925	2	1	1.0	0.00045	0.48	n/a	n/a
Fuel	1980s	5.1%	Slab	1015	22	13	2.0	0.00035	0.37	n/a	R5 for 4'
NEW BUILDINGS (Population is percent of new construction)											
North Region											
Electric	All	23%	Bsmt	1017	23	13	2.0	0.00035	0.47	n/a	R5 for 4'
HPump	All	13%	Bsmt	1020	22	13	2.0	0.00035	0.47	n/a	R5 for 4'
Fuel	All	64%	Bsmt	1115	27	13	2.0	0.00035	0.47	n/a	R5 for 4'
South Region											
Electric	All	30%	Slab	1084	22	13	2.0	0.00035	0.37	n/a	R5 for 2'
HPump	All	35%	Slab	983	22	13	2.0	0.00035	0.37	n/a	R5 for 4'
Fuel	All	35%	Slab	1015	22	13	2.0	0.00035	0.37	n/a	R5 for 4'

1) Prototype characteristics from Ritschard and Huang 1989. New Prototype is 1980s prototype from Ritschard and Huang 1989.
2) Prototype populations and heating types updated using US DOE 1992 data for existing stock and US Bureau of the Census 1990 data on heating fuel shares in new construction for new buildings.
3) Building dimensions are not shown here, but are included in the database. Building dimensions are averages across all units in building types, including bottom/mid/top floor units and middle/end units (e.g., foundation perimeter is exposed perimeter length).
4) Air changes per hour (ACH) calculated from Equivalent Leakage Fraction (ELF) given in Ritschard and Huang 1990 using simulated ACH in Huang et al. 1987b assuming ACH is for heating season.
5) Perimeter configuration insulation distances are vertical distances.

Table 3.11. Building and Thermal Characteristics of Manufactured Home Building Prototypes

Heat Type	Shell Group	Regional Popln. (% of stock)	Fndn Type	Cond. Floor Area (sqft)	No. of Stories	Roof (R)	Wall (R)	Glazing Layers	Infiltration ELF	Infiltration ACH	Foundation Insulation Floor (R)	Foundation Insulation Perim. Config.
EXISTING BUILDINGS (Population is percent of existing stock in 1990)												
North Region												
Electric	All	19.1%	Crawl	1025	1	14	11	2.0	0.00035	0.45	11	n/a
HPump	All	0.8%	Crawl	800	1	14	11	2.0	0.00035	0.45	11	n/a
Fuel	All	80.2%	Crawl	804	1	14	11	2.0	0.00035	0.45	11	n/a
South Region												
Electric	All	19.8%	Crawl	940	1	11	11	1.0	0.00053	0.56	7	n/a
HPump	All	4.0%	Crawl	1040	1	11	11	1.0	0.00053	0.56	7	n/a
Fuel	All	76.0%	Crawl	847	1	11	11	1.0	0.00053	0.56	7	n/a
NEW BUILDINGS (Population is percent of new construction)												
North Region												
All	All	100%	Crawl	1195	1	26	18	2.0	0.00028	0.36	14	n/a
South Region												
All	All	100%	Crawl	1195	1	20	12	1.3	0.00042	0.45	10	n/a

1) Prototype characteristics from Koomey et al. 1991a.
2) Prototype populations and heating types are updated using US DOE 1992 data for existing building stock. Because of limited data, new buildings are not segmented by heating type, and we assume there is not a strong correlation between heating fuel and thermal integrity for new buildings.
3) Building dimensions are not shown here, but are included in the database. Foundation dimensions are based on average width of 20 feet (average between single and double-wide).
4) Equivalent Leakage Fraction (ELF) calculated from air changes per hour (ACH) given in Koomey et al. 1991a using simulated ACH in Huang et al. 1987b assuming ACH is for heating season.
5) Number of stories are above-grade (excludes basements).

Prototype Heating and Cooling Loads

Heating and cooling loads are calculated for the baseline prototypes, and improved buildings, using building component loads generated from DOE-2 simulations of prototype buildings done under ASHRAE Special Project 53 (SP53) (Huang et al. 1987b). The building prototypes considered in this project include a one-story single-family building, a two-story townhouse, and an apartment module. Simulations are performed with a wide variety of insulation packages and window configurations in 45 different climates.

Changes in building loads from improvements to single building components are reduced to a set of component loads for each component on a component dimension basis (square feet or lineal feet). In addition, these component loads are further reduced to a set of coefficients by regressing the component loads versus component U-value or some other measure of thermal integrity. Each heat gain or loss component is considered to be independent of another. The components considered include ceiling, walls, foundations (slab, heated basement, unheated basement, and crawl space), infiltration, window conduction, and window solar loads which are non-linearly dependent on window area, window orientation, and glazing shading coefficient. In addition, there is a residual load, which represents the effect of internal gains and other non-temperature related effects.

There are two ways this database can be used. First, the database gives component loads per unit of component for specific levels of thermal integrity. Second, there is a set of regression coefficients that can be used to determine the component load for any level of thermal integrity. The procedure is summarized in Table 3.12.

The SP53 project includes simulations for 45 different locations. We consider only three of those locations in this project. We use Washington DC to represent the national average climate, Chicago IL to represent the North region, and Charleston, SC to represent the South. The component loads for these locations are given in Tables 3.13 and 3.14. These component loads are additive. For example, ceiling area is multiplied by the appropriate ceiling load, the appropriate foundation dimension (square feet or linear feet) is multiplied by the appropriate foundation load, etc., and the results are summed.

For the regression coefficients the methodology is the same in that the components are treated individually, and the results are summed to calculate the building load. The regression coefficients are given in Tables 3.15 and 3.16. The coefficient methodology is used within the database to calculate heating and cooling loads. The U-value assumptions for the different component constructions are given in Table 3.17.

Windows have a conductive component and a solar component, and the SP53 methodology treats each of these separately. We use the data to calculate total window loads (conductance + solar) for a typical configuration for simplicity of use. These are shown in Table 3.18.

In some ways, the SP53 database is not the best data to use for this project. The database was originally constructed to analyze the impact of conservation measures in *new* construction. Therefore, the building prototypes are chosen to represent average characteristics of newer buildings. However, since the loads are reduced to component loads, such that the important parameters are only the component U-value and thermal integrity, the methodology is also applicable to older buildings. Secondly, the simulations were originally performed to calculate *design* energy use for buildings, and were not meant to represent actual conditions in real life. For example, the simulations assume a constant heating and cooling thermostat set point. Occupants actually may set back heating thermostats at night or when away from the house. Cooling usage may be even more erratic.

Table 3.12. Building Heating and Cooling Load Calculation Methodology

Building load (MMBtu) = roofload + wallload + fndnload + infilload + windload + solarload + resload, where:
roofload = heating or cooling load from roof
wallload = heating or cooling load from walls
fndnload = heating or cooling load from foundation
infilload = heating or cooling load from infiltration
windload = heating or cooling load from conduction through windows
solarload = heating or cooling load from solar gain through windows
resload = residual heating or cooling load

Method 1: Component loads given as kBtu per square foot or kBtu per lineal foot are multiplied by the component dimension. These values are given in Table 3.13 and 3.14

Method 2: Component loads are derived from the component dimension, the thermal parameter particular to the component, and the component coefficients given in Table 3.15 and 3.16 as follows:

Roofs, Walls, Windows, and Crawl Spaces and Unheated Basements

load (MMBtu) = area*(uvalue*slope*24 + uvalue^2*curve*576 + intercept*1000)/10^6

with: area in ft^2
uvalue in Btu/hr-F-ft^2
slope in F-day/yr
curve in (F-day/yr)^2, and
intercept in kBtu/ft^2 (only applicable to foundation loads).

Slab and Heated Basement Foundation

load (MMBtu) = perimeter*(uvalue*slope*24 + uvalue^2*curve*576 + intercept*1000)/10^6

with: perimeter in ft,
uvalue in Btu/hr-F-ft
slope in F-day/yr
curve in (F-day/yr)^2
intercept in kBtu/ft

Infiltration

load (MMBtu) = floorarea*((ELF*1000)*slope + (ELF*1000)^2*curve)/1000

with: floorarea in ft^2 (total conditioned floor area of building)
ELF dimensionless (leakage area/total conditioned floor area)
slope in kBtu/0.001 ELF
curve in kBtu/(0.001 ELF)^2

Window Solar

a. unadjusted solar load:
A (MMBtu) = ∑(windarea*shadco*alpha)/1000 over the four cardinal directions (N, E, S, and W)

with: windarea is window area in ft^2
shadco is the glazing shading coefficient
alphas in kBtu/ft^2 are preliminary solar load estimates assuming a linear relationship with window solar aperature (area ∗ shading coefficient)

b. adjusted solar load:
A * (1 + Beta * A)

with: A is the sum of the preliminary solar load estimates from above (MMBtu)
(1 + Beta * A) is a dimensionless term for solar usability to account for its deacreasing effectiveness to offset heating and increasing penalty to increase cooling loads. This usability is a linear function of the total building solar heat gain (A).

Residual

load (MMBtu) = resid (MMBtu)

Source: Huang et al. 1987b. Values for Beta can be found in tables in this report.
Note that for Method 1 (specific component loads), the input R-values are for cavity insulation values. For Method 2 (regression coefficients) the input u-values are for the entire assembly (insulation plus framing). For both methods, window u-value and shading coefficient are whole-window values (including frame effects) from a source such as the ASHRAE Handbook of Fundamentals.

Table 3.13. Building Component Loads for Single-Family Buildings (also used for Manufactured Homes)

Component Descriptions	Component Level	US (Washington DC) Heating	US (Washington DC) Cooling	North (Chicago IL) Heating	North (Chicago IL) Cooling	South (Charleston SC) Heating	South (Charleston SC) Cooling
Ceiling	R-0	25.63	7.04	34.40	5.42	14.45	8.49
(kBtu/sqft of ceiling)	R-7	10.21	2.89	13.73	2.17	5.69	3.05
ceiling insulation	R-11	7.75	2.23	10.43	1.65	4.29	2.18
R-value	R-19	5.54	1.63	7.47	1.18	3.04	1.40
	R-22	4.69	1.39	6.33	1.01	2.56	1.17
	R-30	3.55	1.05	4.80	0.77	1.92	0.86
	R-38	2.87	0.85	3.87	0.63	1.54	0.67
	R-49	2.26	0.67	3.05	0.49	1.23	0.55
	R-60	1.87	0.55	2.52	0.39	1.04	0.47
Wall	R-0	23.61	3.53	32.85	2.61	12.25	3.90
(kBtu/sqft of wall)	R-7	11.59	1.83	16.01	1.32	5.71	1.49
wall insulation	R-11	9.87	1.59	13.62	1.14	4.78	1.14
R-value	R-13	7.78	1.26	10.72	0.88	3.64	0.78
	R-19	6.74	1.09	9.28	0.75	3.08	0.60
	R-27	4.86	0.79	6.68	0.56	2.26	0.46
	R-34	3.70	0.62	5.08	0.43	1.75	0.37
Slab	R-0	42.63	-7.51	65.02	-7.72	34.26	-42.54
(kBtu/lin. ft of slab)	R-5 2ft	18.89	-7.39	31.58	-6.46	22.16	-42.18
perimeter R-value	R-5 4ft	12.15	-6.90	22.01	-5.49	19.32	-41.51
and depth	R-10 2ft	14.50	-7.33	25.38	-6.10	20.17	-42.06
	R-10 4ft	5.10	-6.60	12.07	-4.89	16.61	-41.21
Heated Bsmt	R-0	79.86	8.28	116.95	2.46	52.82	-21.69
(kBtu/lin. ft of bsmt)	R-5 4ft	52.51	3.76	76.71	0.77	35.23	-22.84
perimeter R-value	R-5 8ft	43.41	3.40	63.63	0.83	30.35	-22.60
and depth	R-10 4ft	45.52	2.55	66.10	0.23	31.01	-23.14
	R-10 8ft	31.36	1.89	45.92	0.29	24.81	-22.90
Unheated Bsmt	R-0	8.61	0.89	12.61	0.26	5.69	-2.34
(kBtu/sqft of fndn)	R-11 flr	1.34	2.53	3.25	1.59	2.58	-1.09
underfloor R-value	R-19 flr	-0.65	2.97	0.60	1.94	1.80	-0.80
	R-30 flr	-1.93	3.25	-1.10	2.16	1.30	-0.61
Crawl Space	R-0	15.10	3.04	23.22	2.14	10.29	-0.59
(kBtu/sqft of fndn)	R-11 flr	1.34	3.73	3.93	2.71	3.10	0.01
underfloor R-value	R-19 flr	-0.99	3.83	0.63	2.75	2.00	0.01
	R-30 flr	-2.41	3.90	-1.46	2.80	1.43	0.03
	R-38 flr	-2.74	3.91	-1.93	2.82	1.30	0.03
	R-49 flr	-3.67	3.96	-3.31	2.85	0.93	0.04
Infiltration	0.0007	14.43	1.70	21.74	0.98	5.79	3.64
(kBtu/sqft of floor)	0.0005	10.21	1.22	15.38	0.68	3.67	2.63
ELF	0.0003	6.07	0.73	9.14	0.39	1.93	1.60
Window Conduction	1-Pane (U=1.10)	112.34	2.09	158.16	2.43	45.91	-7.28
(kBtu/sqft of window)	2-Pane (U=0.49)	53.20	0.95	73.47	1.08	15.99	-6.47
number of panes	3-Pane (U=0.31)	33.83	0.60	46.64	0.68	9.85	-4.28
	R-10 (U=0.10)	11.05	0.19	15.08	0.22	2.62	-1.71
Window Solar	1.00	-53.09	40.88	-70.68	31.08	-31.58	64.76
(kBtu/sqft of window)	0.80	-43.73	32.31	-58.07	24.37	-26.63	51.89
Shading coefficient	0.60	-33.74	23.95	-44.70	17.91	-21.00	38.97
Residual Load (MMBtu/unit)		1.98	-2.06	2.79	-1.96	-0.18	9.38

1) Component loads are from DOE-2 simulations done in Huang et al. 1987b, in support of ASHRAE Special Project 53. Component loads are additive. Simulations assume thermostat setpoints of 70F for heating with no setback and 78F for cooling with no setup, typical internal gains, and window shading coefficients of 0.80 during winter to account for framing effects and 0.60 during summer for shades above the glazing SC given in the table.
2) For infiltration, air changes per hour (ACH) during heating season are Washington (0.79,0.56,0.36), Chicago (0.89,0.64,0.39), and Charleston (0.71,0.53,0.32) for ELF=0.0007, 0.0005, 0.0003, respectively.
3) Window solar loads given are for windows @ 12% of floor area, equally distributed on four sides of the building.

Table 3.14. Building Component Loads for Multi-Family Buildings

Component Descriptions	Component Level	US (Washington DC) Heating	US (Washington DC) Cooling	North (Chicago IL) Heating	North (Chicago IL) Cooling	South (Charleston SC) Heating	South (Charleston SC) Cooling
Ceiling	R-0	26.00	6.24	35.26	4.96	14.70	7.10
(kBtu/sqft of ceiling)	R-7	9.92	2.26	13.62	1.88	5.27	2.45
ceiling insulation	R-11	7.35	1.62	10.16	1.39	3.76	1.71
R-value	R-19	5.04	1.05	7.06	0.94	2.41	1.04
	R-22	4.25	0.87	5.96	0.79	2.01	0.87
	R-30	3.19	0.64	4.48	0.59	1.49	0.65
	R-38	2.55	0.49	3.59	0.47	1.17	0.51
	R-49	2.03	0.41	2.85	0.38	0.94	0.40
	R-60	1.69	0.36	2.38	0.32	0.80	0.33
Wall	R-0	23.11	2.46	32.45	2.24	11.26	2.48
(kBtu/sqft of wall)	R-7	10.63	0.99	15.10	1.12	4.55	0.56
wall insulation	R-11	8.85	0.78	12.63	0.96	3.60	0.29
R-value	R-13	6.86	0.56	9.83	0.78	2.65	0.14
	R-19	5.87	0.45	8.45	0.69	2.18	0.07
	R-27	4.22	0.34	6.06	0.49	1.57	0.03
	R-34	3.21	0.26	4.60	0.36	1.20	0.00
Slab	R-0	54.52	-16.00	85.83	-13.22	24.07	-80.04
(kBtu/lin. ft of slab)	R-5 2ft	29.52	-15.17	49.66	-11.39	12.74	-79.04
perimeter R-value	R-5 4ft	22.85	-14.00	39.33	-9.55	10.91	-78.88
and depth	R-10 2ft	25.19	-14.67	43.00	-10.55	11.57	-79.71
	R-10 4ft	16.02	-13.33	29.16	-8.72	9.41	-78.04
Heated Bsmt	R-0	109.69	8.17	161.66	0.78	45.74	-46.54
(kBtu/lin. ft of bsmt)	R-5 4ft	64.02	3.50	94.33	-0.39	21.41	-46.04
perimeter R-value	R-5 8ft	51.52	3.17	76.66	-0.05	17.57	-46.04
and depth	R-10 4ft	53.69	2.00	79.16	-0.55	17.91	-46.54
	R-10 8ft	36.52	1.67	54.16	-0.39	12.91	-46.21
Unheated Bsmt	R-0	5.48	0.41	8.08	0.04	2.29	-2.33
(kBtu/sqft of fndn)	R-11 flr	1.87	1.83	3.50	1.02	0.97	-1.11
underfloor R-value	R-19 flr	0.59	2.23	1.81	1.36	0.62	-0.85
	R-30 flr	-0.22	2.49	0.72	1.57	0.40	-0.69
Crawl Space	R-0	16.70	2.14	25.34	1.43	9.21	-1.32
(kBtu/sqft of fndn)	R-11 flr	3.30	3.20	6.36	2.17	2.34	-0.05
underfloor R-value	R-19 flr	1.14	3.37	3.20	2.27	1.41	0.00
	R-30 flr	-0.13	3.50	1.23	2.41	1.03	0.02
	R-38 flr	-0.42	3.53	0.77	2.44	0.94	0.02
	R-49 flr	-1.26	3.62	-0.53	2.53	0.68	0.04
Infiltration	0.0007	12.69	1.44	19.78	0.67	4.19	2.72
(kBtu/sqft of floor)	0.0005	8.60	1.05	13.55	0.45	2.21	1.88
ELF	0.0003	4.88	0.64	7.78	0.25	0.85	1.09
Window Conduction	1-Pane (U=1.10)	96.07	-3.89	144.40	-1.65	39.09	-13.87
(kBtu/sqft of window)	2-Pane (U=0.49)	38.40	-3.55	60.86	-1.93	12.18	-11.44
number of panes	3-Pane (U=0.31)	24.02	-2.35	38.28	-1.29	7.39	-7.54
	R-10 (U=0.10)	7.11	-0.94	11.73	-0.54	1.76	-2.96
Window Solar	1.00	-54.82	40.34	-72.79	30.40	-33.47	64.87
(kBtu/sqft of window)	0.80	-44.84	31.97	-59.42	23.94	-27.84	51.96
Shading coefficient	0.60	-34.37	23.75	-45.46	17.66	-21.68	39.01
Residual Load (MMBtu/unit)		1.28	4.18	1.25	2.56	3.22	10.78

1) Component loads are from DOE-2 simulations done in Huang et al. 1987b, in support of ASHRAE Special Project 53. Component loads are additive. Simulations assume thermostat setpoints of 70F for heating with no setback and 78F for cooling with no setup, typical internal gains, and window shading coefficients of 0.80 during winter to account for framing effects and 0.60 during summer for shades above the glazing SC given in the table.
2) For infiltration, air changes per hour (ACH) during heating season are Washington (0.83,0.58,0.35), Chicago (0.89,0.66,0.40), and Charleston (0.74,0.53,0.32) for ELF=0.0007, 0.0005, 0.0003, respectively.
3) Window solar loads given are for windows @ 12% of floor area, equally distributed on four sides of the building.

Table 3.15. Building Component Loads Coefficients for Single-Family Buildings (also used for Manufactured Homes)

Component	Coefficient	National (Washington DC) Heating	National (Washington DC) Cooling	North (Chicago IL) Heating	North (Chicago IL) Cooling	South (Charleston SC) Heating	South (Charleston SC) Cooling
Roof	slope	5170.37	1544.34	6977.53	1111.40	2809.71	1219.54
	curve	-143.06	-60.34	-198.31	-33.36	-62.75	35.71
	intercept	0.00	0.00	0.00	0.00	0.00	0.00
Wall	slope	4831.60	809.06	6627.85	560.40	2195.23	381.44
	curve	-82.36	-28.55	-96.87	-13.80	15.39	63.99
	intercept	0.00	0.00	0.00	0.00	0.00	0.00
Slab	slope	5745.95	-610.01	8407.39	-984.39	1891.66	-756.41
	curve	-80.64	32.28	-121.21	41.75	31.07	40.97
	intercept	-14.36	-4.82	-15.72	-1.93	10.15	-39.15
Heated	slope	3146.97	160.33	4723.43	14.13	1414.18	-44.29
Basement	curve	-29.19	1.04	-45.21	1.16	-8.80	1.73
	intercept	0.00	0.00	0.00	0.00	10.94	-22.61
Unheated	slope	4660.51	-1020.56	6233.26	-804.63	1776.59	-642.35
Basement	curve	-377.50	80.75	-520.25	62.19	-129.16	41.33
	intercept	-5.36	4.00	-5.68	2.76	-0.02	-0.13
Crawl	slope	4421.03	-185.43	6450.79	-80.06	1766.58	60.08
Space	curve	-65.33	-2.15	-129.31	-12.17	46.88	-33.96
	intercept	-5.86	4.04	-6.46	2.87	0.00	0.00
Infiltration	slope	19.94	2.44	30.03	1.23	5.03	5.42
	curve	0.97	0.00	1.46	0.24	4.63	-0.33
	intercept	0.00	0.00	0.00	0.00	0.00	0.00
Window	slope	4739.24	82.23	6453.57	91.81	1054.92	-770.65
	curve	-18.33	-0.12	-17.53	0.02	25.92	18.74
	intercept	0.00	0.00	0.00	0.00	0.00	0.00
Residual		1.98	-2.06	2.79	-1.96	-0.18	9.38
Window	NAlpha	-34.73	26.24	-37.61	17.54	-23.19	46.22
Solar	EAlpha	-56.48	40.47	-74.98	31.80	-39.31	76.09
Coefficients	SAlpha	-97.95	39.43	-139.01	28.05	-63.36	68.17
	WAlpha	-54.82	47.69	-69.30	34.60	-34.69	70.55
	Beta	0.0115	0.0088	0.0080	0.0213	0.0287	-0.0006

Source: Huang et al. 1987b. For a description of how to use these coefficients, see Table 3.12.

Table 3.16. Building Component Loads Coefficients for Multi-Family Buildings

Component	Coefficient	National (Washington DC) Heating	National (Washington DC) Cooling	North (Chicago IL) Heating	North (Chicago IL) Cooling	South (Charleston SC) Heating	South (Charleston SC) Cooling
Roof	slope	4593.79	918.63	6477.18	855.31	2098.79	882.25
	curve	-35.12	22.45	-89.41	-3.11	64.23	53.18
	intercept	0.00	0.00	0.00	0.00	0.00	0.00
Wall	slope	4076.50	297.48	5891.16	486.69	1399.24	-83.82
	curve	40.97	29.60	26.53	-13.19	129.28	101.36
	intercept	0.00	0.00	0.00	0.00	0.00	0.00
Slab	slope	5257.64	-1212.12	8534.83	-1652.06	253.31	-970.47
	curve	-41.62	57.04	-98.34	71.56	119.27	51.83
	intercept	-9.71	-10.94	0.60	-3.70	7.35	-75.59
Heated	slope	3490.64	128.66	5337.97	-50.24	670.13	41.13
Basement	curve	-19.71	1.75	-32.91	1.72	9.49	-1.01
	intercept	0.00	0.00	0.00	0.00	4.95	-46.59
Unheated	slope	3145.91	-943.48	4223.62	-821.95	812.27	-560.76
Basement	curve	-309.56	78.38	-427.18	79.25	-63.66	30.87
	intercept	-3.20	3.81	-2.34	2.17	-0.20	-0.26
Crawl	slope	3918.12	-373.34	6046.94	-317.14	1182.85	75.03
Space	curve	-6.36	10.13	-82.88	15.85	119.70	-64.78
	intercept	-3.78	4.13	-3.49	2.64	0.00	0.00
Infiltration	slope	14.85	2.21	24.21	0.71	0.48	3.42
	curve	4.69	-0.21	5.78	0.37	7.87	0.68
	intercept	0.00	0.00	0.00	0.00	0.00	0.00
Window	slope	2964.96	-425.32	4938.34	-245.39	678.32	-1331.57
	curve	25.54	10.52	20.13	6.93	30.39	30.54
	intercept	0.00	0.00	0.00	0.00	0.00	0.00
Residual	intercept	1.11	5.05	1.25	2.56	3.22	10.78
Window	NAlpha	-34.73	26.24	-37.61	17.54	-23.19	46.22
Solar	EAlpha	-56.48	40.47	-74.98	31.80	-39.31	76.09
Coefficients	SAlpha	-97.95	39.43	-139.01	28.05	-63.36	68.17
	WAlpha	-54.82	47.69	-69.30	34.60	-34.69	70.55
	Beta	0.0115	0.0088	0.0080	0.0213	0.0287	-0.0006

Source: Huang et al. 1987b. For a description of how to use these coefficients, see Table 3.12.

Table 3.17. Construction Type and U-value and Shading Coefficient Assumptions

Component	Construction	U-val	SC	Construction assumptions
Roof	R00	0.25		Uninsulated ceiling below attic
	R07	0.09		R07 insulated ceiling below attic
	R11	0.07		R11 insulated ceiling below attic
	R19	0.05		R19 insulated ceiling below attic
	R22	0.04		R22 insulated ceiling below attic
	R30	0.03		R30 insulated ceiling below attic
	R38	0.02		R38 insulated ceiling below attic
	R49	0.02		R49 insulated ceiling below attic
	R60	0.02		R60 insulated ceiling below attic
Wall	R00	0.22		Uninsulated 2x4 wood frame wall
	R07	0.11		R07 insulated 2x4 wood frame wall
	R11	0.09		R11 insulated 2x4 wood frame wall
	R13	0.07		R13 insulated 2x4 wood frame wall
	R19	0.06		R19 insulated 2x6 wood frame wall
	R27	0.04		R19 insulated 2x6 wood frame wall with insulated sheathing
	R34	0.03		R19 insulated 2x6 wood frame wall with insulated sheathing
Window	1.0-gla	1.10	0.90	Wood Frame Window, 80%glass, single clear glass
	2.0-gla	0.48	0.66	Wood Frame Window, 80%glass, double clear glass, 1/2" air space
	3.0-gla	0.30	0.61	Wood Frame Window, 80%glass, triple clear glass, 1/2" air space
	2-gla loE	0.36	0.59	Wood Frame Window, 80%glass, low emissivity film
	2-gla loEAr	0.30	0.59	Wood Frame Window, 80%glass, low emissivity film, argon fill
	Spect	0.36	0.44	Wood Frame Window, 80%glass, spectrally selective double glass
	Super	0.20	0.51	Wood Frame Window, 80%glass, superwindow
	HMirror	0.29	0.39	Wood Frame Window, 80%glass, heat mirror surface
Floors	R00	0.21		Uninsulated 2x10 floor over basement or crawl space
(crawl or	R11	0.07		R11 insulated 2x10 floor over basement or crawl space
unheated	R19	0.05		R19 insulated 2x10 floor over basement or crawl space
basement)	R30	0.03		R30 insulated 2x10 floor over basement or crawl space
	R38	0.03		R38 insulated 2x10 floor over basement or crawl space
	R49	0.02		R49 insulated 2x10 floor over basement or crawl space
Slab	R-0	0.48		Uninsulated Slab
	R-5 2ft	0.25		Exterior vertical slab insulation to depth and R-value listed
	R-10 2ft	0.21		Exterior vertical slab insulation to depth and R-value listed
	R-5 4ft	0.20		Exterior vertical slab insulation to depth and R-value listed
	R-10 4ft	0.14		Exterior vertical slab insulation to depth and R-value listed
Heated	R-0	1.67		Uninsulated basement wall
Basement	R-5 4ft	0.83		Exterior vertical basement wall insulation to depth and R-value listed
	R-10 4ft	0.67		Exterior vertical basement wall insulation to depth and R-value listed
	R-5 8ft	0.67		Exterior vertical basement wall insulation to depth and R-value listed
	R-10 8ft	0.45		Exterior vertical basement wall insulation to depth and R-value listed

1) All U-value assumptions from SP53 project (Huang et al. 1987b) for insulated components. Foundation (Slab and Heated Basement) U-values are the U-value of foundation concrete and insulation, if any, and are not the effective U-value of the total foundation.
2) Window U-values and shading coefficients from Koomey et al. 1994a. Window U-values and shading coefficients are for whole window unit, including the window frame.

Table 3.18. Window Component Loads for Specific Glazing Types

Location/ Window Type	Whole-Window U-value	Whole-Window SC	Component Loads (kBtu/square foot of window) Heating Conduction	Heating Solar	Heating Total	Cooling Conduction	Cooling Solar	Cooling Total
Washington DC (national)								
1.0-gla	1.10	0.90	112.3	-48.5	63.9	2.1	36.6	38.7
2.0-gla	0.48	0.66	52.2	-36.8	15.4	0.9	26.4	27.4
3.0-gla	0.30	0.61	33.2	-34.3	-1.1	0.6	24.4	24.9
2-gla loE	0.36	0.59	39.6	-33.2	6.4	0.7	23.5	24.2
2-gla loEAr	0.30	0.59	33.2	-33.2	-0.1	0.6	23.5	24.1
Spect	0.36	0.44	39.6	-25.3	14.3	0.7	17.4	18.1
Super	0.20	0.51	22.3	-29.0	-6.7	0.4	20.2	20.6
HMirror	0.29	0.39	32.1	-22.6	9.5	0.6	15.4	15.9
Chicago IL (North)								
1.0-gla	1.10	0.90	158.2	-64.5	93.7	2.4	27.7	30.1
2.0-gla	0.48	0.66	72.0	-48.8	23.2	1.1	19.8	20.9
3.0-gla	0.30	0.61	45.6	-45.4	0.2	0.7	18.2	18.9
2-gla loE	0.36	0.59	54.5	-44.0	10.4	0.8	17.6	18.4
2-gla loEAr	0.30	0.59	45.6	-44.0	1.5	0.7	17.6	18.3
Spect	0.36	0.44	54.5	-33.5	21.0	0.8	12.9	13.7
Super	0.20	0.51	30.6	-38.4	-7.9	0.4	15.1	15.5
HMirror	0.29	0.39	44.1	-29.8	14.2	0.6	11.4	12.0
Charleston SC (South)								
1.0-gla	1.10	0.90	45.9	-29.2	16.7	-7.3	58.3	51.0
2.0-gla	0.48	0.66	15.6	-22.8	-7.2	-6.4	42.9	36.5
3.0-gla	0.30	0.61	8.9	-21.3	-12.4	-4.6	39.6	35.0
2-gla loE	0.36	0.59	11.0	-20.7	-9.7	-5.3	38.3	33.1
2-gla loEAr	0.30	0.59	8.9	-20.7	-11.8	-4.6	38.3	33.8
Spect	0.36	0.44	11.0	-16.0	-5.0	-5.3	28.6	23.4
Super	0.20	0.51	5.7	-18.2	-12.6	-3.3	33.2	29.9
HMirror	0.29	0.39	8.6	-14.4	-5.8	-4.5	25.4	20.9

Based on methodology in Huang et al. 1987b.
Values calculated for One Story Prototype, 1540 square feet.
Window area assumed as 12% of floor area, equally distributed around four sides of building.
Window U-values and shading coefficients are from Koomey et al. 1994a.

On the whole, however, the SP53 database provides a simple method for calculating heating and cooling loads as well as a method for calculating changes in loads from improvements in the thermal integrity of the building. To account for differences between the design energy use and actual field usage, the building loads are calibrated to the baseline UEC derived from other data. This process will be described in the following section. The building loads calculated from the SP53 database are given in Table 3.19, and are calculated using the coefficient method described above.

Where there are analogous LBNL/GRI prototype buildings, heating and cooling loads from these prototypes are compared in Table 3.19 with the building loads from the prototypes in Tables 3.9 through 3.11. Note that the building loads given for the LBNL/GRI prototypes are also calculated using the SP53 methodology as described elsewhere (Hanford and Huang 1992).

The heating and cooling loads for the LBNL/GRI prototypes calculated directly from DOE-2 simulations are typically lower in magnitude than those calculated using the SP53 methodology. The DOE-2 simulations assume different operating conditions (primarily a nighttime thermostat setback of 6° F) and are generally more detailed than the simulations used to generate the SP53 loads.

Building Heating and Cooling Energy Use Calibration

To complete the model of building heating and cooling energy use, we compare the UECs estimated from measured data that were discussed in Section 3.1 (Tables 3.1 and 3.2) with UECs calculated from building heating and cooling loads and average stock equipment and distribution system efficiencies using the generalized UEC equations shown in Section 3.1. Ideally, the UECs determined from each of these two methods would be the same.

Using data for existing buildings, we define a calibration multiplier, which is the ratio of the database UEC (that was estimated from measured and other utility data) to the calculated UEC. This ratio is a measure of the amount of error in the model used to calculate UECs from building loads and equipment data. This calibration multiplier is then applied to the UEC calculated for new buildings to determine the database UEC for new buildings.

The calibration of the heating and cooling energy use model is shown in Tables 3.20 and 3.21. The magnitude of the calibration multiplier ranges from 0.4 to 3.1 for heating, from 0.5 to 2.0 for CAC and HP cooling systems, and from 0.2 to 0.7 for RAC cooling. The low value for room air conditioning reflects the fact that with RAC, the entire building is not typically cooled, whereas the simulated prototype cooling load assumes that the entire building is cooled.

Because we have better knowledge of the characteristics of the heating and cooling efficiencies, the distribution system efficiencies, and the UECs, the calibration multiplier is assumed to apply in total to the building heating and cooling loads. Obviously, there are unknowns in all of these areas. More work is required in this area to more fully characterize the sector.

Table 3.19. Residential Forecasting Database (RFD) Building Prototype Populations and Heating and Cooling Loads
(comparison of RFD prototype Loads to LBL/GRI prototype loads)

Vintage	House Type	Region	Heat Type	Heat Fuel Share	Shell Group	Shell Share	Popln (million)	Heat MMBtu	Cool MMBtu
Stock	SF	North	Electric	0.08	Loose	0.231	0.64	89.4	7.6
			Electric	0.08	Tight	0.769	2.12	66.9	6.5
Stock	SF	North	Fuel	0.88	Loose	0.487	14.74	105.0	9.0
			Fuel	0.88	Tight	0.513	15.53	81.5	7.3
Stock	SF	North	Heat Pump	0.04	Loose	0.028	0.04	120.0	11.5
			Heat Pump	0.04	Tight	0.972	1.34	59.4	6.4
	RFD 1990 prototypes		34.4	million			wtd average	90.0	8.0
	LBL/GRI prototypes		34.1	million			wtd average	81.4	11.4
							% difference	*10%*	*-43%*
Stock	SF	South	Electric	0.13	Loose	0.288	1.04	31.5	20.7
			Electric	0.13	Tight	0.712	2.58	26.5	18.8
Stock	SF	South	Fuel	0.77	Loose	0.557	11.97	46.3	30.5
			Fuel	0.77	Tight	0.443	9.52	36.9	26.3
Stock	SF	South	Heat Pump	0.10	Loose	0.142	0.40	40.0	24.7
			Heat Pump	0.10	Tight	0.858	2.39	24.2	17.6
	RFD 1990 prototypes		27.9	million			wtd average	38.7	26.4
	LBL/GRI prototypes		26.3	million			wtd average	27.4	24.8
							% difference	*29%*	*6%*
							(%)		
New	SF	North	Electric	0.08	All	1	0.08	58.2	7.0
New	SF	North	Fuel	0.78	All	1	0.78	73.0	9.0
New	SF	North	Heat Pump	0.13	All	1	0.13	70.3	8.8
	RFD 1990 prototypes							70.7	8.7
	LBL/GRI prototypes							64.2	9.8
							% difference	*9%*	*-12%*
New	SF	South	Electric	0.13	All	1	0.13	22.8	17.6
New	SF	South	Fuel	0.57	All	1	0.57	24.3	17.9
New	SF	South	Heat Pump	0.31	All	1	0.31	22.3	16.9
	RFD 1990 prototypes							23.7	17.7
	LBL/GRI prototypes							19.7	22.2
							% difference	*17%*	*-25%*

1) RFD prototype populations from Appendix B.
2) LBL/GRI prototype populations and population heating and cooling loads from Hanford and Huang 1992.
3) Heating and cooling loads calculated using ASHRAE SP53 loads database methodology (loads are uncalibrated to actual field conditions).

Table 3.19 (cont.). RFD Building Prototype Populations and Heating and Cooling Loads
(comparison of RFD prototype Loads to LBL/GRI prototype loads)

Vintage	House Type	Region	Heat Type	Heat Fuel Share	Shell Group	Shell Share	Popln (million)	Heat MMBtu	Cool MMBtu
Stock	MF	North	Electric	0.15	1980s	0.201	0.46	21.3	4.6
			Electric	0.15	pre-80s	0.799	1.85	48.3	7.2
Stock	MF	North	Fuel	0.84	1980s	0.053	0.69	22.2	5.0
			Fuel	0.84	pre-80s	0.947	12.25	51.7	7.8
Stock	MF	North	Heat Pump	0.01	1980s	0.278	0.04	21.6	4.4
			Heat Pump	0.01	pre-80s	0.722	0.11	34.4	6.0
	RFD 1990 prototypes		15.4	million			wtd average	48.9	7.5
	LBL/GRI prototypes		15.6	million			wtd average	37.4	9.2
							% difference	*24%*	*-22%*
Stock	MF	South	Electric	0.42	1980s	0.276	1.18	6.5	11.7
			Electric	0.42	pre-80s	0.724	3.10	14.7	15.7
Stock	MF	South	Fuel	0.53	1980s	0.106	0.57	6.3	11.6
			Fuel	0.53	pre-80s	0.894	4.83	16.2	16.4
Stock	MF	South	Heat Pump	0.06	1980s	0.224	0.14	6.3	11.5
			Heat Pump	0.06	pre-80s	0.776	0.47	14.9	15.5
	RFD 1990 prototypes		10.2	million			wtd average	14.0	15.4
	LBL/GRI prototypes		9.3	million			wtd average	12.3	15.3
							% difference	*13%*	*1%*
New	MF	North	Electric	0.23	All	1	0.23	21.3	4.6
New	MF	North	Fuel	0.63	All	1	0.63	22.2	5.0
New	MF	North	Heat Pump	0.13	All	1	0.13	21.6	4.4
	RFD 1990 prototypes							21.7	4.8
	LBL/GRI prototypes							14.0	6.5
							% difference	*35%*	*-36%*
New	MF	South	Electric	0.30	All	1	0.30	6.5	11.7
New	MF	South	Fuel	0.34	All	1	0.34	6.3	11.6
New	MF	South	Heat Pump	0.35	All	1	0.35	6.3	11.5
	RFD 1990 prototypes							6.3	11.5
	LBL/GRI prototypes							5.0	17.0
							% difference	*20%*	*-48%*

1) RFD prototype populations from Appendix B.
2) LBL/GRI prototype populations and population heating and cooling loads from Hanford and Huang 1992.
3) Heating and cooling loads calculated using ASHRAE SP53 loads database methodology (loads are uncalibrated to actual field conditions).

Table 3.19 (cont.). RFD Building Prototype Populations and Heating and Cooling Loads
(comparison of RFD prototype Loads to LBL/GRI prototype loads)

Vintage	House Type	Region	Heat Type	Heat Fuel Share	Shell Group	Shell Share	Popln (million)	Heat MMBtu	Cool MMBtu
Stock	MH	North	Electric	0.11	All	1	0.31	43.9	6.1
Stock	MH	North	Fuel	0.88	All	1	2.46	35.8	4.4
Stock	MH	North	Heat Pump	0.01	All	1	0.03	58.3	6.5
	RFD 1990 prototypes		2.8	million			wtd average	36.9	4.6
Stock	MH	South	Electric	0.27	All	1	0.73	20.7	20.8
Stock	MH	South	Fuel	0.72	All	1	1.94	17.0	18.7
Stock	MH	South	Heat Pump	0.02	All	1	0.05	11.2	16.5
	RFD 1990 prototypes		2.7	million			wtd average	18.1	19.4
New	MH	North	All		All	1		35.6	6.1
New	MH	South	All		All	1		15.6	19.7

1) RFD prototype populations from Appendix B.
2) Heating and cooling loads calculated using ASHRAE SP53 loads database methodology (loads are uncalibrated to actual field conditions).

Table 3.20. Calibration of Forecasting Prototype Heating Loads with Database UECs

Vintage	Region	Heat Type	Heat Fuel	Heat Tech	Region Heat Share (%)	Bldg Popln (mill)	Prototype Heat Load (MMBtu)	Average Efficiency (%) Eqmt	Dist	System	Prototype UEC (MMBtu) (kWh)	Database UEC (MMBtu) (kWh)	Calibration Multiplier
EXISTING SINGLE-FAMILY													
Existing	North												
		Fuel	G	FRN	47%	16.0	92.9	68%	80%	54%	171	93	0.54
		Fuel	G	H2O	9%	3.1	92.9	67%	90%	60%	154	111	0.72
		Fuel	G	RM	2%	0.8	92.9	65%	100%	65%	143	83	0.58
			avg.		*58%*	*19.9*					*167*	*96*	*0.57*
		Fuel	O	FRN	9%	3.0	92.9	76%	80%	61%	153	83	0.55
		Fuel	O	H2O	9%	3.2	92.9	76%	90%	68%	136	112	0.82
		Fuel	O	RM	1%	0.2	92.9	75%	100%	75%	124	79	0.64
			avg.		*19%*	*6.4*					*143*	*97*	*0.68*
		Fuel	L	FRN	3%	1.0	92.9	67%	80%	54%	173	74	0.43
		Fuel	L	H2O	0%	0.1	92.9	67%	90%	60%	154	116	0.75
		Fuel	L	RM	1%	0.4	92.9	65%	100%	65%	143	59	0.41
			avg.		*4%*	*1.4*					*164*	*73*	*0.45*
		Elec	E	FRN	2%	0.7	72.1	100%	80%	80%	26406	14000	0.53
		Elec	E	H2O	0%	0.0	72.1	100%	90%	90%	23472	14000	0.60
		Elec	E	RM	7%	2.5	72.1	100%	100%	100%	21125	14000	0.66
			avg.		*9%*	*3.2*					*22330*	*14000*	*0.63*
		HtPump	E	HP	2%	0.8	61.1	6.6*	80%		11660	9000	0.77
Existing	South												
		Fuel	G	FRN	38%	10.7	42.1	68%	70%	47%	89	52	0.58
		Fuel	G	H2O	1%	0.3	42.1	67%	90%	60%	70	79	1.14
		Fuel	G	RM	17%	4.7	42.1	65%	100%	65%	65	38	0.59
			avg.		*56%*	*15.7*					*81*	*48*	*0.59*
		Fuel	O	FRN	3%	0.8	42.1	76%	70%	53%	79	55	0.69
		Fuel	O	H2O	1%	0.1	42.1	76%	90%	68%	62	86	1.39
		Fuel	O	RM	2%	0.6	42.1	75%	100%	75%	56	46	0.82
			avg.		*5%*	*1.5*					*68*	*54*	*0.80*
		Fuel	L	FRN	2%	0.6	42.1	67%	70%	47%	90	59	0.66
		Fuel	L	RM	3%	1.0	42.1	65%	100%	65%	65	35	0.53
			avg.		*6%*	*1.5*					*74*	*44*	*0.59*
		Elec	E	FRN	10%	2.7	27.9	100%	70%	70%	11678	6000	0.51
		Elec	E	RM	5%	1.3	27.9	100%	100%	100%	8175	6000	0.73
			avg.		*14%*	*4.0*					*10559*	*6000*	*0.57*
		HtPump	E	HP	13%	3.6	26.4	6.5*	70%		5758	5000	0.87

Table 3.20 (cont.). Calibration of Forecasting Prototype Heating Loads with Database UECs

Vintage	Region	Heat Type	Heat Fuel	Heat Tech	Region Heat Share (%)	Bldg Popln (mill)	Prototype Heat Load (MMBtu)	Average Efficiency (%) Eqmt	Dist	System	Prototype UEC (MMBtu) (kWh)	Database UEC (MMBtu) (kWh)	Calibration Multiplier
NEW SINGLE-FAMILY													
New	North												
		Fuel	G	FRN	53%		73	78%	80%	62%	117	64	0.55
		Fuel	G	H2O	4%		73	80%	90%	72%	102	74	0.72
			avg.		*58%*						*116*	*65*	*0.56*
		Fuel	O	FRN	4%		73	80%	80%	64%	114	62	0.55
		Fuel	O	H2O	6%		73	85%	90%	76%	96	79	0.82
			avg.		*10%*						*103*	*73*	*0.71*
		Fuel	L	FRN	8%		73	82%	80%	65%	112	48	0.43
		Fuel	L	H2O	0%		73	82%	90%	73%	100	75	0.75
			avg.		*8%*						*112*	*49*	*0.44*
		Elec	E	FRN	4%		58.2	100%	80%	80%	21316	11301	0.53
		Elec	E	H2O	0%		58.2	100%	90%	90%	18947	11301	0.60
		Elec	E	RM	3%		58.2	100%	100%	100%	17053	11301	0.66
			avg.		*8%*						*19372*	*11301*	*0.58*
		HtPump	E	HP	13%		70.3	7*	80%		12500	9648	0.77
New	South												
		Fuel	G	FRN	46%		24.3	78%	70%	55%	45	26	0.58
		Fuel	G	H2O	0%		24.3	80%	90%	72%	34	39	1.14
			avg.		*46%*						*45*	*26*	*0.58*
		Fuel	O	FRN	1%		24.3	80%	70%	56%	44	30	0.69
			avg.		*1%*						*44*	*30*	*0.69*
		Fuel	L	FRN	7%		24.3	82%	70%	57%	43	28	0.66
			avg.		*7%*						*43*	*28*	*0.66*
		Elec	E	FRN	9%		22.8	100%	70%	70%	9543	4903	0.51
		Elec	E	RM	3%		22.8	100%	100%	100%	6680	4903	0.73
			avg.		*12%*						*8886*	*4903*	*0.55*
		HtPump	E	HP	31%		22.3	7*	70%		4532	3935	0.87

Table 3.20 (cont.). Calibration of Forecasting Prototype Heating Loads with Database UECs

Vintage	Region	Heat Type	Heat Fuel	Heat Tech	Region Heat Share (%)	Bldg Popln (mill)	Prototype Heat Load (MMBtu)	Average Efficiency (%) Eqmt	Dist	System	Prototype UEC (MMBtu) (kWh)	Database UEC (MMBtu) (kWh)	Calibration Multiplier
EXISTING MULTI-FAMILY													
Existing	North												
		Fuel	G	FRN	23%	3.5	50.1	68%	80%	54%	92	69	0.75
		Fuel	G	H2O	32%	4.9	50.1	67%	90%	60%	83	65	0.78
		Fuel	G	RM	3%	0.5	50.1	65%	100%	65%	77	63	0.82
			avg.		*58%*	*8.9*					*86*	*67*	*0.77*
		Fuel	O	FRN	2%	0.4	50.1	76%	80%	61%	82	66	0.79
		Fuel	O	H2O	16%	2.5	50.1	76%	90%	68%	73	66	0.90
		Fuel	O	RM	1%	0.1	50.1	75%	100%	75%	67	60	0.90
			avg.		*19%*	*3.0*					*74*	*66*	*0.89*
		Elec	E	FRN	4%	0.6	42.9	100%	80%	80%	15712	8700	0.55
		Elec	E	H2O	0%	0.0	42.9	100%	90%	90%	13966	8700	0.62
		Elec	E	RM	16%	2.4	42.9	100%	100%	100%	12570	8700	0.69
			avg.		*20%*	*3.0*					*13167*	*8700*	*0.66*
		HtPump	E	HP	2%	0.3	30.8	6.5*	80%		5878	4000	0.68
Existing	South												
		Fuel	G	FRN	24%	2.4	15.2	68%	70%	47%	32	31	0.96
		Fuel	G	H2O	4%	0.4	15.2	67%	90%	60%	25	35	1.40
		Fuel	G	RM	19%	1.9	15.2	65%	100%	65%	23	19	0.79
			avg.		*46%*	*4.8*					*28*	*26*	*0.94*
		Fuel	O	H2O	1%	0.1	15.2	76%	90%	68%	22	68	3.05
		Fuel	O	RM	0%	0.0	15.2	75%	100%	75%	20	11	0.53
			avg.		*1%*	*0.1*					*23*	*40*	*1.76*
		Elec	E	FRN	24%	2.5	12.4	100%	70%	70%	5190	3700	0.71
		Elec	E	RM	11%	1.1	12.4	100%	100%	100%	3633	3700	1.02
			avg.		*35%*	*3.6*					*4701*	*3700*	*0.79*
		HtPump	E	HP	14%	1.4	13	6.6*	70%		2835	2100	0.74

Table 3.20 (cont.). Calibration of Forecasting Prototype Heating Loads with Database UECs

Vintage	Region	Heat Type	Heat Fuel	Heat Tech	Region Heat Share (%)	Bldg Popln (mill)	Prototype Heat Load (MMBtu)	Average Efficiency (%) Eqmt	Dist	System	Prototype UEC (MMBtu) (kWh)	Database UEC (MMBtu) (kWh)	Calibration Multiplier
NEW MULTI-FAMILY													
New	North												
		Fuel	G	FRN	22%		22.2	78%	80%	62%	36	27	0.75
		Fuel	G	H2O	38%		22.2	80%	90%	72%	31	24	0.78
			avg.		*60%*						*33*	*25*	*0.77*
		Fuel	O	H2O	1%		22.2	85%	90%	76%	29	26	0.90
			avg.		*1%*						*29*	*26*	*0.90*
		Elec	E	FRN	8%		21.3	100%	80%	80%	7801	4320	0.55
		Elec	E	RM	15%		21.3	100%	100%	100%	6241	4320	0.69
			avg.		*23%*						*6801*	*4320*	*0.64*
		HtPump	E	HP	13%		21.6	7*	80%		3841	2614	0.68
New	South												
		Fuel	G	FRN	25%		6.3	78%	70%	55%	12	11	0.96
		Fuel	G	H2O	2%		6.3	80%	90%	72%	9	12	1.40
		Fuel	G	RM	5%		6.3	67%	100%	67%	9	8	0.80
			avg.		*32%*						*11*	*11*	*0.95*
		Fuel	O	H2O	0%		6.3	85%	90%	76%	8	25	3.04
			avg.		*0%*						*8*	*25*	*3.04*
		Elec	E	FRN	28%		6.5	100%	70%	70%	2721	1940	0.71
		Elec	E	RM	2%		6.5	100%	100%	100%	1905	1940	1.02
			avg.		*30%*						*2671*	*1940*	*0.73*
		HtPump	E	HP	35%		6.3	7*	70%		1280	948	0.74

Table 3.20 (cont.). Calibration of Forecasting Prototype Heating Loads with Database UECs

Vintage	Region	Heat Type	Heat Fuel	Heat Tech	Region Heat Share (%)	Bldg Popln (mill)	Prototype Heat Load (MMBtu)	Average Efficiency (%) Eqmt	Dist	System	Prototype UEC (MMBtu) (kWh)	Database UEC (MMBtu) (kWh)	Calibration Mulitplier
EXISTING MANUFACTURED HOME													
Existing	North												
		Fuel	G	FRN	41%	1.1	35.8	68%	80%	54%	66	65	0.98
		Fuel	G	RM	1%	0.0	35.8	65%	100%	65%	55	63	1.14
			avg.		*41%*	*1.2*					*66*	*65*	*0.99*
		Fuel	O	FRN	17%	0.5	35.8	76%	80%	61%	59	59	1.00
			avg.		*17%*	*0.5*					*59*	*59*	*1.00*
		Fuel	L	FRN	14%	0.4	35.8	67%	80%	54%	67	51	0.77
		Fuel	L	RM	1%	0.0	35.8	65%	100%	65%	55	55	1.00
			avg.		*16%*	*0.4*					*66*	*52*	*0.78*
		Elec	E	FRN	16%	0.4	43.9	100%	80%	80%	16078	8000	0.50
		Elec	E	RM	4%	0.1	43.9	100%	100%	100%	12863	8000	0.62
			avg.		*19%*	*0.5*					*15494*	*8000*	*0.52*
		HtPump	E	HP	1%	0.0	58.3	6.5*	80%		11126	6300	0.57
Existing	South												
		Fuel	G	FRN	31%	0.8	17	68%	70%	47%	36	36	1.00
		Fuel	G	RM	3%	0.1	17	65%	100%	65%	26	28	1.07
			avg.		*34%*	*0.9*					*35*	*35*	*1.01*
		Fuel	O	FRN	8%	0.2	17	76%	70%	53%	32	61	1.91
		Fuel	O	RM	2%	0.0	17	75%	100%	75%	23	18	0.78
			avg.		*10%*	*0.3*					*30*	*54*	*1.77*
		Fuel	L	FRN	23%	0.6	17	67%	70%	47%	36	32	0.87
		Fuel	L	RM	8%	0.2	17	65%	100%	65%	26	13	0.48
			avg.		*31%*	*0.8*					*34*	*27*	*0.79*
		Elec	E	FRN	13%	0.3	20.7	100%	70%	70%	8664	4500	0.52
		Elec	E	RM	7%	0.2	20.7	100%	100%	100%	6065	4500	0.74
			avg.		*20%*	*0.5*					*7707*	*4500*	*0.58*
		HtPump	E	HP	4%	0.1	11.2	6.5*	70%		2443	1500	0.61

Table 3.20 (cont.). Calibration of Forecasting Prototype Heating Loads with Database UECs

Vintage	Region	Heat Type	Heat Fuel	Heat Tech	Region Heat Share (%)	Bldg Popln (mill)	Prototype Heat Load (MMBtu)	Average Efficiency (%) Eqmt	Dist	System	Prototype UEC (MMBtu) (kWh)	Database UEC (MMBtu) (kWh)	Calibration Multiplier
NEW MANUFACTURED HOME													
New	North												
		Fuel	G	FRN	34%		35.6	78%	80%	62%	57	56	0.99
		Fuel	G	RM	4%		35.6	67%	100%	67%	53	61	1.14
			avg.		*38%*						*57*	*57*	*1.00*
		Fuel	O	FRN	20%		35.6	80%	80%	64%	56	56	1.00
			avg.		*20%*						*56*	*54*	*0.97*
		Fuel	L	FRN	20%		35.6	82%	80%	65%	55	42	0.77
		Fuel	L	RM	5%		35.6	78%	100%	78%	46	46	1.00
			avg.		*25%*						*53*	*43*	*0.81*
		Elec	E	FRN	11%		35.6	100%	80%	80%	13038	6488	0.50
		Elec	E	RM	7%		35.6	100%	100%	100%	10431	6488	0.62
			avg.		*18%*						*12031*	*6488*	*0.54*
New	South												
		Fuel	G	FRN	6%		15.6	78%	70%	55%	29	29	1.00
		Fuel	G	H2O	3%		15.6	80%	90%	72%	22	22	1.00
			avg.		*9%*						*26*	*26*	*1.00*
		Fuel	L	FRN	25%		15.6	82%	70%	57%	27	24	0.87
		Fuel	L	RM	5%		15.6	78%	100%	78%	20	10	0.48
			avg.		*29%*						*26*	*22*	*0.82*
		Elec	E	FRN	55%		15.6	100%	70%	70%	6530	3391	0.52
			avg.		*55%*						*6530*	*3391*	*0.52*
		HtPump	E	HP	6%		15.6	7*	70%		3170	1947	0.61

* Heat Pump values are in kBtu/kWh.

Sources:

1) Existing HVAC shares are from US DOE 1992. Data are segmented into North and South regions using census division and heating degree day data.

2) Building populations are based on US DOE 1994 total national building population estimates and HVAC shares noted above.

3) Prototype heating loads are calculated from prototype descriptions using ASHRAE SP53 loads database methodology (see Table 3.19).

4) Existing buildings database UEC sources: Fuel heating UECs for all building types are from US DOE 1989a. UECs for existing single-family electric heating in North are estimated from Cohen et al. 1991 for post-retrofit houses at 6000 heating degree days (see Fig. 3.8). UECs for single-family electric heating in South are estimated from utility survey data in the UEC database in South region (see Fig. 3.6). Single-family heat pump heating UECs are estimated from averages of regional utility survey data in UEC database in North and South regions (see Fig. 3.7). Electric and heat pump heating UECs for multi-family and manufactured home prototypes are estimated from fuel heating calibration multipliers and single-family UEC calibration multipliers for electric heat.

5) Database UECs for new buildings are calculated using the prototype heating load, equipment efficiency, and distribution system efficiency and the calibration multiplier from the existing vintage buildings.

6) Equipment efficiencies for the new vintage are taken from 1990 as shown in Figures 3.12 and 3.15.
For equipment not shown in these figures, or not covered by available data, efficiencies for new equipment are estimates.

7) Stock equipment efficiencies are calculated from historical shipment and efficiency data in the database with an assumed equipment lifetime. For equipment not shown in these figures, or not covered by available data, efficiencies for stock equipment are estimates.

8) Distribution system efficiencies are assumed base cases for stock and new building systems as shown in Table 3.4.

Table 3.21. Calibration of Forecasting Prototype Cooling Loads with Database UECs

Vintage	Region	Cool Type	Cool Fuel	Cool Tech	Region Cool Share (%)	Bldg Popln (mill)	Prototype Cool Load (MMBtu)	Average Efficiency Eqmt (kBtu/kWh)	Dist (%)	Prototype UEC (kWh)	Database UEC (kWh)	Calibration Multiplier
EXISTING SINGLE-FAMILY												
Existing	North											
		Central	E	CAC	0.289	9.9	8.0	8.2	80%	1230	1160	0.94
		HPump	E	HP	0.022	0.8	6.5	8.4	80%	963	1176	1.22
		Room	E	RAC	0.292	10.0	8.0	7.4	100%	1072	375	0.35
			avg.		*0.603*	*20.7*				*1143*	*781*	*0.68*
Existing	South											
		Central	E	CAC	0.402	11.3	26.2	8.2	70%	4588	3821	0.83
		HPump	E	HP	0.128	3.6	18.6	8.4	70%	3148	4077	1.29
		Room	E	RAC	0.246	6.9	27.4	7.4	100%	3692	1358	0.37
			avg.		*0.776*	*21.7*				*4067*	*3082*	*0.76*
NEW SINGLE-FAMILY												
New	North	Central	E	CAC	0.552		8.9	9.2	80%	1200	1132	0.94
		HPump	E	HP	0.129		8.8	9.4	80%	1167	1425	1.22
		Room	E	RAC	0.084		8.7	8.7	100%	1004	352	0.35
			avg.		*0.765*					*1173*	*1096*	*0.93*
New	South											
		Central	E	CAC	0.506		17.8	9.2	70%	2758	2297	0.83
		HPump	E	HP	0.311		16.9	9.4	70%	2560	3316	1.30
		Room	E	RAC	0.056		17.9	8.7	100%	2055	756	0.37
			avg.		*0.873*					*2643*	*2561*	*0.97*
EXISTING MULTI-FAMILY												
Existing	North	Central	E	CAC	0.168	2.6	7.3	8.2	80%	1114	515	0.46
		HPump	E	HP	0.019	0.3	5.6	8.4	80%	829	517	0.62
		Room	E	RAC	0.422	6.5	7.6	7.4	100%	1019	160	0.16
			avg.		*0.609*	*9.4*				*1039*	*269*	*0.26*
Existing	South											
		Central	E	CAC	0.461	4.7	15.2	8.2	70%	2652	1366	0.52
		HPump	E	HP	0.136	1.4	14.6	8.4	70%	2471	1371	0.55
		Room	E	RAC	0.152	1.6	15.5	7.4	100%	2085	424	0.20
			avg.		*0.749*	*7.7*				*2504*	*1176*	*0.47*

Table 3.21 (cont.). Calibration of Forecasting Prototype Cooling Loads with Database UECs

Vintage	Region	Cool Type	Cool Fuel	Cool Tech	Region Cool Share (%)	Bldg Popln (mill)	Prototype Cool Load (MMBtu)	Average Efficiency Eqmt (kBtu/kWh)	Dist (%)	Prototype UEC (kWh)	Database UEC (kWh)	Calibration Multiplier
NEW MULTI-FAMILY												
New	North	Central	E	CAC	0.225		4.9	9.2	80%	663	307	0.46
		HPump	E	HP	0.129		4.4	9.0	90%	548	342	0.62
		Room	E	RAC	0.484		4.9	8.7	100%	565	89	0.16
			avg.		*0.838*					*589*	*186*	*0.32*
New	South											
		Central	E	CAC	0.406		11.6	9.2	70%	1801	928	0.52
		HPump	E	HP	0.352		11.5	8.9	90%	1457	808	0.55
		Room	E	RAC	0.034		11.7	8.7	100%	1340	273	0.20
			avg.		*0.792*					*1628*	*847*	*0.52*
EXISTING MANUFACTURED HOME												
Existing	North	Central	E	CAC	0.284	0.8	4.8	8.2	80%	731	1443	1.97
		HPump	E	HP	0.008	0.0	6.5	8.4	80%	963	1544	1.60
		Room	E	RAC	0.263	0.7	4.7	7.4	100%	629	447	0.71
			avg.		*0.555*	*1.6*				*686*	*972*	*1.42*
Existing	South											
		Central	E	CAC	0.275	0.7	19.3	8.2	70%	3369	2988	0.89
		HPump	E	HP	0.04	0.1	16.5	8.4	70%	2793	3175	1.14
		Room	E	RAC	0.355	1.0	19.1	7.4	100%	2575	1007	0.39
			avg.		*0.67*	*1.8*				*2914*	*1950*	*0.67*
NEW MANUFACTURED HOME												
New	North	Central	E	CAC	0.363		6.1	9.2	80%	825	1630	1.97
		Room	E	RAC	0.351		6.1	8.7	100%	701	499	0.71
			avg.		*0.714*					*764*	*1074*	*1.40*
New	South											
		Central	E	CAC	0.516		19.7	9.2	70%	3046	2702	0.89
		HPump	E	HP	0.062		19.7	9.2	70%	3046	3463	1.14
		Room	E	RAC	0.219		19.7	8.7	100%	2264	886	0.39
			avg.		*0.797*					*2831*	*2262*	*0.80*

Sources:

1) Stock HVAC shares are from US DOE 1992. Data are segmented into North and South regions using census division and heating degree day data.

2) Building populations are based on US DOE 1994 total national building population estimates and HVAC shares noted above.

3) Database UECs for stock buildings are from LBL electricity supply curves (Koomey et al. 1991a), which are derived from prototype descriptions.

4) Database UECs for new buildings are calculated using the prototype cooling load, equipment efficiency, and distribution system efficiency and the calibration multiplier from the existing vintage buildings.

5) Equipment efficiencies for the new vintage are taken from 1990 as shown in Figure 3.12 and 3.15.
For equipment not shown in these figures, or not covered by available data, efficiencies for new equipment are estimates.

6) Stock equipment efficiencies are calculated from historical shipment and efficiency data in the database with an assumed equipment lifetime. For equipment not shown in these figures, or not covered by available data, efficiencies for stock equipment are estimates.

7) Distribution system efficiencies are assumed base cases for stock and new building systems as shown in Table 3.4.

8) Prototype heating loads are calculated from prototype descriptions using ASHRAE SP53 loads database methodology (see Table 3.19).

3.6. Standards

Equipment Standards

Efficiency standards for space conditioning equipment were enacted in 1987 under the National Appliance Energy Conservation Act (NAECA). The date of initial implementation depends upon the type of equipment. The standards for heating equipment are given in Table 3.22, while those for cooling are given in Table 3.23. All standards are based on an efficiency (or energy factor) derived from a test procedure.

Table 3.22. Minimum Efficiency Standards for Residential Heating Equipment (1)

Type	Database Code	Fuel	Year Effective (2)	Minimum Efficiency (3)	
Heat Pump					
Split System	HP	Elec	1992	6.8	HSPF
Single Package	HP	Elec	1993	6.6	HSPF
Furnace	FRN	Gas	1992	78	AFUE
Furnace	FRN	Oil	1992	78	AFUE
Boiler	H2O	Gas	1992	80	AFUE
Boiler	H2O	Oil	1992	80	AFUE
Direct Heating					
wall heater w/fan					
<42000 Btu/hr	RM	Gas	1990	73	AFUE
>42000 Btu/hr	RM	Gas	1990	74	AFUE
wall heater (gravity)					
<10000 Btu/hr	RM	Gas	1990	59	AFUE
10-12000 Btu/hr	RM	Gas	1990	60	AFUE
12-15000 Btu/hr	RM	Gas	1990	61	AFUE
15-19000 Btu/hr	RM	Gas	1990	62	AFUE
19-27000 Btu/hr	RM	Gas	1990	63	AFUE
27-46000 Btu/hr	RM	Gas	1990	64	AFUE
>46000 Btu/hr	RM	Gas	1990	65	AFUE
floor heater					
<37000 Btu/hr	RM	Gas	1990	56	AFUE
>37000 Btu/hr	RM	Gas	1990	57	AFUE
room heater					
<18000 Btu/hr	RM	Gas	1990	57	AFUE
18-20000 Btu/hr	RM	Gas	1990	58	AFUE
20-27000 Btu/hr	RM	Gas	1990	63	AFUE
27-46000 Btu/hr	RM	Gas	1990	64	AFUE
>46000 Btu/hr	RM	Gas	1990	65	AFUE
Shipment-weighted avg (4)				*64*	*AFUE*

1) All standards levels from NAECA 1987.
2) Effective date is January 1 of year indicated.
3) AFUE is Annual Fuel Utilization Efficiency (%); HSPF is Heating Season Performance Factor (kBtu/kWh).
4) Shipment-weighted average standard-level for direct heating equipment based on 1993 shipments (GRI 1994).

Table 3.23. Minimum Efficiency Standards for Residential Cooling Equipment (1)

Type	Database Code	Fuel	Year Effective (2)	Minimum Efficiency (3)	
Central Air Conditioner					
Split System	CAC	Elec	1992	10.0	SEER
Single Package	CAC	Elec	1993	9.7	SEER
Heat Pump					
Split System	HP	Elec	1992	10.0	SEER
Single Package	HP	Elec	1993	9.7	SEER
Room Air Conditioner					
w/o reverse cycle and w/louvers					
<6000 Btu/hr	RAC	Elec	1990	8.0	EER
6000-7999 Btu/hr	RAC	Elec	1990	8.5	EER
8000-13999 Btu/hr	RAC	Elec	1990	9.0	EER
14000-19999 Btu/hr	RAC	Elec	1990	8.8	EER
>20000 Btu/hr	RAC	Elec	1990	8.2	EER
w/o reverse cycle and w/o louvers					
<6000 Btu/hr	RAC	Elec	1990	8.0	EER
6000-7999 Btu/hr	RAC	Elec	1990	8.5	EER
8000-13999 Btu/hr	RAC	Elec	1990	8.5	EER
14000-19999 Btu/hr	RAC	Elec	1990	8.5	EER
>20000 Btu/hr	RAC	Elec	1990	8.2	EER
w/reverse cycle and w/louvers	RAC	Elec	1990	8.5	EER
w/reverse cycle and w/o louvers	RAC	Elec	1990	8.0	EER
Shipment-weighted average standard (4)				*8.5*	*EER*
Room Air Conditioner					
w/o reverse cycle and w/louvers					
<6000 Btu/hr	RAC	Elec	2000	9.7	EER
6000-7999 Btu/hr	RAC	Elec	2000	9.7	EER
8000-13999 Btu/hr	RAC	Elec	2000	9.8	EER
14000-19999 Btu/hr	RAC	Elec	2000	9.7	EER
>20000 Btu/hr	RAC	Elec	2000	8.5	EER
w/o reverse cycle and w/o louvers					
<6000 Btu/hr	RAC	Elec	2000	9.0	EER
6000-7999 Btu/hr	RAC	Elec	2000	9.0	EER
8000-13999 Btu/hr	RAC	Elec	2000	8.5	EER
14000-19999 Btu/hr	RAC	Elec	2000	8.5	EER
>20000 Btu/hr	RAC	Elec	2000	8.5	EER
w/reverse cycle and w/louvers					
<20000 Btu/hr	RAC	Elec	2000	9.0	EER
>20000 Btu/hr	RAC	Elec	2000	8.5	EER
w/reverse cycle and w/o louvers					
<14000 Btu/hr	RAC	Elec	2000	8.5	EER
>14000 Btu/hr	RAC	Elec	2000	8.0	EER
casement-only	RAC	Elec	2000	8.7	EER
casement-slider	RAC	Elec	2000	9.5	EER

1) All standards levels from NAECA 1987, except for latest room air standards (1997 Final Rulemaking in Federal Register vol. 62, no. 185).
2) Effective date is January 1 of year indicated, except for latest room air standards, which become effective October 1, 2000.
3) SEER is seasonal energy efficiency ratio (kBtu/kWh); EER is energy efficiency ratio (kBtu/kWh).
4) Shipment-weighted average standard based on 1994 shipments (AHAM 1996).

4. WATER HEATING END-USE DATA

Water heating accounts for approximately 15% of electricity usage and 25% of natural gas consumption in residential buildings. Water heating is comparable to space heating in terms of the complexity of the issues surrounding level of usage, behavioral impacts, and climatic impacts. Water heat energy use varies widely across households, which is partly due to household size (Kempton 1984), as well as the ages of members of the household and the presence of other appliances that use hot water, such as dishwashers and clotheswashers (Lutz et al. 1996). In addition, there are subtle climatic effects on water heating energy use, since colder areas of the country also have colder inlet water temperatures and thus greater water heating requirements. This affects both the amount of energy needed to heat a gallon of water to a specific temperature and the fraction of hot water needed to yield warm water at the tap.

Water heating is a complex end-use because of the unknowns involved, including hot water demand in gallons, incoming cold water temperatures, and the hot water temperature at the point of use. These parameters are inter-related. For example, if the hot water temperature of the storage water heater is higher, less hot water will be needed to meet a certain need since it is usually mixed with cold water to achieve the desired temperature.

4.1. Water Heating UECs

Measured data on electric water heating UECs are plentiful, but show the large variability previously described. Measured data on gas water heat energy use is limited; the RECS conditional demand estimates and a few studies summarized by Usibelli (1984) provide virtually the only estimates of national average gas water heating energy use. Other measurement studies (with a few notable exceptions) have failed to capture the important data necessary for truly understanding how hot and cold water are used in US residences. For example, studies often report the number of gallons per day of hot water use per household, averaged over all households with different appliances. This number is only useful for determining total water heating energy use--it provides no guidance as to what impact different conservation measures might have on that usage. It is also of limited usefulness in assessing the energy use for water heating in a particular household. The only way to assess such issues is to disaggregate total hot water use to reflect the various components of hot water loads. For these reasons, forecasting models usually calculate water heating UECs according to engineering principles. However, these calculations require assumptions regarding key parameters.

UEC equation

There are several different ways of incorporating usage and efficiency data in calculating water heating UECs. The equations below show a simplified method that uses the Energy Factor of a water heater determined from the DOE test procedure.

Electric: $$\text{kWh/yr} = \frac{\text{Use * TempRise * 8.2928 * 365}}{\text{3413 Btu/kWh * (EF/100)}}$$

Fuel: $$\text{MMBtu/yr} = \frac{\text{Use * TempRise * 8.2928 * 365}}{\text{(EF/100)}}$$

where: Use is the household hot water use (gallons/day)

TempRise = annual avg. temperature difference between incoming cold water and tank temperature (77° F)

8.2928 is the specific heat of water (Btu/gal-F)

365 is days per year

EF is the energy factor from the DOE test procedure (%)

This equation may not be valid for levels of consumption that are far from the base test procedure usage, however. In order to evaluate the effects of policies on household level hot water use, one must develop “bottom-up” estimates of water usage. Such estimates are based on realistic estimates of usage behavior (such as number of minutes per person per day) and flow rates (gallons per minute) of particular devices (showers, baths, faucets, toilets, dishwashers, clotheswashers, and landscaping/other). Once overall usage patterns are established, one must account for three factors affecting hot water use: energy factor (the energy delivered in the hot water at the tap, divided by total energy input); recovery efficiency (the efficiency of delivering heat to the water in the tank); and standby losses (the constant losses associated with keeping the water in the tank hot and ready for use). These three factors are related using the following equations (Koomey et al. 1994b):

$$\text{Energy Factor} = \frac{\text{Energy content of hot water delivered}}{\text{Total energy used to heat the water}}$$

$$\text{Total energy used to heat water} = \frac{(\text{Energy content of hot water delivered} + \text{Standby losses})}{\text{Recovery eficiency}}$$

Table 4.1 shows estimates for the three components of water heater energy use, for both stock and new water heaters before and after the 1990 energy efficiency standards. The shipment-weighted energy factors are taken from AHAM (1996), while the average recovery efficiencies are from US DOE (1993c). Standby losses are calculated from the other two factors. The table demonstrates that manufacturers met the energy factors specified in the 1990 water heater standards by reducing standby losses rather than by increasing recovery efficiency. The final column shows the efficiency potential of a heat pump water heater.

Table 4.1. Characteristics of water heaters

	Units	*Stock 1990*	*Stock 1993 w/1990 stds*	*New late 1980s*	*New 1990*	*Heat Pump Water Heater*
Energy Factors						
Electricity	%	82%	83%	84%	88%	189%
Gas	%	49%	50%	49%	54%	–
Oil	%	46%	46%	47%	51%	--
Standby losses						
Electricity	Wh.th/hr	97	89	86	57	10
Electricity	Btus.th/hr (site)	332	303	294	194	34
Gas	Btus.th/hr	1576	1453	1510	1125	–
Oil	Btus.th/hr	1576	1453	1510	1125	–
Recovery efficiency						
Electricity	%	98%	98%	98%	98%	193%
Gas	%	76%	76%	76%	76%	–
Oil	%	76%	76%	76%	76%	--

(1) Standby losses and recovery efficiency for gas and electric water heaters (WHs) derived from US DOE (1993c). Oil water heaters assumed to be the same as gas.
(2) Energy factors (EFs) for stock (1990 and 1993) and late 1980s sales derived from historical shipments taken from Hanford et al. 1994. EFs for 1990 sales equal the 1990 standards. Recovery effici ency for heat pump water heaters varies depending on water temperatures. Recovery efficiency shown here is an overall average.
(3) (Standby losses + the heat content of water used)/recovery efficiency = total WH energy use.
Energy factor = the heat content of water used/total WH energy use.
(4) Calculation of Stock and late 1980s sales standby losses assumes that all measures used by manufacturers to improve the WH EF affected only standby losses.
(5) Wh.th/hr = watt-hour (thermal) per hour; Btus.th/hr = Btus (thermal) per hour.

Stock UECs

The weighted average UECs from several studies are 3660 kWh/yr (n=105) for electric water heating and 23.6 MMBtu/yr (n=31) for gas water heating across all building types (Appendix A). We assume that oil water heater UECs are the same as gas for stock units. There are few measured data specifically addressing the difference between water heat usage between housing types, so we do not distinguish water heating UECs by house type.

New UECs

UECs for new water heaters are calculated based on the UEC for stock units, adjusted for the percentage difference between the average energy factor for new water heaters in 1984 and 1990, derived from historical efficiency data (see Figure 4.4 and below). Over that period, average energy factor for electric units increased 5.3%, while the energy factor for gas units increased 2.7%. Therefore, we estimate that UECs for new water heaters are 3466 kWh/yr for electric, and 23.0 MMBtus for gas and oil. Table 4.2 provides 1990 stock and new water heating UECs.

Table 4.2. Water Heating UECs

Fuel Type	1990 Stock	1990 New
Electric (kWh/yr)	3660	3466
Gas (MMBtu/yr)	23.6	23.0
Oil (MMBtu/yr)	23.6	23.0

1) Stock electric and gas UECs from Appendix A.
2) New electric and gas UECs estimated based on 1990 stock UECs and changes in new unit efficiency from 1984 to 1990 (Figure 4.4).

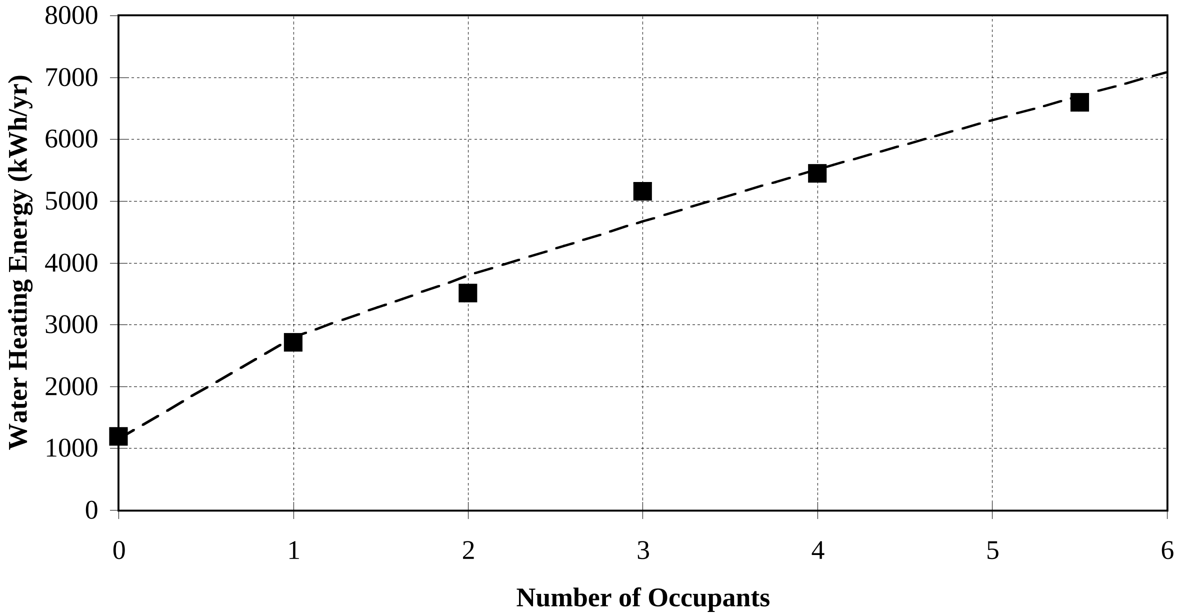
Both the stock and new UECs do not accout for water efficiency standards for plumbing fittings in the Energy Policy Act of 1990. Therefore, they may slightly over-estimate the average UEC.

4.2. Hot Water Usage

In a summary of hot water usage studies, Usibelli (1984) estimates that hot water consumption averages 17.7 gallons per person per day. Several different metered studies in the Pacific Northwest estimate per capita water use between 16.5 and 21.0 gallons per day. Measured data from the BPA REMP program (Taylor et al. 1991) specifically gives electric water heating energy use across number of occupants (see Figure 4.1). Assuming standby losses (energy use at zero usage) and a 77° F temperature rise, a quadratic fit through the kWh data allows the calculation of gallons for the level of occupancy. These data are shown in Figure 4.2. The quadratic curve means that the incremental hot water consumption drops off with increasing numbers of persons per home. At the national average of 2.61 persons per household (US DOE 1992), these data give national average hot water consumption of 45.3 gallons per day per household, or 17.5 gallons per person per day, which compares well with the other estimates of per capita usage. Assuming a 77° F rise between the incoming cold water temperature and the hot water setpoint temperature, 45.3 gallons per day per household gives UECs that are similar to the estimated UECs shown above. A more recent study, using the "bottom-up" methodology described in Section 4.1, shows total hot water use for average early 1990s dwellings of 59.5 gallons per day (Koomey et al. 1994b).

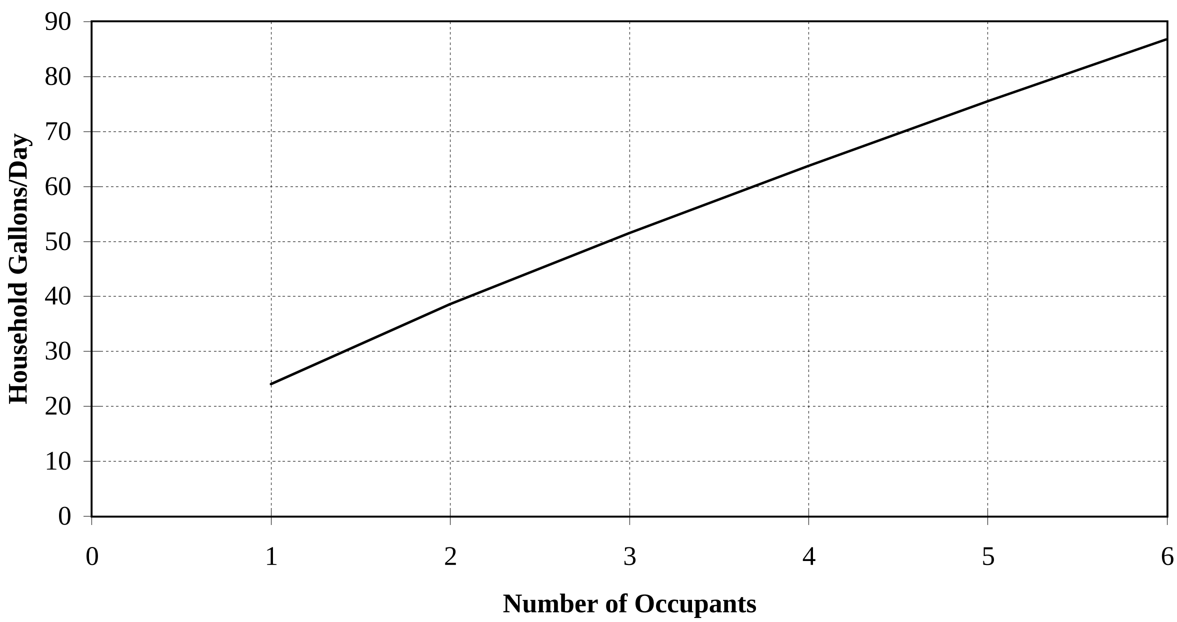
The estimates are in disagreement with the usage assumed in the U.S. DOE test procedure for water heaters, where the average usage is 64.3 gallons per day. A summary of several available water heating studies for ASHRAE supported average usage levels near the U.S. DOE test procedure level (ASHRAE 1991), but these were not necessarily representative samples.

Figure 4.1. Water Heating Energy vs Household Size, Raw Data and Quadratic Fit



Source: Taylor et al. 1991. Data includes 200 houses in sample (single-family only). Quadratic fit gives R-squared of 0.983. Standby losses (usage at zero occupancy) are estimated from vacation days during monitoring period.

Figure 4.2. Hot Water Consumption vs Household Size



Source: Calculated from kWh vs. household size regression results assuming 77 F temperature rise. At national average 2.61 persons/household (US DOE 1993a), hot water consumption is 45.3 gal/day/household, or 17.5 gal/day-capita.

Gilbert and Associates developed a residential hot water consumption model for the Electric Power Research Institute (EPRI) in 1985 (Ladd 1985). This model was specifically designed to estimate hot water usage in households with higher than average water use. The EPRI model has been modified to predict hot water demand by time-of-day for a broader variety of households, including those that do not own dishwashers or clotheswashers (Lutz et al. 1996). However, the model still relies on hot water metering data from studies conducted 10 to 15 years ago; more recent measurements of hot water use are needed to improve estimates of water heating UECs.

4.3. Water Heating Technology Data

There are two basic types of water heater technology: individual storage water heaters (STR), where water is heated in a tank for individual households, and common storage water heating systems (CMN), which are found in multi-family buildings. A third technology type, small instantaneous water heaters, are a small portion of the market and are not included. Technology data on common systems are not available.

Historical Efficiency Data

Shipments of each type of storage water heater are shown in Figure 4.3 and the energy factor of new storage water heaters sold over time is shown in Figure 4.4. Efficiencies have apparently changed little since 1980. Efficiencies associated with common water heating systems in multi-family buildings are not well known.

Cost vs. Efficiency for New Equipment

Estimates of cost vs. efficiency for new water heaters purchased for electric and gas storage-type water heaters are shown in Figure 4.5 and 4.6. Heat pump water heaters are still in small production volumes and are not currently available on a wide basis.

Product Lifetimes

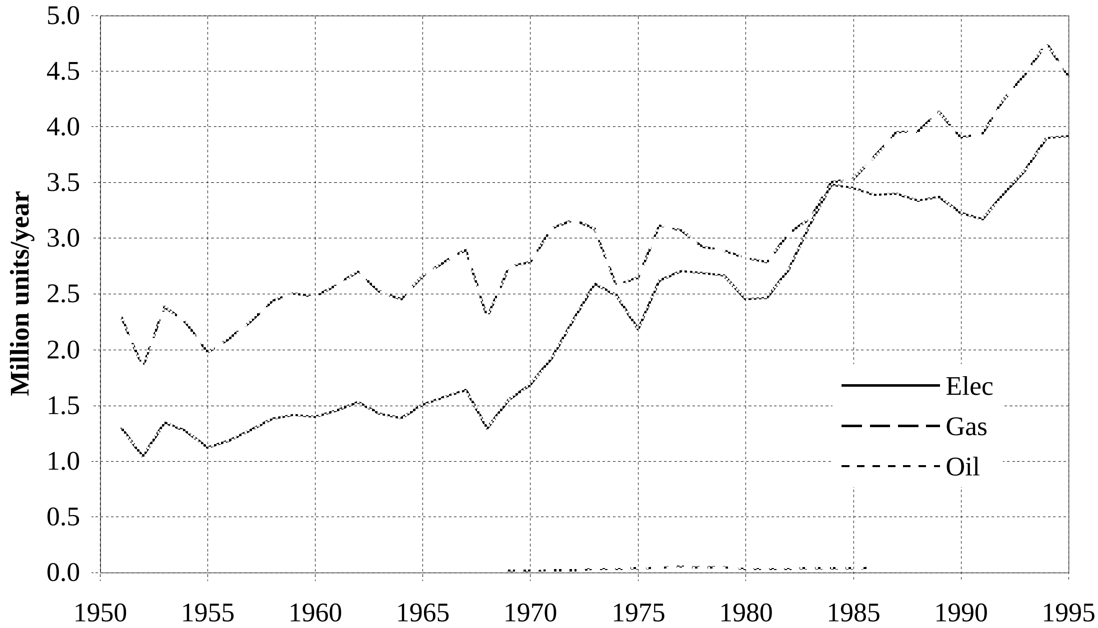
Estimates of storage water heater lifetimes from several sources are listed in Table 4.3.

Table 4.3. Estimates of Residential Storage Water Heater Lifetimes

		Lifetime in Years		
Source	Estimate	Gas Water Heater	Oil Water Heater	Electric Water Heater
Appliance	Low	5	n/a	5
	Avg	9	n/a	10
	High	14	n/a	16
Lewis/Clark	Low	10	n/a	10
	Point	10	n/a	12
	High	15	n/a	15
LBNL/REM	Low	n/a	4	5
	Avg	14	11	10
	High	n/a	15	14

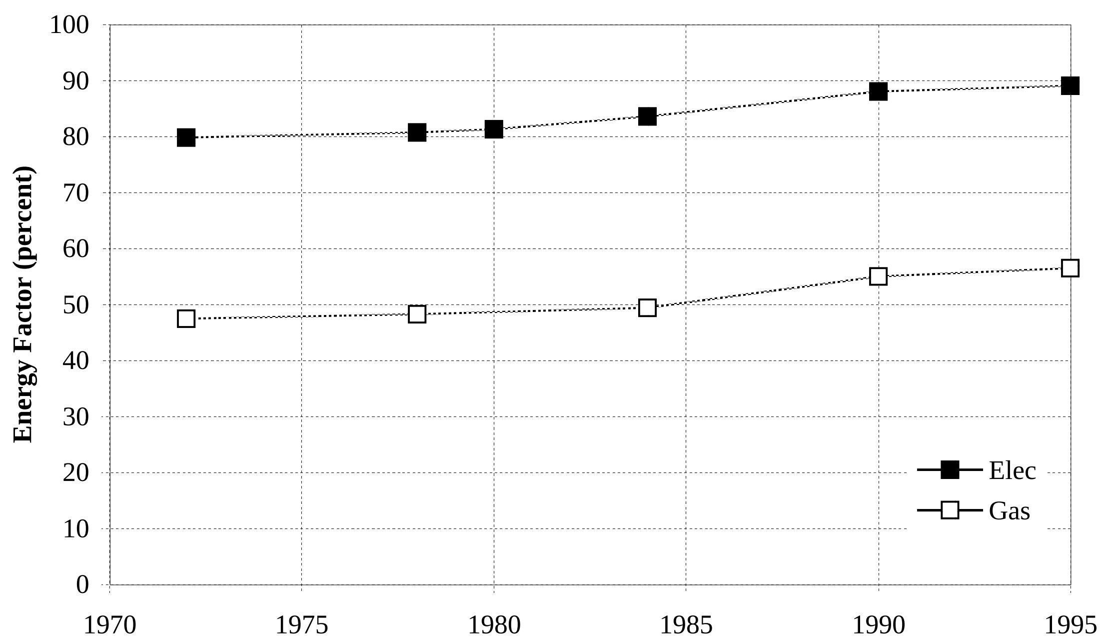
Sources: Appliance 1996 (first owner lifetime only); ASHRAE 1987; Lewis and Clarke 1990; LBNL-REM 1991.

Figure 4.3. Annual Storage Water Heater Shipments, 1951-1995



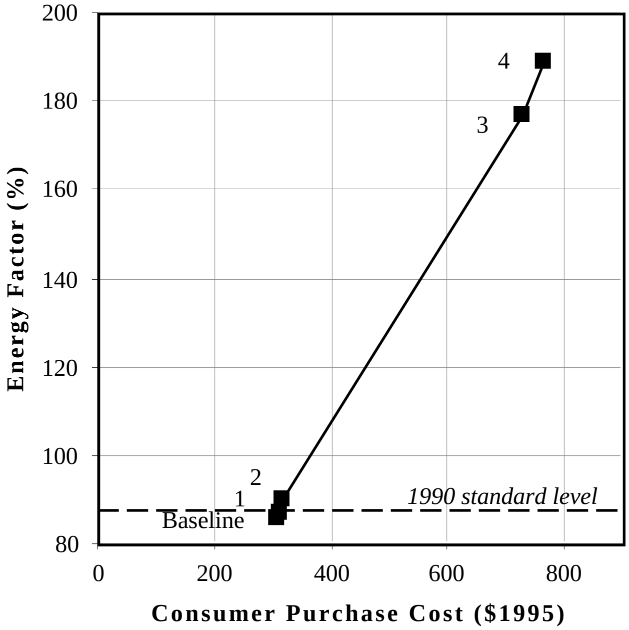
Source: GAMA 1995. Gas includes LPG appliances.

Figure 4.4. Average Energy Factor for Storage Water Heaters, 1972-1995



Source: US DOE 1982b, GAMA 1991, NAECA 1987, GAMA 1995.
1990 values are NAECA standards for a unit with the average volume; 1995 values are unweighted average energy factors of all available models.

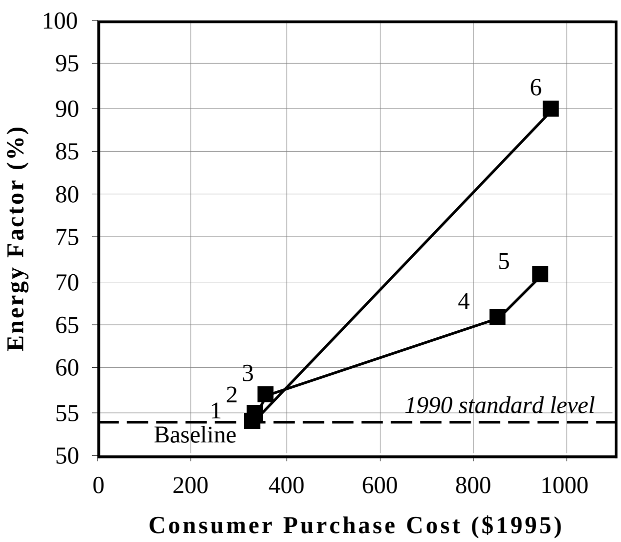
Figure 4.5. Cost Versus Efficiency for New Electric Storage Water Heater



Option	Description
Baseline	Electric water heater - 52 gallon unit
1	0 + Reduce Heat Leaks
2	1 + Heat Traps
3	2 + Add On Heat Pump
4	3 + R-25 Insulation

Source: US DOE 1993c. Costs adjusted from $1990 using the chain type price index for personal consumption expenditures of 1.158.

Figure 4.6. Cost Versus Efficiency for New Gas Storage Water Heater



Option	Description
Baseline	Gas water heater - 40 gallon unit, 1990 Standard
1	0 + Heat Traps
2	1 + Reduce Heat Leaks
3	2 + R-16 Insulation
4	3 + Improve Flue Baffle with Standard Venting
5	4 + Electronic Ignition w/Flue Damper
6	0 + Submerged Combustion

Source: US DOE 1993c. Annual electricity use is 137 kWh for option 5 and 356 kWh for option 6. Costs adjusted from $1990 using the chain type price index for personal consumption expenditures of 1.158.

4.4. Market Shares

We derived fuel and technology market shares for water heating at the national level. Stock market shares are from the RECS data for 1981, 1984, 1987, 1990, and 1993. Market shares in new buildings are derived for buildings built during the previous 5 to 7 years from the RECS data (for example, market shares in new construction in 1993 are derived from the 1993 RECS data for buildings built between 1988 and 1993). Stock market shares over time, as well as new market shares by housing type from the 1993 RECS data, are shown in Figures 4.7 and 4.8. According to the RECS data, electric water heating gained market share from 1981 to 1993, while fuel-fired systems market shares have been dropping. Market shares by fuel in new single- and multi-family homes are fairly equal, while nearly all units in new manufactured homes are electric. (The multi-family saturations include common systems, which include hydronic boilers that may be used for both space- and water-heating).

4.5. Standards

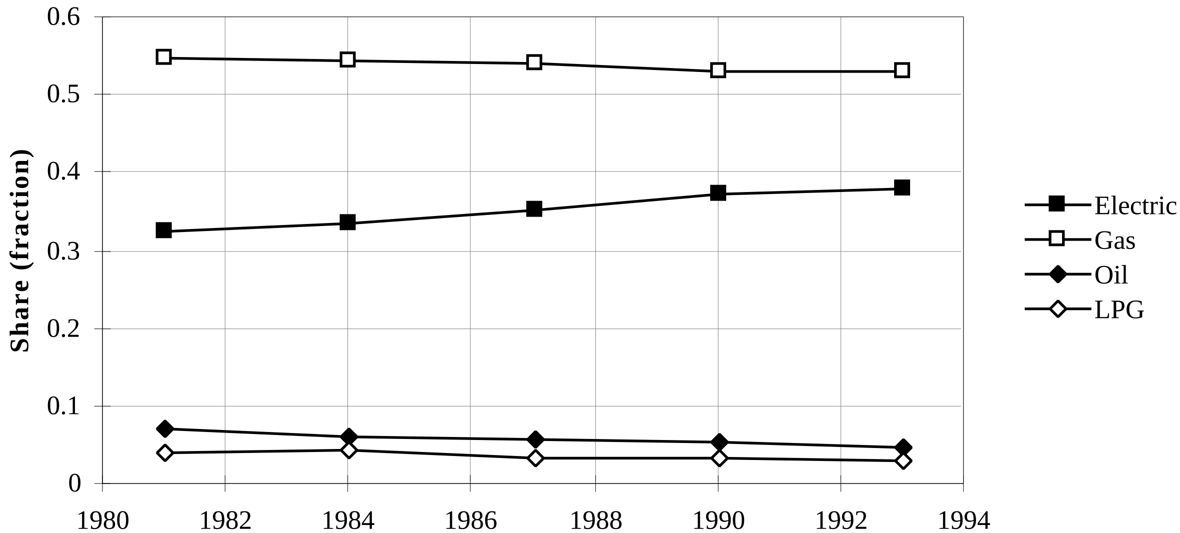
Efficiency standards for water heaters were enacted in 1987 under the National Appliance Energy Conservation Act (NAECA) and were implemented in 1990. The standard specifies a minimum energy factor for storage water heaters based on water heater size. The energy factor is based on the U.S. DOE test procedure mentioned above. The standard and estimated UECs associated with the standard are shown in Table 4.4.

Table 4.4. Minimum Efficiency Standards for Residential Storage Water Heaters

Fuel	Year Eff.	Minimum Efficiency Standard Equation	Average Volume	Calculated Standard EF	Calculated Standard UEC
Gas	1990	EF=0.62-(0.0019 * Volume)	40 gallons	0.54	19.4 MMBtu/yr
Oil	1990	EF=0.59-(0.0019 * Volume)	32 gallons	0.51	20.5 MMBtu/yr
Electric	1990	EF=0.95-(0.00132 * Volume)	52 gallons	0.88	3510 kWh/yr

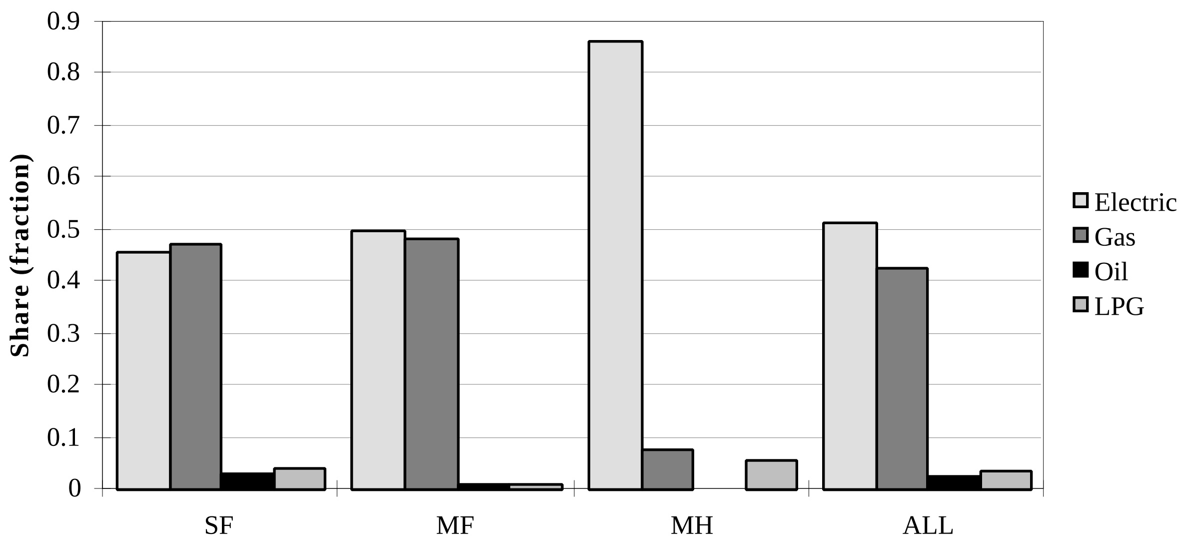
1) Effective date is January 1 of year indicated.
2) Standard level from NAECA 1987. Volume is rated storage volume in gallons.
3) Average volume is for typical size unit.
4) UEC based on usage of 45.3 gal/day and at 77F temperature rise.

Figure 4.7. Water Heating Fuel Shares in Total Housing Stock, 1981-1993



Source: US DOE 1982a, 1986, 1989a, 1993b, 1995b.
13% of multifamily units with Electric have common systems, 55% of multifamily units with Gas have common systems, and 94% of multifamily units with Oil have common systems. Common systems include hydronic boilers that provide both space- and water-heating.

Figure 4.8. Water Heating Fuel Shares for New Construction by Housing Type



Source: US DOE 1995b data for buildings built between 1988 and 1993.
6% of multifamily units with Electric have common systems, 35% of multifamily units with Gas have common systems, and 64% of multifamily units with Oil have common systems. Common systems include hydronic boilers that provide both space- and water-heating.

5. REFRIGERATOR END-USE DATA

Refrigerators are the single largest consumer of electricity among the typical household appliances. Refrigerators use approximately 125 TWh or 15% of residential electricity consumption. This is due to the fact that refrigerators are present in almost all households, a large percentage of households have multiple refrigerators, and each unit uses a significant amount of electricity. Refrigerators have been extensively studied, and occupant behavior has relatively small effects, so refrigerator energy consumption is well understood. Refrigerator UEC depends slightly on ambient temperature.

5.1. Refrigerator UECs

Refrigerator UECs for new units are measured using a laboratory test procedure from U.S. DOE. Research has shown that this test provides a reasonably good estimate of actual field usage, but it is not exact (Meier and Heinemeier 1990). The UEC database of measured and estimated data on field energy usage of refrigerators contains 98 records, and the estimates show large variability (Appendix A). This variability may be partly due to large improvements in efficiency of the refrigerators entering the appliance stock. In addition, there are several different classes of refrigerators (manual defrost, automatic defrost), size differences, and variations in features that affect the energy consumption of the unit.

UEC equation

The equation below shows the relationship between efficiency, capacity (volume), and energy consumption for refrigerators used in standards setting procedures and in the U.S. DOE test procedure.

UEC: $$\text{kWh/yr} = \frac{365 * \text{Capacity}}{\text{EF}}$$

where: 365 is days per year

Capacity is adjusted volume (cubic feet)

Adjusted volume = 1.63 x freezer volume (cubic feet) + refrigerator volume (cubic feet)

EF is the energy factor from the DOE test procedure (cubic feet-day/kWh)

Stock UECs

We estimate the 1990 stock average UEC for refrigerators (based on the test procedure) to be 1270 kWh/yr. based on historical shipment data of test UECs for refrigerators (AHAM 1991) and a straight line decay function with a minimum lifetime of 7 years and a maximum lifetime of 29 years. The analysis of available data for refrigerators in the UEC database (n=57 for studies that are generally representative of all product classes) suggests that the UEC may be lower, at around 1144 kWh/yr (Appendix A). For automatic defrost units only, which represent the majority of the stock, the UEC database analysis results are 1338 kWh/yr. Overall, the UEC database results are slightly lower than the test values, which is consistent with earlier findings (Meier and Heinemeier 1990). To maintain consistency with the AHAM historical data, we include the estimate based on the AHAM data in the UEC database.

New UECs

New unit average UEC derived from the laboratory tests and reported by the industry for 1990 is 916 kWh/yr for the overall average sales of new refrigerators. This is similar to the average for top-freezer automatic defrost units, which comprise approximately 67% of the new refrigerator market (AHAM 1991). The new unit average UEC has dropped dramatically in the past few years, to 649 kWh/yr in 1995, due to the new federal efficiency standards for refrigerators that took effect in 1993.

5.2. Refrigerator Usage

Recent research suggests that the DOE test procedure for refrigerators accurately predicts the actual consumption of a group of refrigerators within 10 percent. A review of recent studies found that several factors can affect actual energy use. The most important is ambient temperature; a reduction in ambient temperature by only a few degrees can reduce energy use by 5 to 20 percent. Door openings and humidity also slightly affect energy consumption, while refrigerator maintenance, such as cleaning coils or replacing gaskets, has relatively little effect (Meier 1995).

5.3. Refrigerator Technology Data

As previously stated, there are several different classes of refrigerators that each have specific performance characteristics related to energy use. In this sourcebook we include technology data that best represent the entire refrigerator market. For some measures, we include data that are an average across all refrigerator types. For other measures, we include data on top-mounted auto defrost refrigerators, which accounts for approximately two-thirds of the unit sales and has characteristics that approximate the market average.

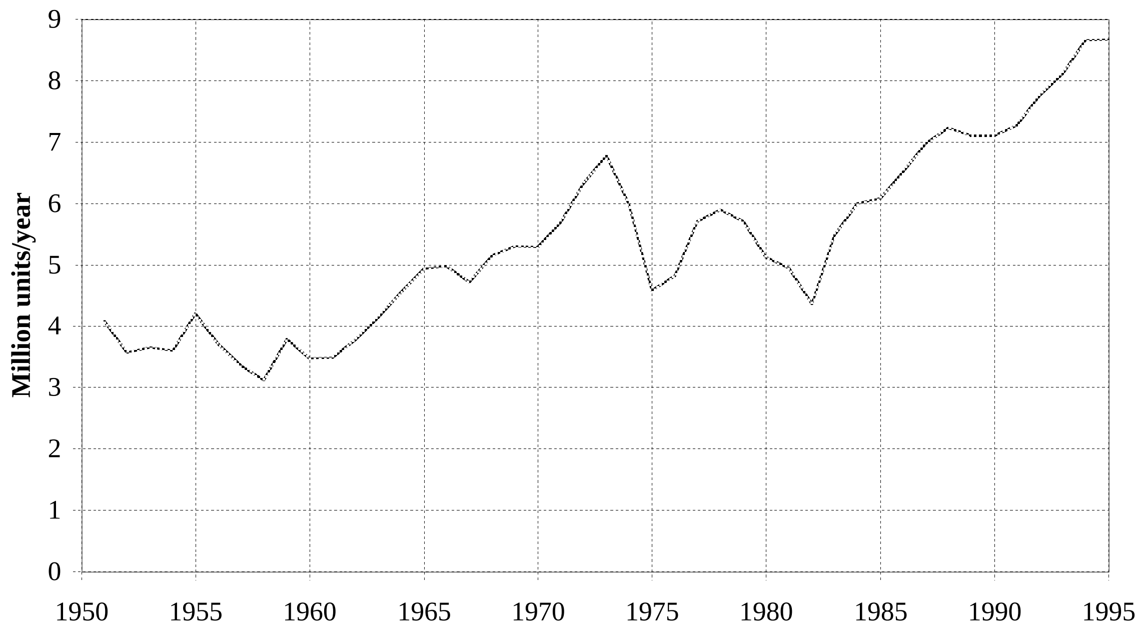
Historical Efficiency Data

Annual refrigerator shipments from 1951 to 1995 are shown in Figure 5.1 and the overall average efficiency of new refrigerators sold over time is shown in Figure 5.2 along with the average size (capacity, or adjusted volume, in cubic feet). Efficiencies have risen dramatically since the first recorded data in 1972. Technological changes (such as the transition from fiberglass to polyurethane foam insulation in the 1970s) and minimum efficiency standards (in California in 1978 and nationally in 1990 and 1993) are the major factors influencing this trend. Note that average capacity has not change significantly over the last 15 years. A recent study indicates that manufacturers were able to meet the energy efficiency standards for refrigerators, while increasing average capacity and providing more amenities (such as glass shelving), without significantly increasing purchase prices (Greening et al 1996).

Cost vs. Efficiency for New Equipment

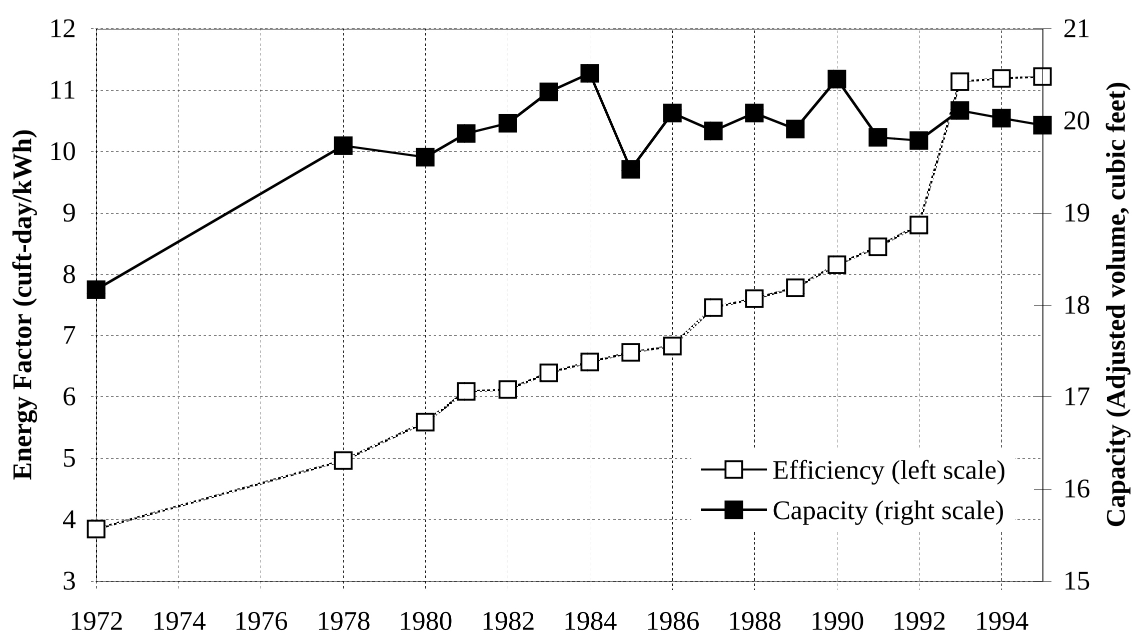
Estimates of cost vs. efficiency for new top-mounted automatic defrost refrigerators are shown in Figure 5.3. The values are based on data from the U.S. DOE appliance standards analysis (US DOE 1995c), adjusted to 1995$.

Figure 5.1. Annual Refrigerator Shipments, 1951-1995



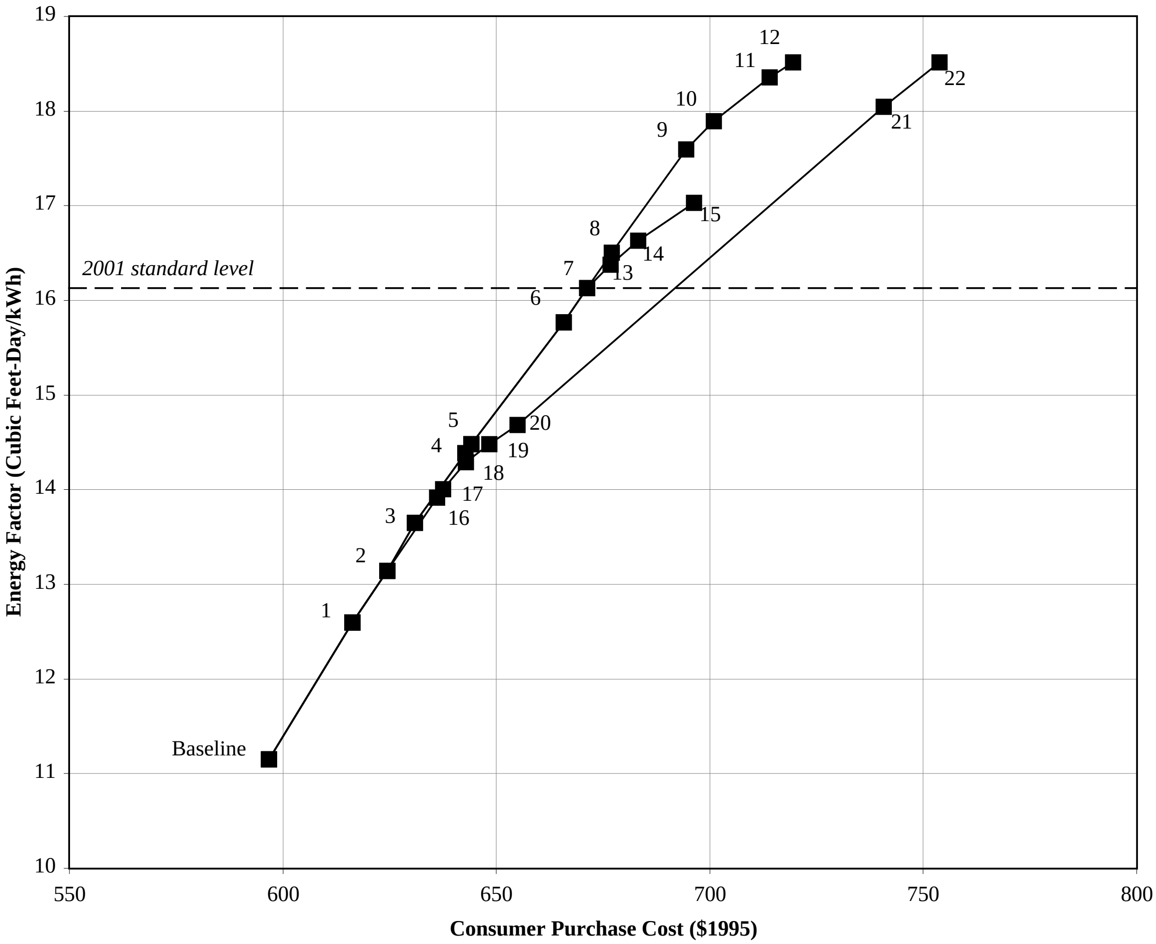
Source: AHAM data given in USDOE 1989b and AHAM 1995.

Figure 5.2. Shipment-Weighted Energy Factor and Capacity for Refrigerators, 1972-1995



Source: AHAM 1995.

Figure 5.3. Cost Versus Efficiency for New Top-Mount, Auto Defrost Refrigerator-Freezer



Source: US DOE 1995c. Costs adjusted from $1992 using the chain type price index for personal consumption expenditures of 1.076.

Option	Description	Option	Description
Baseline	21.4 cu.ft. adjusted volume. Top-mount freezer, auto defrost. Meets 1993 Standard. No CFCs.		
1	0 + 5.45 EER Compressor	13	7 + Increase Evaporator Area
2	1 + Reduce Condenser Motor Power	14	13 + Increase Condenser Area
3	2 + Add 1/2" Insulation to Doors	15	14 + Adaptive Defrost
4	3 + Reduce Evaporator Motor Power		
5	4 + Improve Evaporator Fan Efficiency	16	2 + Reduce Evaporator Motor Power
6	5 + Add 1/2" Insulation to Walls	17	16 + Improve Evaporator Fan Efficiency
7	6 + Reduce Gasket Heat Leak	18	17 + Reduce Gasket Heat Leak
8	7 + Add Another 1/2" Insulation to Doors	19	18 + Increase Evaporator Area
9	8 + Add Another 1/2" Insulation to Walls	20	19 + Increase Condenser Area
10	9 + Increase Condenser Area	21	20 + Vacuum Panels on Walls & Doors
11	10 + Adaptive Defrost	22	21 + Adaptive Defrost
12	11 + Increase Evaporator Area		

Product Lifetimes

Estimates of the lifetimes of refrigerators are listed in Table 5.1.

Table 5.1. Estimates of Residential Refrigerator Lifetimes

Source	Estimate	Years
Appliance	Low	10
	Avg	15
	High	20
LBNL/REM	Low	13
	Avg	19
	High	25

Sources: Appliance 1996 (first owner lifetime only); LBNL-REM from Fechtel et al 1980.

5.4. Market Shares

National stock market shares for refrigerators by housing type are derived from the RECS data (US DOE 1982a, 1986, 1989a, 1993b, 1995b). Total market shares and specific market shares for manual defrost and automatic defrost can be derived from RECS. Market shares in new buildings are derived for buildings built during the previous 5 to 7 years from the RECS data (for example, market shares in new construction in 1993 are derived from the 1993 RECS data for buildings built between 1988 and 1993). Some of these data are shown in Figures 5.4 and 5.5. Note that these are total "saturations" of refrigerators (market shares x housing stock = refrigerator stock) to account for multiple refrigerators per household. The share of houses with no refrigerators is virtually zero.

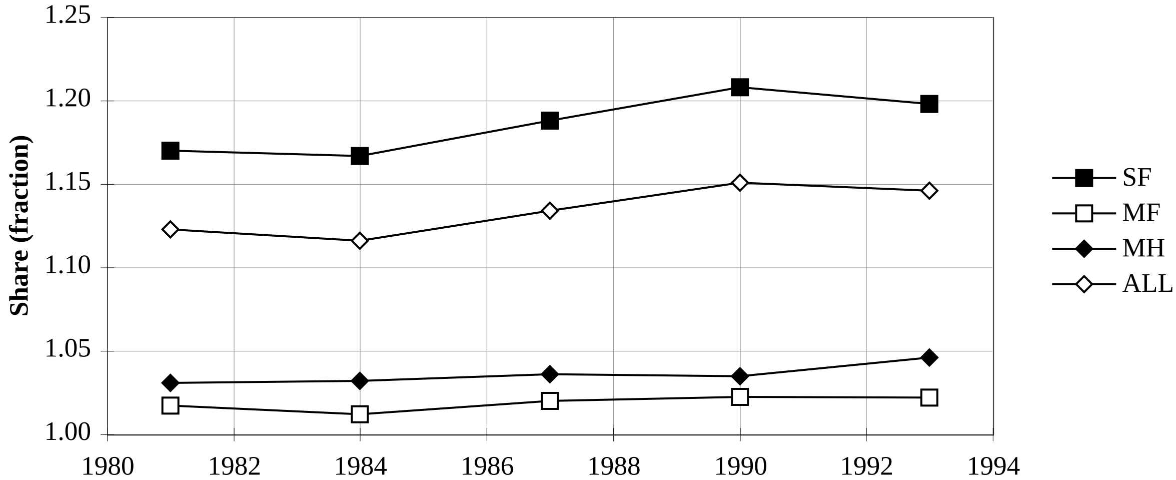
According to the RECS data, the number of refrigerators per household is growing over time. In comparing the stock market shares with new market shares, we see that this growth is not necessarily due to greater refrigerator saturations in newly constructed homes since the "new" market shares are essentially the same as for the stock as a whole. This suggests that the growth in refrigerator saturations is mainly due to the acquisition of second refrigerators in existing houses. On the other hand, the 1993 RECS data show a slight decrease in saturations, suggesting that the increase in previous years may be within the uncertainty of the RECS survey sample.

5.5. Standards

National efficiency standards for refrigerators were enacted under the National Appliance Energy Conservation Act (NAECA) and first implemented in 1990. The standard specifies a maximum energy use for refrigerators based on the type of refrigerator and the size. The energy usage is based on the U.S. DOE test procedure. More stringent standards were implemented in 1993; a third round of national standards will become effective July 1, 2001. The standard levels are summarized in Table 5.2.

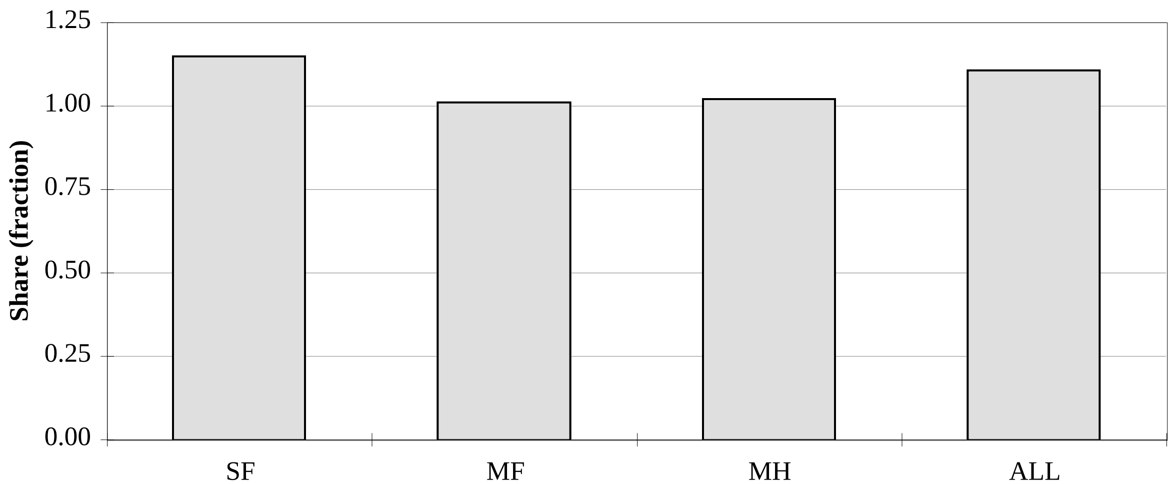
Note that the 2001 standards will result in a near-doubling of the average energy factor under the 1990 standard levels, and a near-tripling of the average energy factor in 1980 (Figure 5.2). In other words, the average energy consumption of new units will have been reduced by nearly two-thirds over a twenty-year period.

Figure 5.4. Refrigerator Ownership Shares by Housing Type, 1981-1993



Source: US DOE 1982a, 1986, 1989a, 1993b, 1995b.
Shares are for total saturations across households (includes multiple refrigerators per household).

Figure 5.5. Refrigerator Ownership Shares for New Construction by Housing Type



Source: US DOE 1995b data for buildings built between 1988 and 1993.
Shares are for total saturations across households (includes multiple refrigerators per household).

Table 5.2. Minimum Efficiency Standards for Residential Refrigerators

Type	Year Eff. (1)	Maximum UEC Equation (2)	Average Capacity (Adj. Vol.) (3)	Calculated UEC	Calc. EF (4)	Fraction of Sales (5)
MND	1990	UEC= 16.3 * Capacity + 316	5.0 cuft	398 kWh/yr	4.60	4.7%
PAD	1990	UEC= 21.8 * Capacity + 429	14.6 cuft	747 kWh/yr	7.13	5.6%
TAD	1990	UEC= 23.5 * Capacity + 471	20.6 cuft	956 kWh/yr	7.88	72.9%
SAD	1990	UEC= 27.7 * Capacity + 488	27.2 cuft	1243 kWh/yr	8.00	6.2%
BAD	1990	UEC= 27.7 * Capacity + 488	27.2 cuft	1243 kWh/yr	8.00	2.5%
TADI	1990	UEC= 26.4 * Capacity + 535	20.6 cuft	1079 kWh/yr	6.97	0.7%
SADI	1990	UEC= 30.9 * Capacity + 547	27.2 cuft	1389 kWh/yr	7.16	7.4%
Average (6)	1990	n/a	20.6 cuft	976 kWh/yr	7.71	100.0%
MND	1993	UEC= 13.5 * Capacity + 299	3.6 cuft	348 kWh/yr	3.78	13.0%
PAD	1993	UEC= 10.4 * Capacity + 398	14.6 cuft	550 kWh/yr	9.69	0.0%
TAD	1993	UEC= 16.0 * Capacity + 355	20.7 cuft	686 kWh/yr	11.01	66.4%
SAD	1993	UEC= 11.8 * Capacity + 501	27.5 cuft	826 kWh/yr	12.16	8.0%
BAD	1993	UEC= 16.5 * Capacity + 367	27.5 cuft	821 kWh/yr	12.23	1.1%
TADI	1993	UEC= 17.6 * Capacity + 391	20.7 cuft	755 kWh/yr	10.00	1.2%
SADI	1993	UEC= 16.3 * Capacity + 527	27.5 cuft	975 kWh/yr	10.29	10.4%
Average (6)	1993	n/a	19.8 cuft	686 kWh/yr	10.54	100.0%
MND	2001	UEC= 19.9 * Capacity + 98	3.6 cuft	170 kWh/yr	7.75	13.0%
PAD	2001	UEC= 10.4 * Capacity + 398	14.6 cuft	550 kWh/yr	9.69	0.0%
TAD	2001	UEC= 9.8 * Capacity + 276	20.7 cuft	479 kWh/yr	15.78	66.4%
SAD	2001	UEC= 4.9 * Capacity + 508	27.5 cuft	643 kWh/yr	15.62	8.0%
BAD	2001	UEC= 4.6 * Capacity + 459	27.5 cuft	586 kWh/yr	17.14	1.1%
TADI	2001	UEC= 10.2 * Capacity + 356	20.7 cuft	567 kWh/yr	13.32	1.2%
SADI	2001	UEC= 10.1 * Capacity + 406	27.5 cuft	684 kWh/yr	14.68	10.4%
Average (6)	2001	n/a	19.8 cuft	476 kWh/yr	15.21	100.0%

Type:

MND	Refrigerators and Refrigerator-Freezers with manual defrost
PAD	Refrigerator-Freezer - partial automatic defrost
TAD	Refrigerator-Freezers - automatic defrost with: Top-mounted freezer w/o through-the-door ice service
SAD	Refrigerator-Freezers - automatic defrost with: Side-mounted freezer w/o through-the-door ice service
BAD	Refrigerator-Freezers - automatic defrost with: Bottom-mounted freezer w/o through-the-door ice service
TADI	Refrigerator-Freezers - automatic defrost with: Top-mounted freezer w/ through-the-door ice service
SADI	Refrigerator-Freezers - automatic defrost with: Side-mounted freezer w/ through-the-door ice service

1) Effective dates of 1990 and 1993 standards are January 1; effective date of 2001 standard is July 1.
2) 1990 Standards level equation from NAECA 1987. 1993 Standards level equation from US DOE 1989b. 2001 Standards level equation from US DOE 1995c. Capacity measure is adjusted volume (AV), where AV=refrigerator volume + 1.63 * freezer volume.
3) Average volume for different product classes from AHAM for shipments in years 1990 and 1993.
4) EF calculated from UEC as 365*Capacity/UEC. Units are cuft-day/kWh.
5) 1990 sales fractions by product class are 1988 data from US DOE 1989b; 1993 and 2001 sales fractions are 1992 data from US DOE 1995c.
6) Weighted average across all product classes is similar to data for the TAD product class.

6. FREEZER END-USE DATA

Freezers, specifically those that are separate from the freezer compartment of the refrigerator, are a relatively large consumer of electricity among typical household appliances, using approximately 33 TWh, or 5% of sector electricity consumption. Like refrigerators, freezer energy consumption is well understood because of extensive research and the relatively small effect of occupant behavior on appliance performance.

6.1. Freezer UECs

Freezer UECs for new units are measured using a laboratory test procedure such as for refrigerators. These provide estimates of the UECs of new units entering the market. The UEC database of measured and estimated data on energy usage of the freezer stock contains 83 records, but the estimates show large variability (Appendix A). This variability may be partly due to large improvements in efficiency for freezers, but also reflects the problems with estimating field usage of appliances. In addition, there are many different sizes and several different classes of freezers (upright and chest types, manual defrost and automatic defrost types) which vary widely in energy consumption.

UEC equation

The relationship between freezer UEC, efficiency, and capacity is the same as that for refrigerators, and is as follows:

UEC: $$\text{kWh/yr} = \frac{365 * \text{Capacity}}{EF}$$

where: 365 is days per year
Capacity is adjusted volume (cubic feet)
Adjusted volume = 1.73 x freezer volume (cubic feet)
EF is the energy factor from the DOE test procedure (cubic feet-day/kWh)

Stock UECs

Based on historical shipment data of test UECs for freezers (AHAM 1996) and a straight line decay function with a minimum lifetime of 11 years and a maximum lifetime of 31 years, we estimate the 1990 stock test UEC for freezers to be 1025 kWh/yr. The analysis of available data for freezers in the UEC database (n=53 for studies that are generally representative of all product classes) also gives results of 1026 kWh/yr for a freezer UEC. We use this value for stock freezer UEC.

New UECs

New unit UECs derived from the U.S. DOE test procedure and reported by the industry for 1990 are 600 kWh/yr for the overall average, 471 kWh/yr for chest, manual defrost (54% of sales), 679 kWh/yr for upright, manual defrost (37% of sales), and 1030 kWh/yr for upright, automatic defrost (9% of sales). The current sales are best described by an average of the two manual defrost classes. The new unit average UEC has dropped dramatically in the past few years, to 465 kWh/yr in 1995, due to the new federal efficiency standards for freezers that took effect in 1993.

6.2. Freezer Usage

The energy usage of freezers will vary in the field with number of door openings as well as the ambient temperature in the vicinity of the freezer and the level of maintenance.

6.3. Freezer Technology Data

There are three different classes of freezers that each have specific performance characteristics related to energy use; we include technology data here that best represent the entire freezer market. For some measures, we include data that are averages across product classes. For other measures, we include data on chest manual and upright manual freezers, which together comprise over 90% of the unit sales and, together, have characteristics that approximate the market average. The automatic defrost units use significantly more energy but are only a small portion of current sales.

Historical Efficiency Data

Annual freezer shipments from 1951 to 1995 are shown in Figure 6.1 and the overall average efficiency of new freezers sold over time is shown in Figure 6.2 along with the average size (capacity, or adjusted volume, in cubic feet). Efficiencies have risen dramatically since the first recorded data in 1972. National efficiency standards took effect in 1990, and more stringent standards took effect in 1993. In addition, average freezer size has been decreasing over time.

Cost vs. Efficiency for New Equipment

Estimates of cost vs. efficiency for new chest manual and upright manual freezers are shown in Figure 6.3. The values are based on estimates in the U.S. DOE appliance standards analysis (US DOE 1995c), adjusted to $1995.

Product Lifetimes

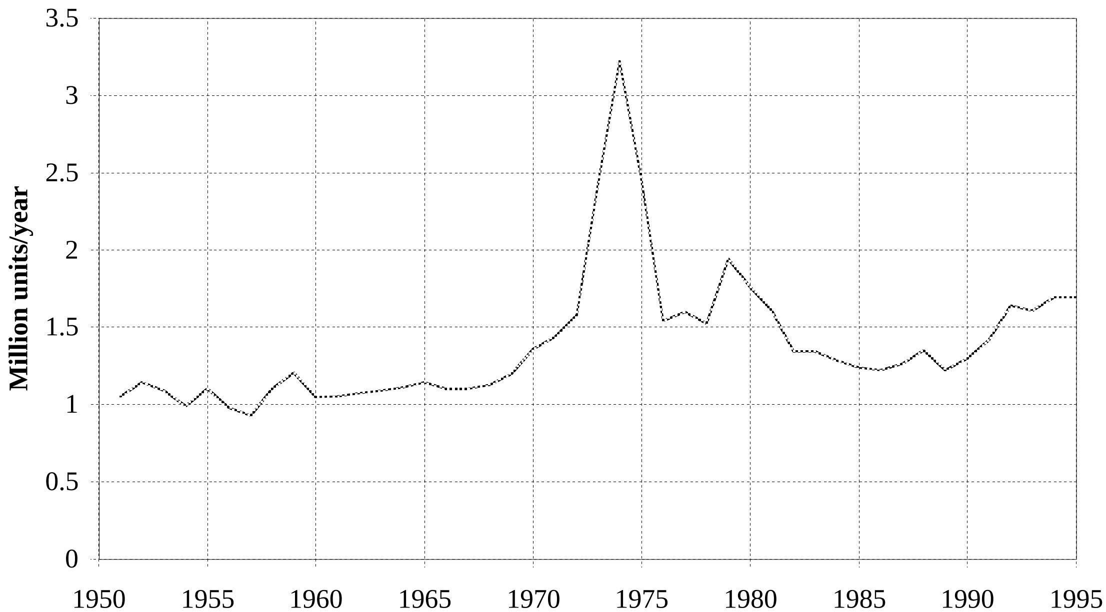
Estimates from two sources of the lifetimes of freezers are listed in Table 6.1.

Table 6.1. Estimates of Residential Freezer Lifetimes

Source	Estimate	Years
Appliance	Low	11
	Avg	12
	High	18
LBNL/REM	Low	15
	Avg	19
	High	23

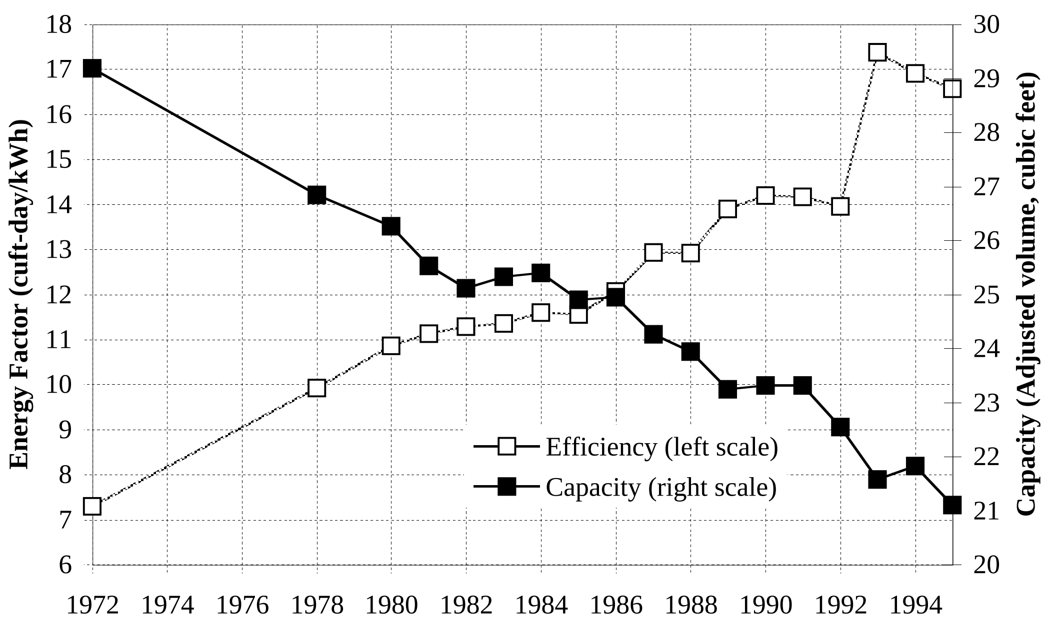
Appliance 1996 (first owner lifetime only); LBNL-REM 1991.

Figure 6.1. Annual Freezer Shipments, 1951-1995



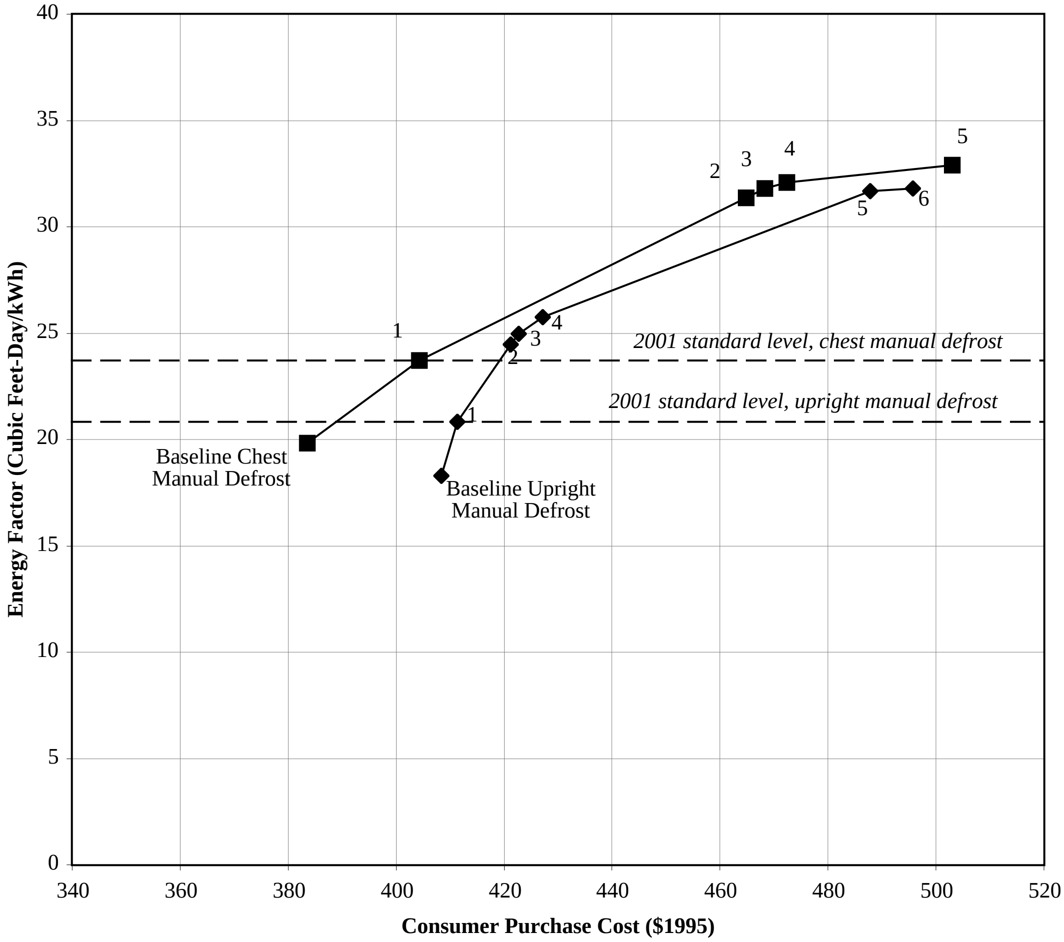
Source: US DOE 1989b and AHAM 1996.

Figure 6.2. Shipment-Weighted Energy Factor and Capacity for Freezers, 1972-1995



Source: AHAM 1996.

Figure 6.3. Cost Versus Efficiency for New Freezers



Source: US DOE 1995c. Costs adjusted from $1992 using the chain type price index for personal consumption expenditures of 1.076.

Option	Description
Baseline	Upright Manual Defrost Freezer. 24.2 cubic feet adjusted volume. 1993 Standard.
1	0 + Foam Insulation to Door
2	1 + 5.15 EER Compressor
3	2 + Enhanced Condensor Heat Transfer Surface
4	3 + Reduce Gasket Heat Leak
5	4 + Vacuum Panel Insulation in Walls & Door
6	5 + Increase Evaporator Area

Option	Description
Baseline	Chest Manual Defrost Freezer. 25.6 cubic feet adjusted volume. 1993 Standard.
1	0 + 4.95 EER Compressor
2	1 + Vacuum Panel Insulation on Walls & Door
3	2 + Reduce Gasket Heat Leak
4	3 + Increase Evaporator Area
5	4 + Enhanced Condensor Heat Transfer Surface

6.4. Market Shares

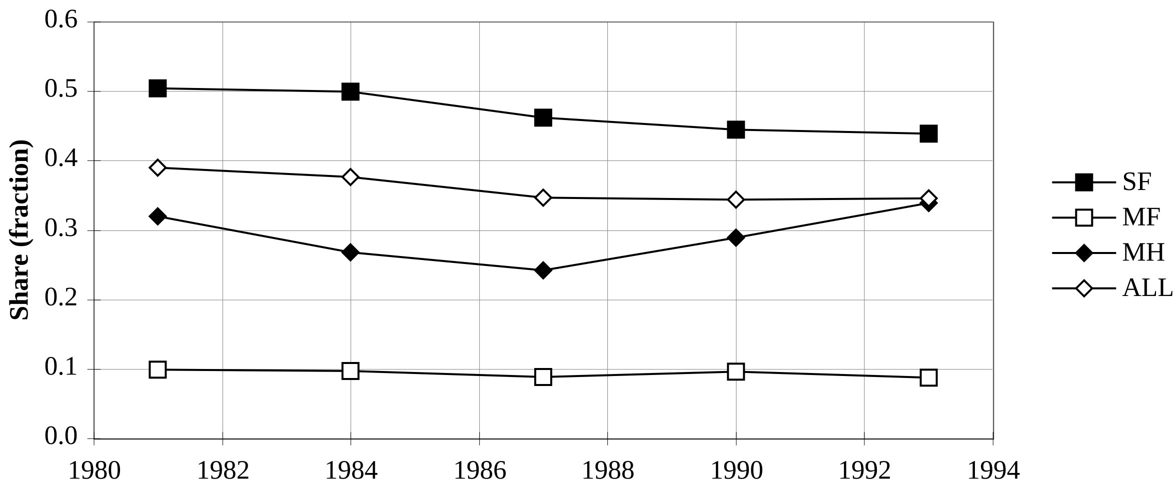
National stock market shares for freezer by housing type are derived from the RECS data (US DOE 1982a, 1986, 1989a, 1993b, 1995b). Total market shares and specific market shares for manual defrost and automatic defrost can be derived from RECS. Market shares in new buildings are derived for buildings built during the previous 5 to 7 years from the RECS data (for example, market shares in new construction in 1993 are derived from the 1993 RECS data for buildings built between 1988 and 1993). Some of these data are shown in Figures 6.4 and 6.5. The market shares of manual defrost and automatic defrost units, particularly for new buildings, does not agree with the shipments data reported by the industry. The RECS data show a much larger portion of automatic defrost units. The RECS data may be less accurate since the type of freezer is determined during a quick survey of the household. Note that these are total "saturations" of freezers (market shares x housing stock = freezer stock) to account for multiple freezers per household (except for the 1990 data).

According to the RECS data, the number of freezers per household is decreasing over time (because the 1990 survey does not record the number of freezers in each household, the 1990 data point should be considered slightly low; however, the 1993 survey does record number of freezers per household). In comparing the stock market shares with market shares in new construction, we see that the new market shares are generally less than those for the stock as a whole. Thus, the decrease in overall market shares may be partly due to fewer freezers in new households, but may also be due to retired freezers not being replaced. Note that the market shares for manufactured homes (MH) grew from 1987 to 1993, but since the RECS sample for this housing type is relatively small, the change may not be statistically significant.

6.5. Standards

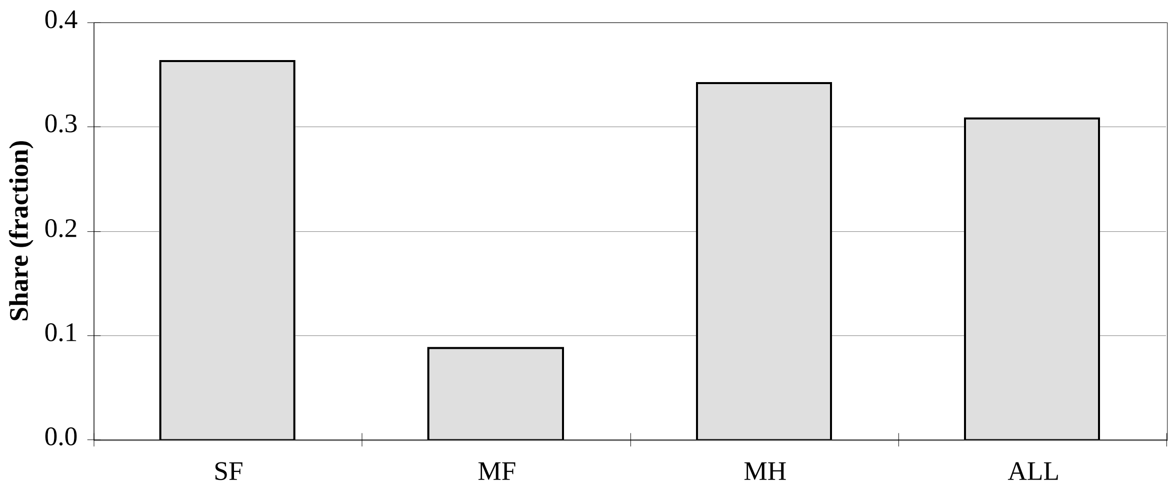
Efficiency standards for freezers were enacted under the National Appliance Energy Conservation Act (NAECA) and first implemented in 1990. The standard specifies a maximum energy use for freezers based on type and size. The energy usage is based on the U.S. DOE test procedure mentioned above. More stringent standards were implemented at the start of 1993; a third round of national standards will become effective July 1, 2001. The standard levels are summarized in Table 6.2.

Figure 6.4. Freezer Ownership Shares by Housing Type, 1981-1993



Source: US DOE 1982a, 1986, 1989a, 1992, 1995.
Shares are for total saturations across households (includes multiple freezers per household). 1990 and 1993 data do not include multiple freezers. (Not part of 1990 or 1993 survey. Approximately 1% in earlier years).

Figure 6.5. Freezer Ownership Shares for New Construction by Housing Type



Source: US DOE 1995 data for buildings built between 1988 and 1993.

Table 6.2. Efficiency Standards for Residential Freezers

Type	Year Eff. (1)	Maximum UEC Equation (2)	Average Capacity (Adj. Vol.) (3)	Calculated UEC	Calc. EF (4)	Fraction of Sales (5)
UPM	1990	UEC= 10.9 * Capacity + 422	26.3 cuft	709 kWh/yr	13.55	36.6%
UAD	1990	UEC= 16.0 * Capacity + 623	29.4 cuft	1093 kWh/yr	9.81	9.5%
CHT	1990	UEC= 14.8 * Capacity + 223	20.2 cuft	522 kWh/yr	14.13	53.9%
Average (6)	1990	n/a	23.3 cuft	645 kWh/yr	13.20	100.0%
UPM	1993	UEC= 10.3 * Capacity + 264	23.3 cuft	504 kWh/yr	16.87	37.9%
UAD	1993	UEC= 14.9 * Capacity + 391	29.3 cuft	828 kWh/yr	12.93	12.5%
CHT	1993	UEC= 11.0 * Capacity + 160	18.5 cuft	364 kWh/yr	18.59	49.7%
Average (6)	1993	n/a	21.7 cuft	475 kWh/yr	16.67	100.0%
UPM	2001	UEC= 7.6 * Capacity + 258	23.3 cuft	434 kWh/yr	19.59	37.9%
UAD	2001	UEC= 12.4 * Capacity + 326	29.3 cuft	691 kWh/yr	15.50	12.5%
CHT	2001	UEC= 9.9 * Capacity + 144	18.5 cuft	327 kWh/yr	20.69	49.7%
Average (6)	2001	n/a	21.7 cuft	413 kWh/yr	19.17	100.0%

Type: UPM Upright Freezers with Manual Defrost
UAD Upright Freezers with Automatic Defrost
CHT Chest Freezers and all other freezers

1) Effective dates of 1990 and 1993 standards are January 1; effective date of 2001 standard is July 1.
2) 1990 Standards level equation from NAECA 1987. 1993 Standards level equation from US DOE 1989b. 2001 Standards level equation from US DOE 1995c. Capacity measure is adjusted volume (AV), where AV = 1.73 * freezer volume.
3) Average volume for different product classes from AHAM 1996 for shipments in years 1990 and 1993.
4) EF calculated from UEC as 365*Capacity/UEC. Units are cuft-day/kWh.
5) 1990 sales fractions by product class are 1988 data from US DOE 1989b; 1993 and 2001 sales fractions are 1992 data from US DOE 1995c.
6) Weighted average across entire product category is approximately midway between UPM and CHT product classes.

7. DISHWASHER END-USE DATA

Dishwashers use energy primarily by increasing the water heating use for a residence. Thus, they can be major energy consumers for a typical household.

7.1. Dishwasher UECs

Dishwasher UECs for new units are measured using a laboratory test procedure from U.S. DOE. This procedure determines the total energy use -- both for the motor, dryer, booster heater, if present, and for the hot water required from the water heater. These UECs are typically calculated assuming electric water heat, even though most households' hot water is supplied by a gas water heater. The UEC of a dishwasher in the field will be directly proportional to the frequency of its use. Recent research has shown that average field usage of dishwashers is approximately 229 cycles per year (US DOE 1990b). Currently, however, the U.S. DOE test procedure is based on a usage estimate of 322 cycles per year.

Average energy use for stock dishwashers is difficult to estimate without direct metering of the appliance as well as the water heater. In collecting data for the UEC database, we found that it was difficult to determine if the water heat portion of the dishwasher was included in the UEC estimate, even where the source may have explicitly stated whether or not it was included, as shown by some incredibly high values given for the non-water heat portion. The UEC database contains 24 estimates of the total dishwasher energy use and 39 estimates of the non-water heat portion only (see Appendix A).

UEC equation

The equation below shows the relationship between dishwasher efficiency and energy consumption. The energy factor (EF) includes the hot water usage of the dishwasher, calculated using electric water heating at 100% efficiency (i.e. standby losses of the electric water heater are not included in the accounting for the dishwashing appliance). However, the question remains whether or not the recovery efficiency of the external water heater, used to heat the water prior to it being drawn into the dishwasher, should be included in the calculation of the energy consumption of the dishwasher.

UEC: $$\text{kWh/yr} = \frac{\text{Use}}{\text{EF}} = \text{Use} * (\text{Motor} + \text{Dryer} + \text{Booster Heater} + \text{Hot Water Energy})$$

where: Use is in cycles/year

EF is the energy factor (cycles/kWh)

Motor, Dryer, Booster Heater, and Hot Water Energy are components of the UEC (kWh/cycle)

Stock UECs

The best estimate of the UEC for dishwashers resulting from weighted averaging of the UECs in the UEC database is 250 kWh/yr for the non-water heater portion and 1010 kWh for the total. However, these estimates are primarily from utility conditional demand studies, which are not well suited to differentiating between various points of hot water usage. Thus, we base our UEC estimates on the baseline "Standard Water Heating Dishwasher" unit used in the U.S. DOE appliance standards analysis (US DOE 1990b), where at a usage of 229 cycles per year, the annual energy usage is 179 kWh/yr for the motor and 636 kWh/yr total. This assumes that the typical unit sold in 1988 is representative of the entire stock in 1990, which may be a reasonable assumption since efficiencies have been changing very little over time, and that the assumed usage is representative of all dishwashers. The data for this baseline dishwasher, based on 100% water heater recovery efficiency, as well as that of the typical electric and gas water heater, are summarized in Table 7.1. These UECs are quite a bit lower than those derived from the UEC database.

Table 7.1. 1990 Stock and New Dishwasher UECs

Description	Water Heater Recovery Efficiency			Units
	100%	98%	76%	
Per Cycle Usage				
Motor + Heater + Dryer Energy	0.78	0.78	0.78	kWh/cycle
Hot Water Demand	11.90	11.90	11.90	gal/cycle
Hot Water Load	2.00	2.00	2.00	kWh/cycle
Hot Water Energy	2.00	2.04	2.63	kWh/cycle
Total Energy	2.78	2.82	3.41	kWh/cycle
Annual Usage				
Motor + Heater + Dryer Energy	179	179	179	kWh/yr
Hot Water Demand	2725	2725	2725	gal/yr
Hot Water Load	458	458	458	kWh/yr
Hot Water Energy	458	467	603	kWh/yr
Total Energy	636	646	781	kWh/yr
Energy Factor	0.36	0.35	0.29	load/kWh

Source: Koomey et al 1994b for water heater recovery efficiencies, US DOE 1990b, baseline Standard Water Heating Dishwasher, for all other assumptions.
98% recovery efficiency corresponds to the typical electric water heater, while 76% recovery efficiency corresponds to the typical gas water heater. kWhs must be converted to Btu for gas water heaters using a conversion factor of 3412 Btu per kWh.
Hot water load calculated at 70° F temperature rise.
Annual energy use calculated assuming 229 cycles per year.

New UECs

Our UEC for new units (circa 1990) is estimated to be the same as for the 1990 stock, since we base the stock value on the typical unit sold in 1988. Since appliance standards did not affect sales until 1994, this assumption is reasonable. UECs for units sold after 1994 are likely to be similar to the 1994 standard levels.

7.2. Dishwasher Usage

The energy usage of dishwashers will vary in the field with number of cycles the appliance is used as well as the temperature settings (hot wash, hot rinse; cold wash, cold rinse; etc.) for each of those cycles. The most recent estimate of number of cycles is from Proctor and Gamble and is 229 cycles per year (US DOE 1990b). A recent analysis indicates that average daily hot water use for dishwashers ranges from 17 liters per day, for a household of one, to 39 liters per day, for a household of 5 or more. Hot water use for washing dishes by hand ranges from 10 liters per day, for a household of one, to 12 liters per day, for a household of five or more (Lutz et al 1996). Homeowner usage of various temperature and drying options also affects hot water use, and is difficult to ascertain. Estimates of these impacts are used in the standards analysis for dishwashers, but are not included in the UEC database.

7.3. Dishwasher Technology Data

There are three different classes of dishwashers: the standard dishwasher, the standard water heating dishwasher (which has a small booster heater in the appliance), and the compact dishwasher. Virtually all new dishwashers have the booster water heater; the 1994 energy standards effectively eliminated standard dishwashers without a booster heater, and compact dishwashers make up a very small fraction of new dishwasher shipments.

Historical Efficiency Data

Annual dishwasher shipments and the annual sales and overall average efficiency of new dishwashers sold over time are shown in Figures 7.1 and 7.2. Note that the efficiencies are largely determined by hot water demand since the hot water use is the greatest portion of the total energy use. However, these historical data do not specify the motor and water heat portions separately. In addition, the efficiency is calculated assuming electric water heating. The average efficiency of new units sold increased between 1972 and 1980, and remained fairly stable until the efficiency standards came into effect in 1994.

Cost vs. Efficiency for New Equipment

Estimates of cost vs. efficiency for new dishwashers with no or coarse food filters and with fine food filters are shown in Figures 7.3 and 7.4, respectively. The values are based on estimates in the U.S. DOE appliance standards analysis (Biermayer 1996). Two other technologies may reduce dishwasher energy use. Some manufacturers are building models with adaptive controls, which automatically adjust water usage and/or temperature based on how soiled the dishes are (which is measured by the amount of food soil in the water). Ultrasonic washing uses ultrasonic waves to dislodge soil from dishes that are entirely submerged in water. The extent to which either of these new technologies reduces energy is not clear at this time.

Product Lifetimes

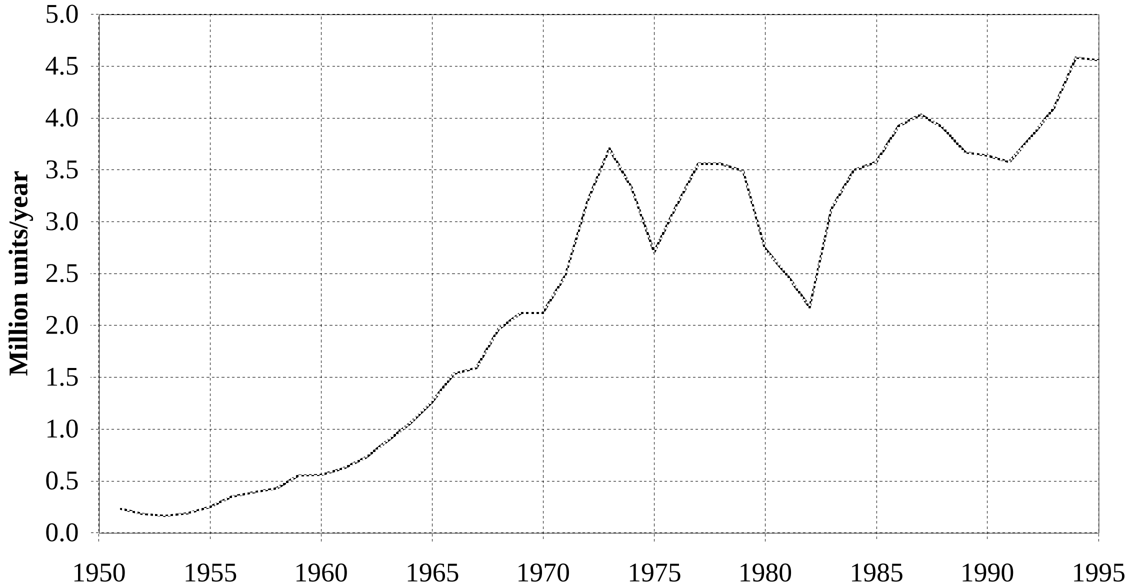
Estimates from two sources of the lifetimes of dishwashers are summarized in Table 7.2.

Table 7.2. Estimates of Residential Dishwasher Lifetimes

Source	Estimate	Years
Appliance	Low	7
	Avg	9
	High	12
LBNL/REM	Low	n/a
	Avg	13
	High	n/a

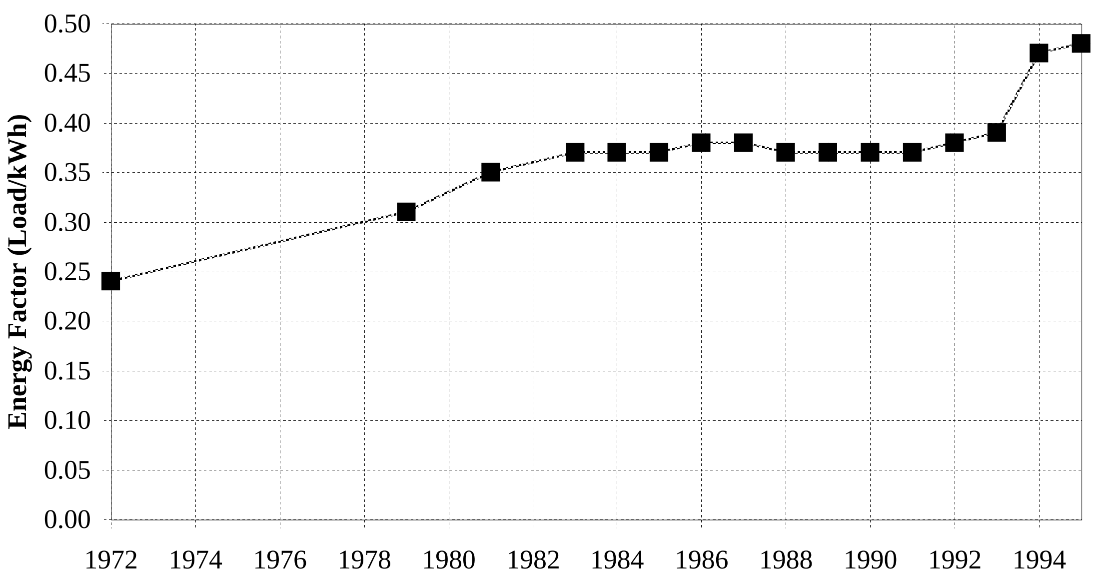
Appliance 1996 (first owner lifetime only); LBNL-REM 1991.

Figure 7.1. Annual Dishwasher Shipments, 1951-1995



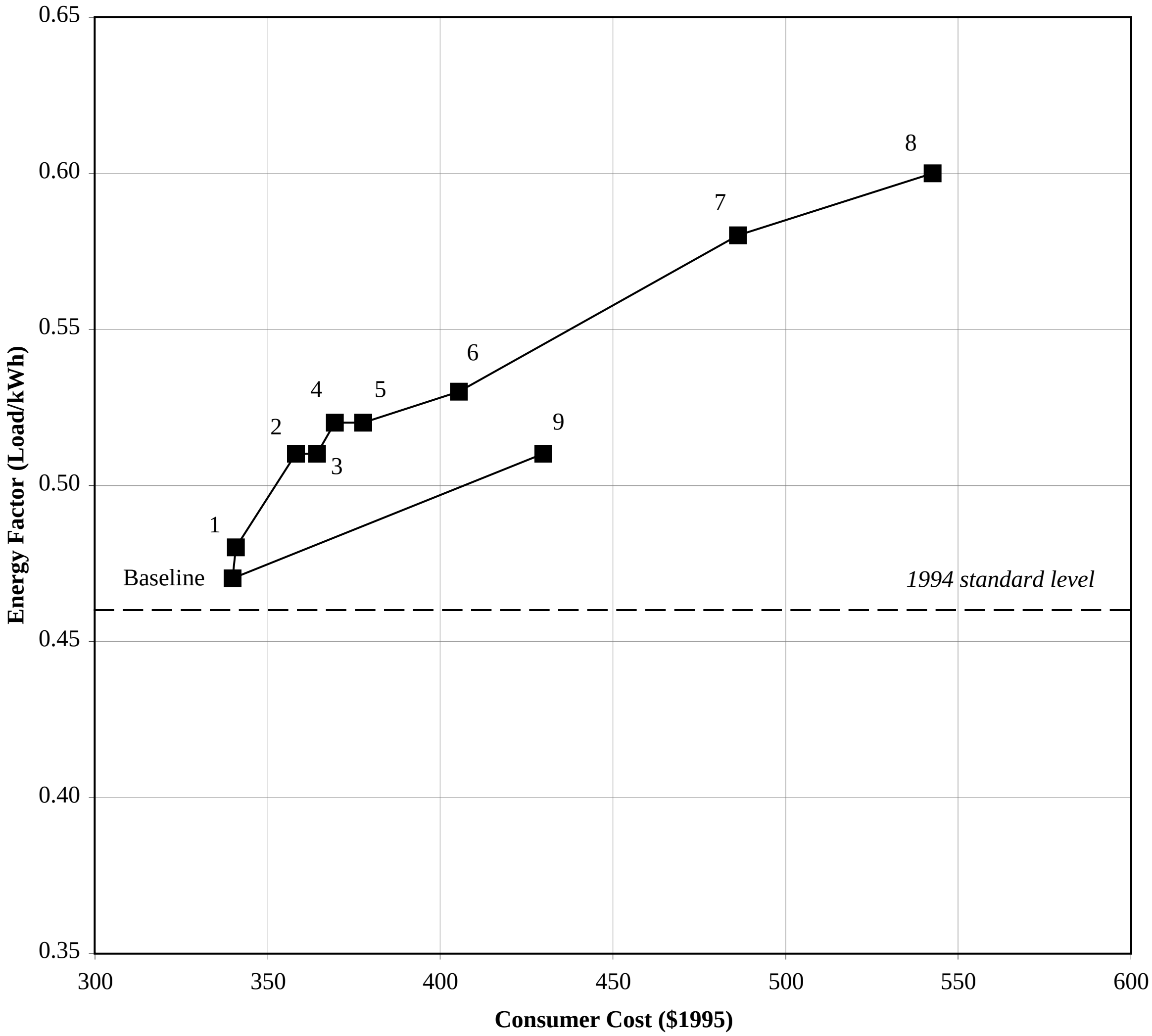
Source: Fechtel et al. 1980 (1951-1956); Appliance Magazine (1976-96); US DOE 1990b (1951-1975).

Figure 7.2. Shipment-Weighted Efficiency for Dishwashers, 1972-1995



Source: AHAM 1996. EF calculated assuming electric water heating @ 100% efficiency.

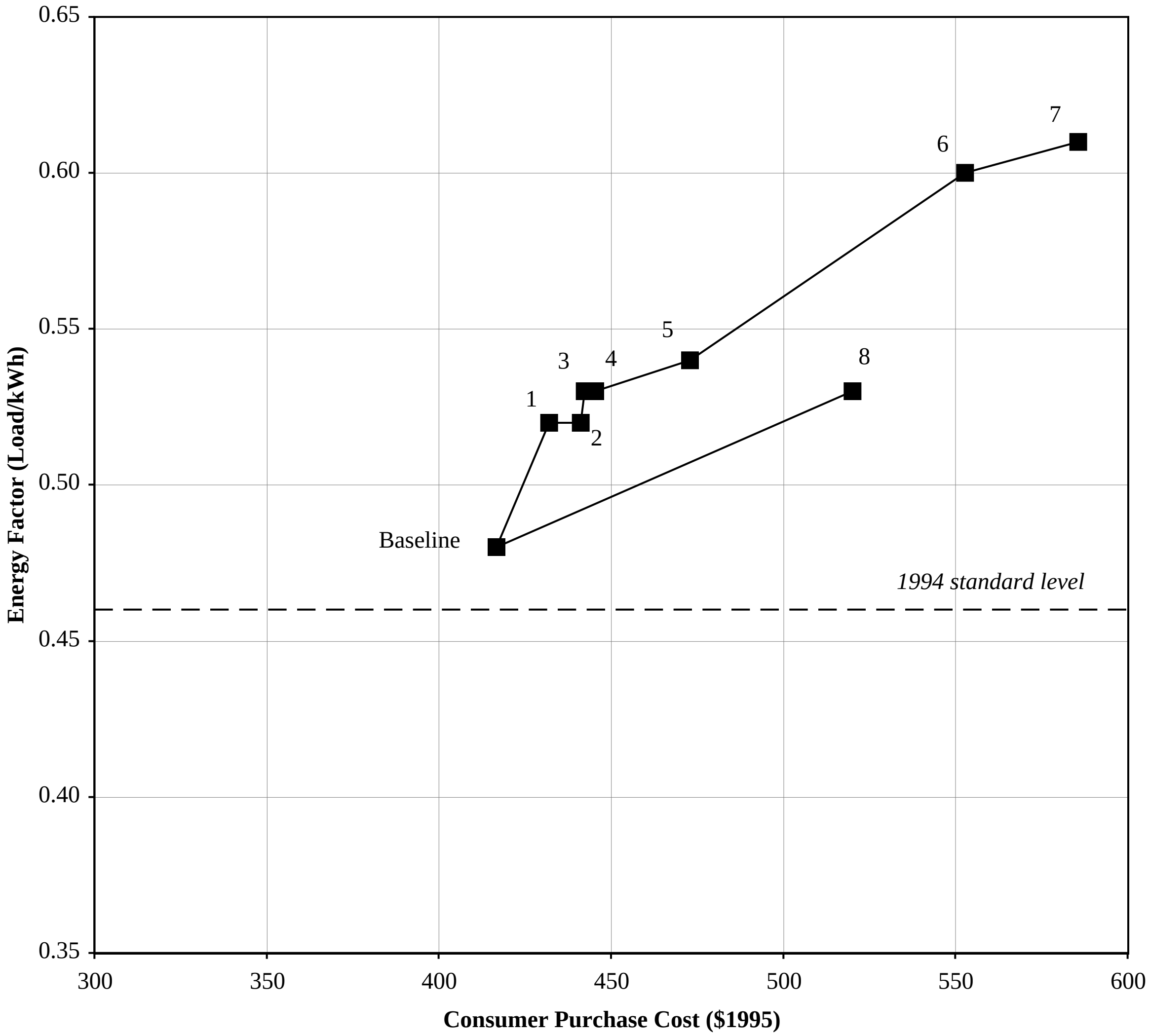
Figure 7.3. Cost Versus Efficiency for New Dishwasher, No or Coarse Food Filter



Source: Biermayer 1996. Dishwashers with no or a coarse food filter represent about half of new dishwasher sales. UEC and EF calculated assuming electric water heat at 100% efficiency. Converted from $1994 using the chain type price index for personal consumption expenditures of 1.024.

Option	Description
Baseline	Water heating dishwasher with no or coarse food filter. 250 cycles per year.
	Water heater efficiency = 100% electric, 75% gas
1	Improved spray arm geometry
2	1 + Add improved food filter
3	2 + Add modified sump geometry and modified pump design
4	3 + Add increased motor efficiency by 10%
5	4 + Add improved dry cycle
6	5 + Add increased motor efficiency 20% above baseline
7	6 + Reduced inlet water temp. w/plumbing
8	7 + Increased insulation
9	Improved wash cycle

Figure 7.4. Cost Versus Efficiency for New Dishwasher, Fine Food Filter



Source: Biermayer 1996. Dishwashers with fine food filter represent about half of new dishwasher sales. UEC and EF calculated assuming electric water heat at 100% efficiency. Converted from $1994 using the chain type price index for personal consumption expenditures of 1.024.

Option	Description
Baseline	Water heating dishwasher with fine food filter. 250 cycles per year.
	Water heater efficiency = 100% electric, 75% gas
1	Improved food filter and spray arm geometry
2	1 + Add modified sump geometry & modified pump design
3	2 + Add increased motor efficiency by 10%
4	3 + Add improved dry cycle
5	4 + Add increased motor efficiency by 10% over level 3 (20% total)
6	5 + Add reduced inlet water temp. w/plumbing
7	6 + Add increased insulation
8	Improved wash cycle

7.4. Market Shares

National stock market shares for dishwashers by housing type are derived from the RECS data (US DOE 1982a, 1986, 1989a, 1993b, 1995b). Market shares in new buildings are derived for buildings built during the previous 5 to 7 years from the RECS data (for example, market shares in new construction in 1993 are derived from the 1993 RECS data for buildings built between 1988 and 1993). Some of these data are shown in Figures 7.5 and 7.6. Figure 7.5 shows that dishwasher market shares remained stable between 1990 and 1993, with market shares in SF housing growing and market shares in MF and MH housing declining. Market shares in new buildings are significantly greater than in the building stock except for the MH building type. These data suggest that the share of households in the stock with dishwashers will continue to grow somewhat over time.

7.5. Standards

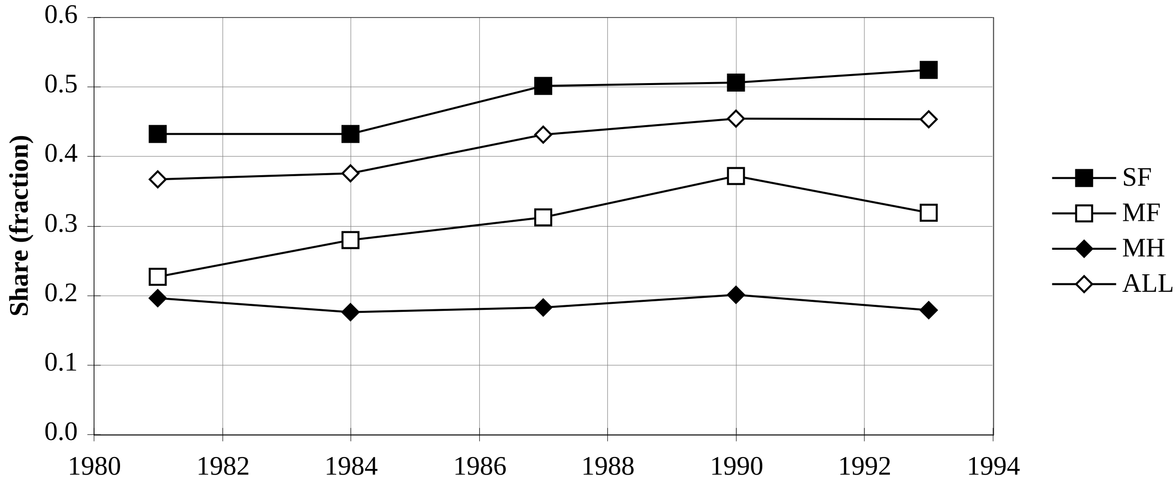
Efficiency standards for dishwashers were first enacted under the National Appliance Energy Conservation Act (NAECA) and implemented in 1988. These standards required only that dishwashers have the option to dry without heat. Further efficiency standards became effective in 1994, as shown in Table 7.3.

Table 7.3. Minimum Efficiency Standards for Residential Dishwashers

Type	Database Code	Year Effective	Min. EF	Hot Water Energy (kWh/cycle)	Motor, Booster, & Dryer Energy (kWh/cycle)	Total UEC (kWh/cycle)
Standard	DW	1994	0.46	1.60	0.58	2.17
Standard Water Heating	DW	1994	0.46	1.60	0.58	2.17
Compact (Water Heating)	DW	1994	0.62	1.11	0.51	1.61

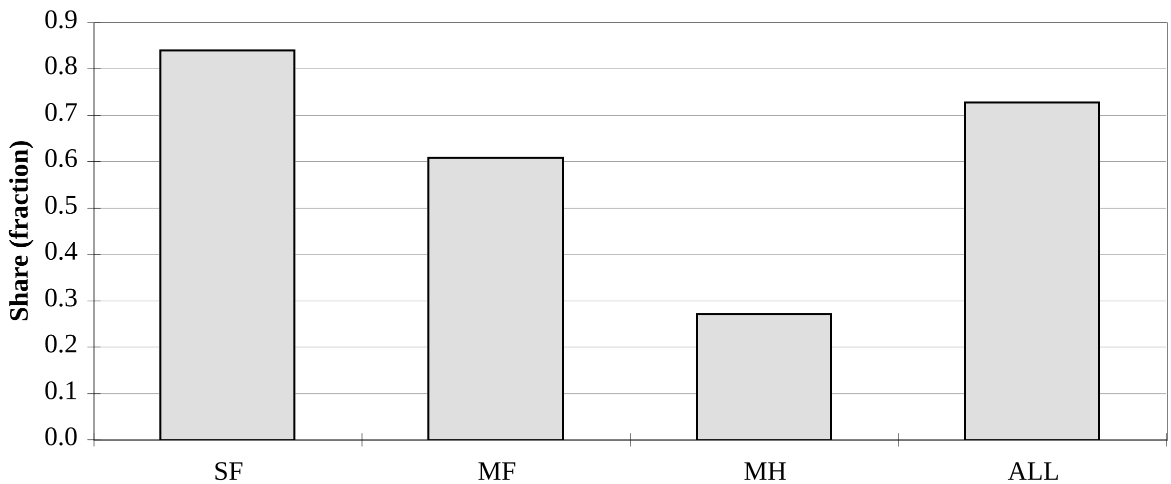
Source: US DOE 1990b. Hot water energy and motor, booster and dryer energy do not add to total energy due to rounding errors.
1) Effective date is May 14 of year indicated.
2) Standards specified in NAECA 1987 and effective starting 1988 for dishwashers required dishwashers to be equipped with an option to dry without heat.
3) EF units are load/kWh.
4) UEC per cycle calculated as 1/EF. Includes assumption of electric water heating @ 100% efficiency. Hot water use portion from US DOE 1990b. Other energy use is for the motor, booster heater and dryer within the machine itself.
Mandated efficiency level for standard dishwasher essentially makes it a water heating dishwasher. The standard specifies only the EF, and in practice manufacturers may not use the specific design options trading off motor, booster heater, dryer, and hot water energies shown above.

Figure 7.5. Dishwasher Ownership Shares by Housing Type, 1981-1993



Source: US DOE 1982a, 1986, 1989a, 1992, 1995.

Figure 7.6. Dishwasher Ownership Shares for New Construction by Housing Type



Source: US DOE 1995 data for buildings built between 1988 and 1993.

8. *CLOTHES WASHER END-USE DATA*

Clothes washers use energy primarily by increasing the water heating use for a residence. Thus, they can be major energy consumers for a typical household.

8.1. Clothes Washer UECs

Clothes washer UECs for new units are measured using a laboratory test procedure from U.S. DOE. This procedure determines the total energy use -- both for the motor and other items in the washer and for the hot water required from the water heater. These UECs are typically calculated assuming electric water heat, even though most households' hot water will be supplied by a gas water heater. Obviously, the UEC of a clothes washer in the field will be directly proportional to the amount the appliance is used.

Average energy use for stock clothes washers is difficult to estimate without direct metering of the appliance as well as the water heater. In collecting data for the UEC database, we found that it was difficult to determine if the water heat portion of the clothes washer was included in the UEC estimate, even where the source may have explicitly stated whether or not it was included, as shown by some incredibly high values given for the non-water heat portion. The UEC database contains 15 estimates of the total clotheswasher energy use and 30 estimates of the non-water heat portion only (Appendix A).

UEC equation

The equation below shows the relationship between clothes washer efficiency and energy consumption. The energy factor (EF) includes the hot water usage of the clothes washer, calculated using electric water heating (i.e. standby losses of the electric water heater are not included in the accounting for the clothes washer). However, the question remains whether or not the recovery efficiency of the external water heater, used to heat the water prior to it being drawn into the clothes washer, should be included in the calculation of the energy consumption of the clothes washer.

UEC: $$\text{kWh/yr} = \frac{\text{Use} * \text{Capacity}}{\text{EF}} = \text{Use} * (\text{Motor} + \text{Hot Water Energy})$$

where: Use is in cycles/year

Capacity is volume (cubic feet)

EF is the energy factor from the DOE test procedure (cubic feet/kWh)

Motor and Hot Water Energy are the components of the UEC (kWh/cycle)

Stock UECs

The best estimate of the UEC for clothes washers resulting from weighted averaging of the UECs in the UEC database is 100 kWh/yr for the motor portion (n=30) and 600 kWh for the total including water heating (n=15). However, these estimates are primarily from utility conditional demand studies, which are not well suited to differentiating between various points of hot water usage. Thus, we base our UEC estimates on the baseline "Standard Clothes Washer" unit used in the U.S. DOE appliance standards analysis (US DOE 1990b), where at a usage of 380 cycles per year, the annual energy usage is 103 kWh for the motor and 1148 kWh/yr for the total. This assumes that the typical unit sold in 1988 is representative of the entire stock in 1990, which is probably a reasonable assumption since efficiencies did not change substantially between 1979 and 1990 (see Figure 8.2). The data for this baseline clothes washer, based on 100% water heater recovery efficiency, as well as that of the typical electric and gas water heater, are summarized in Table 8.1.

Table 8.1. 1990 Stock and New Clothes Washer UECs

	Water Heater Recovery Efficiency			
Description	100%	98%	76%	Units
Per Cycle Usage				
Motor Energy	0.27	0.27	0.27	kWh/cycle
Hot Water Demand	12.80	12.80	12.80	gal/cycle
Hot Water Load	2.75	2.75	2.75	kWh/cycle
Hot Water Energy	2.75	2.81	3.62	kWh/cycle
Total Energy	3.02	3.08	3.89	kWh/cycle
Annual Usage				
Motor Energy	103	103	103	kWh/yr
Hot Water Demand	4864	4864	4864	gal/yr
Hot Water Load	1045	1045	1045	kWh/yr
Hot Water Energy	1045	1066	1375	kWh/yr
Total Energy	1148	1169	1478	kWh/yr
Energy Factor	0.86	0.85	0.67	cu. ft./kWh

Source: Koomey et al 1994b for water heater recovery efficiencies, US DOE 1990b, baseline standard clothes washer, for all other assumptions.
98% recovery efficiency corresponds to the typical electric water heater, while 76% recovery efficiency corresponds to the typical gas water heater. kWhs must be converted to Btu for gas water heaters using a conversion factor of 3412 Btu per kWh.
Hot water load calculated at 90° F temperature rise.
EF calculated for capacity of 2.60 cubic feet.
Annual energy use calculated assuming 380 cycles per year.

New UECs

Our UEC for new units (circa 1990) is estimated to be the same as for the 1990 stock, since we base the stock value on the typical unit sold in 1988. Since appliance standards did not affect technology choices until 1994, this assumption is reasonable.

8.2. Clothes Washer Usage

The energy usage of clothes washers will vary in the field with the frequency of use as well as the temperature settings (hot wash, hot rinse; cold wash, cold rinse; etc.) for each of those cycles. The most recent estimate of number of cycles is from Proctor and Gamble (US DOE 1990b) and is 380 cycles per year. Currently, however, the U.S. DOE test procedure is based on a usage estimate of 416 cycles per year. A recent analysis indicates that average daily hot water use for clothes washers ranges from 22 liters per day, for a household of one, to 67 liters per day, for a household of 5 or more (Lutz et al 1996). Clothes washers often have many different options that would also affect energy usage such as hot vs. cold rinse. These various temperature settings are included in the appliance standards analysis and the UECs given above.

8.3. Clothes Washer Technology Data

There are two different classes of clothes washers: the standard clothes washer and the compact clothes washer. The standard washer accounts for 96% of new sales; it is the only class of clothes washer considered here.

Historical Efficiency Data

Annual clothes washer shipments from 1957 to 1995 are shown in Figure 8.1 and the overall average efficiency of new clothes washers sold over time is shown in Figure 8.2 along with the average size (capacity in cubic feet). Note that the efficiencies are largely determined by hot water demand since the hot water use is the greatest portion of the total energy use. In addition, the efficiency is calculated assuming electric water heating. The average efficiency of new units sold increased between 1972 and 1980, remained essentially level from 1981 to 1993, and increased dramatically (20%) when the new standards became effective in 1994. The average size of clothes washers has increased about 10% since 1980.

Cost vs. Efficiency for New Equipment

Estimates of cost vs. efficiency for new standard clothes washers are shown in Figure 8.3. The values are based on estimates in the U.S. DOE appliance standards analysis (Biermayer 1996) adjusted to $1995. The curves are constructed from data provided by manufacturers; different washer drum capacities are used since energy data were not available for all technologies with the same capacity. Modified energy factors, which normalize energy consumption for differing washer drum capacities, are shown in Figure 8.3. The MEFs include the energy needed to dry clothes to a certain remaining moisture content (RMC). The curves show the effect of reducing the remaining moisture content of laundry to specified levels, using unspecified technologies (such as increased spin speed, changing rotation direction, lengthening spin cycle, or increasing number of size of drainage holes in washer drum). The primary means of efficiency improvement is to move to a horizontal axis clothes washer, which uses significantly less hot water and achieves higher RMCs using less energy.

Product Lifetimes

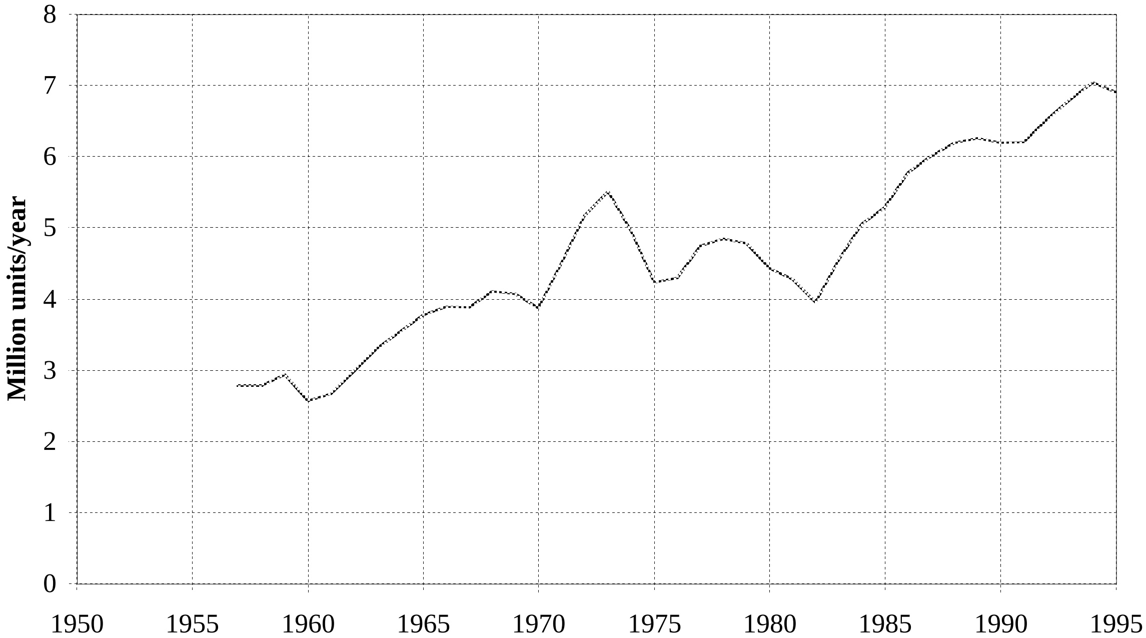
Estimates of the lifetimes of clothes washers from two sources are listed in Table 8.2.

Table 8.2. Estimates of Residential Clothes Washer Lifetimes

Source	Estimate	Years
Appliance	Low	11
	Avg	13
	High	14
LBNL/REM	Low	12
	Avg	14
	High	17

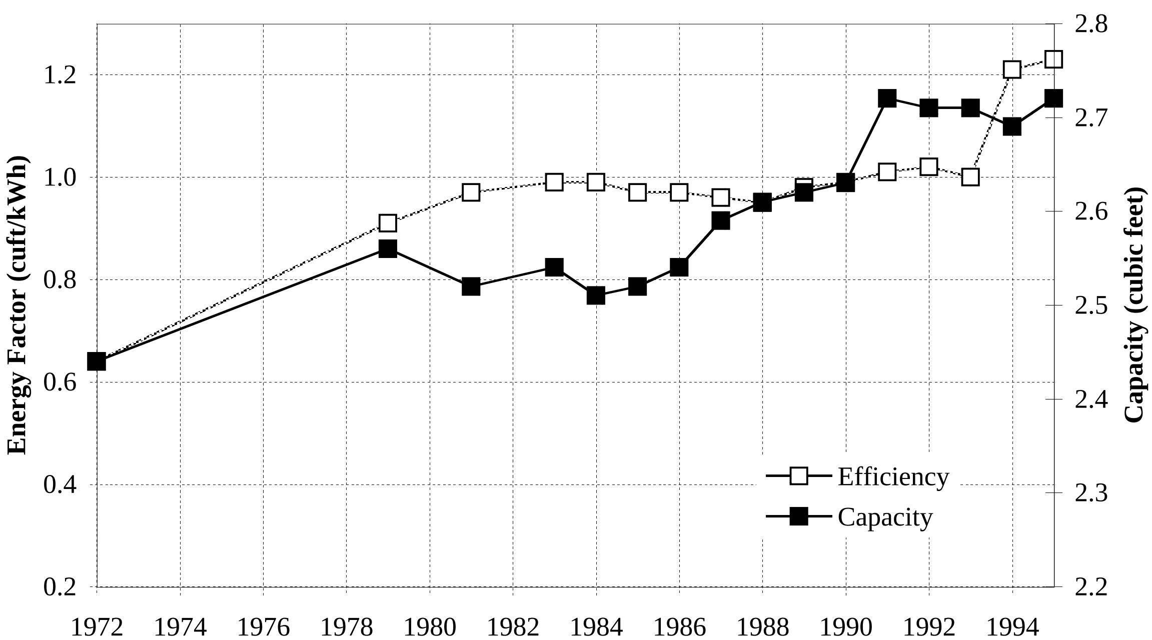
Appliance 1996 (first owner lifetime only); LBNL-REM from Fechtel et al 1980.

Figure 8.1. Annual Clothes Washer Shipments, 1957-1995



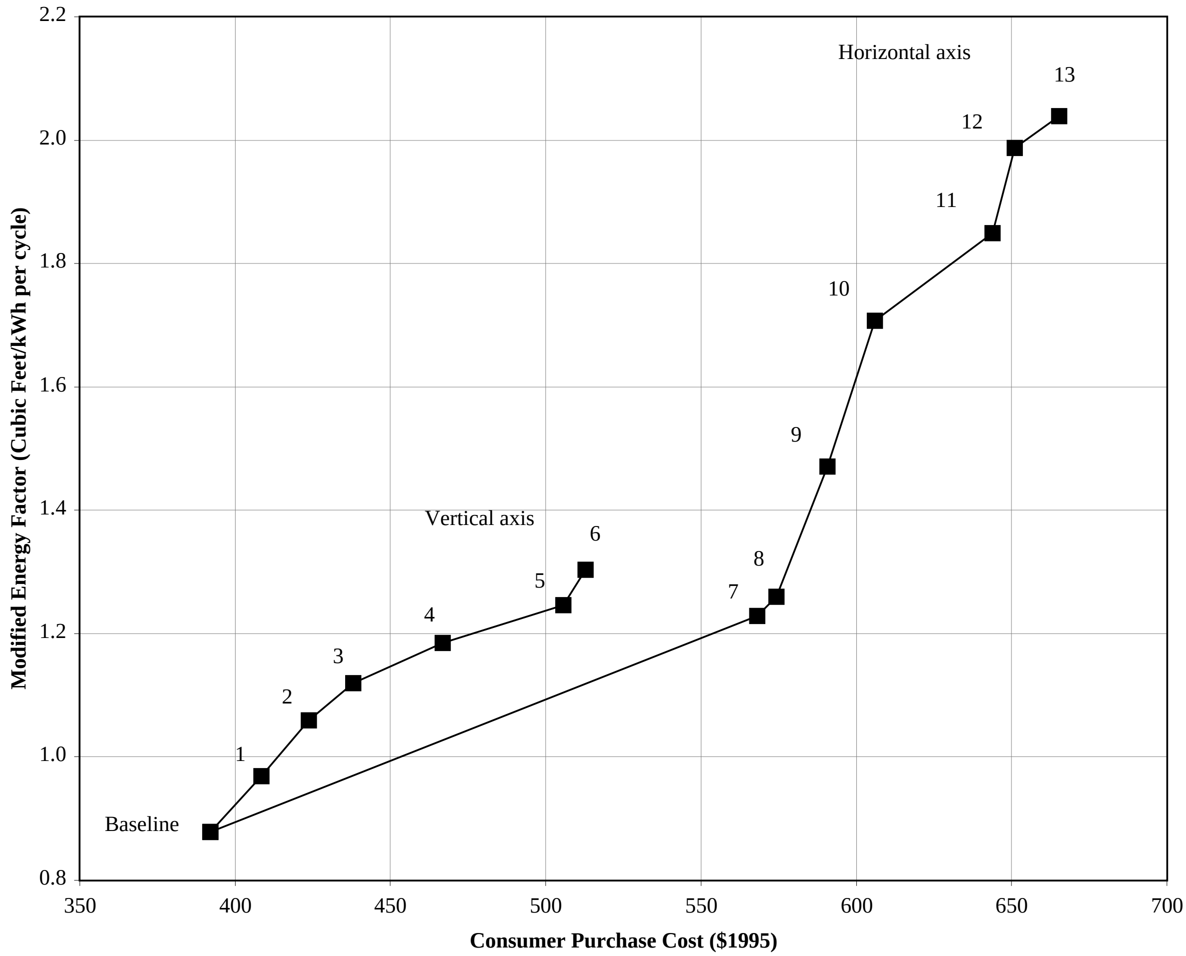
Source: US DOE 1990b (1957-75); Appliance Magazine (1976-96).

Figure 8.2. Shipment-Weighted Efficiency for Clothes Washers, 1972-1995



Source: AHAM 1996. Efficiency calculated assuming electric water heat at 100% efficiency.

Figure 8.3. Cost Versus Efficiency for New Clothes Washer



Source: Biermayer 1996. Modified Energy Factor normalizes for different washer drum capacities. UEC and MEF calculated assuming electric water heat at 100% efficiency, and including dryer energy required to dry clothes to 4% remaining moisture content. Costs adjusted from $1994 using the chain type price index for personal consumption expenditures of 1.024.

Level	Description	
Baseline	Standard clothes washer; 392 cycles per year; WH efficiency = 100% (electric); MEF includes clothes dryer energy	
1	0 + Reduce remaining moisture content (RMC) to 50%	2.93 cu.ft.
2	0 + Reduce RMC to 40%	2.93 cu.ft.
3	2 + Add thermostatic mixing valve	2.93 cu.ft.
4	3 + Add improved fill control	2.93 cu.ft.
5	4 + Reduce RMC to 35%	2.93 cu.ft.
6	4 + Reduce RMC to 30%	2.93 cu.ft.
7	0 + Horizontal axis	2.77 cu.ft.
8	7 + Add water recirculation	2.74 cu.ft.
9	8 + Reduce RMC to 50%	2.74 cu.ft.
10	8 + Reduce RMC to 40%	2.74 cu.ft.
11	8 + Reduce RMC to 35%	2.74 cu.ft.
12	8 + Reduce RMC to 30%	2.74 cu.ft.
13	12 + Add thermostatic mixing valve	2.74 cu.ft.

8.4. Market Shares

National stock market shares for clothes washers by housing type are derived from the RECS data (US DOE 1982a, 1986, 1989a, 1993b, 1995b). These data include a small number of wringer washing machines, which are slightly different from automatic washers. Market shares in new buildings are derived for buildings built during the previous 5 to 7 years from the RECS data (for example, market shares in new construction in 1993 are derived from the 1993 RECS data for buildings built between 1988 and 1993). Some of these data are shown in Figures 8.4 and 8.5. Figure 8.4 shows that clothes washer market shares are increasing only slightly overall, with market shares in SF and MH housing growing and market shares declining in MF housing. Market shares in new buildings are about 10% higher than those in the building stock; approximately 86% of new housing units have clothes washers.

8.5. Standards

Efficiency standards for clothes washers were first enacted under the National Appliance Energy Conservation Act (NAECA). These standards required only that clothes washers have an unheated water option for the rinse cycle. New standards became effective in 1994, and are shown in Table 8.3.

Table 8.3. Efficiency Standards for Residential Clothes Washers

Type	Database Code	Year Effective	Min. EF	Hot Water Energy (kWh/cycle)	Motor Energy (kWh/cycle)	Total UEC (kWh/cycle)
Using DOE Test Procedure						
Standard, Top-Loading	CW	1994	1.18	1.94	0.27	2.21
Compact, Top-Loading	CW	1994	0.90	1.36	0.25	1.61
Using P&G Data						
Standard, Top-Loading	CW	1994	1.18	1.50	0.27	1.77
Compact, Top-Loading	CW	1994	0.90	1.05	0.25	1.30

Source: US DOE 1990b.

1) Effective date is May 14 of year indicated.

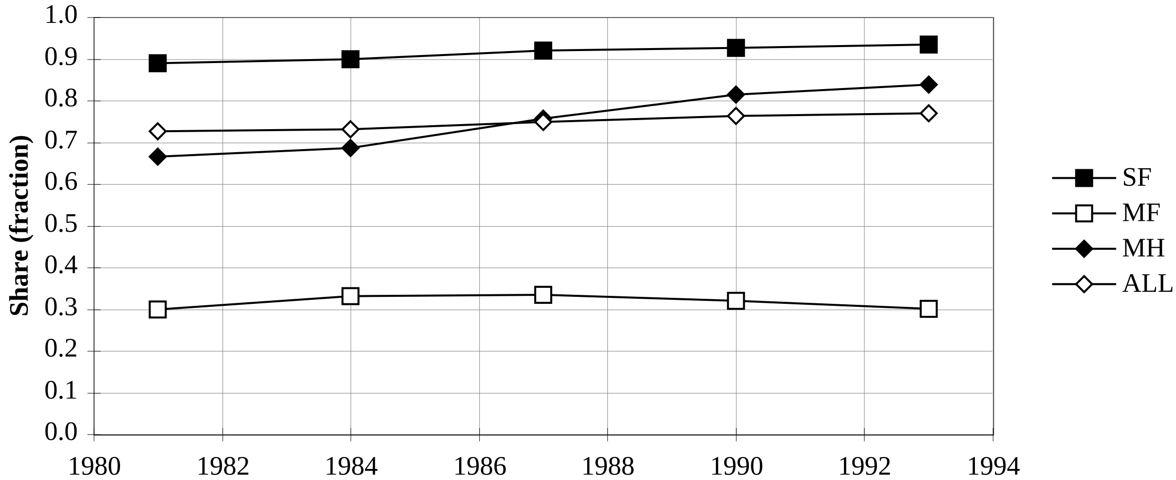
2) Standards specified in NAECA 1987 and effective starting 1988 for clothes washers required clothes washers to be equipped with an unheated water rinse option.

3) EF units are capacity (cu.ft.)/kWh per cycle.

4) UEC per cycle calculated as capacity/EF, using 2.60 cu.ft. for standard size and 1.45 cu.ft. for compact size. Includes assumption of electric water heating at 100% efficiency. Hot water use portion from US DOE 1990b; the motor also draws energy. The standard specifies only the EF, and in practice manufacturers may not use the specific design options trading off motor and hot water energies shown above.

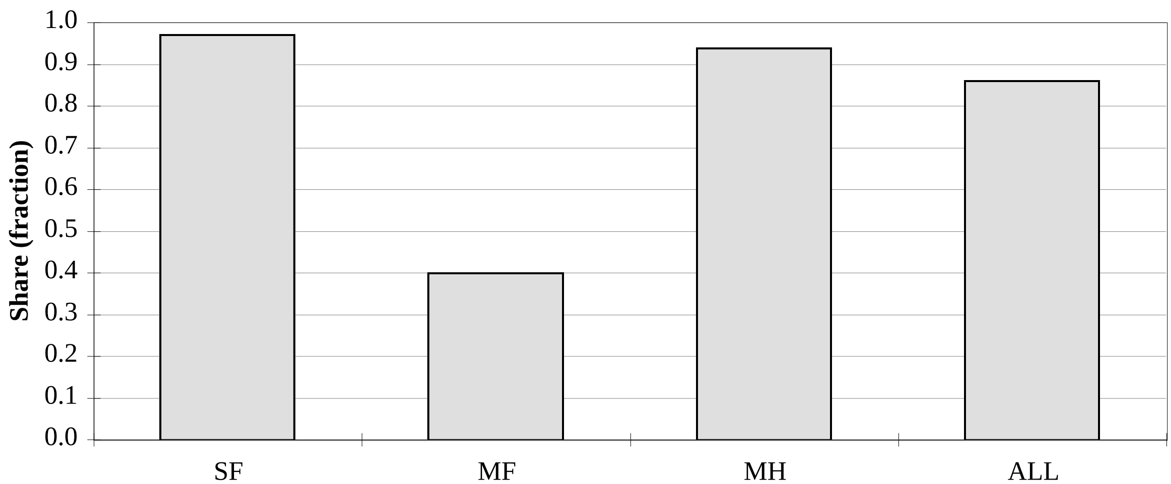
5) Other (top loading, semiautomatic; front loading; and suds saving) are not regulated under the 1994 standards but must have unheated water rinse option.

Figure 8.4. Clothes Washer Ownership Shares by Housing Type, 1981-1993



Source: US DOE 1982a, 1986, 1989a, 1992, 1995.
Approximately 2% of all clothes washers are "wringer" type in 1981-87 surveys.

Figure 8.5. Clothes Washer Ownership Shares for New Construction by Housing Type



Source: US DOE 1995 data for buildings built between 1988 and 1993.

9. CLOTHES DRYER END-USE DATA

Clothes dryers account for about 6% of total electricity usage and 2% of total natural gas usage in the residential sector. Dryers are a relatively well understood end-use and have been studied as part of the U.S. DOE appliance standards process.

9.1. Clothes Dryer UECs

Clothes dryer UECs for new units are measured using a laboratory test procedure from U.S. DOE. This regime determines the total energy use for a cycle of drying using a standard quantity of wet clothing. The UEC of a clothes dryer in the field will be directly proportional to the amount the appliance is used.

Average energy use for stock clothes dryers is estimated by utilities and other groups through direct metering or statistical techniques. In the UEC database, only 4 of the 67 estimates for electric clothes dryers come from metering studies, while only 1 of the 9 estimates for gas dryers comes from metering. However, there are more than 40 statistically-derived estimates of electric dryer UECs (Appendix A).

UEC Equation

The U.S. DOE test procedure is used to determine per-cycle energy consumption, or UEC, from which the energy factor is derived. The relationship between the UEC and the energy factor is as follows.

UEC (electric): $\text{kWh/yr} = \dfrac{\text{Use * Capacity}}{\text{EF}}$

UEC (gas): $\text{MMBtu} = \dfrac{\text{Use * Capacity * 0.003412}}{\text{EF}}$

where: Use is in cycles/year

Capacity is unit size (lb/load, or 7 lbs for standard dryer)

EF is the energy factor from the DOE test procedure (lb/kWh)

0.003412 is the kWh to MMBtu conversion factor

The electricity consumption of the motor of a gas dryer is only included when the overall consumption is expressed in kWh (and not when expressed as MMBtu)

Stock UECs

The analysis of the clothes dryer UECs in the UEC database resulted in estimates of 1000 kWh/yr for electric (n=67) and 3.9 MMBtu/yr for gas (n=10) dryers (it is unlikely that these figures include the elecricity used for motors in gas dryers). These values are close to the baseline new unit energy consumption in the U.S. DOE appliance standard analysis (967 kWh/yr and 3.73 MMBtu/yr). The similarities suggest that both the assumption for cycles in U.S. DOE 1990b (based on Proctor & Gamble data) is reasonable and that the efficiencies have not been changing over time. Efficiencies for electric dryers have changed very little since 1972, whereas gas dryer efficiency has increased 20% (from EF = 2.0 to 2.4). For simplicity, we use the UEC of the appliance standards base unit as the stock UEC.

New UECs

The UEC for new dryers is assumed to be the same as for stock units, since the stock UEC is a new unit average.

9.2. Clothes Dryer Usage

The energy usage of clothes dryers will vary in the field with number of cycles the appliance is used. The most recent estimate of number of cycles is from Proctor and Gamble (US DOE 1990b) and is 359 cycles per year. Currently, however, the U.S. DOE test procedure assumes that usage averages 416 cycles per year.

9.3. Clothes Dryer Technology Data

There are three different classes of electric clothes dryers: the standard clothes dryer and two types of compact clothes dryers. Since the standard dryer accounts for 94% of new sales, it is the only class of electric dryer considered here. There is only one class of gas clothes dryers.

Historical Efficiency Data

Annual clothes dryer shipments from 1957 to 1995 are shown in Figure 9.1 and the average efficiency of new clothes dryers sold over time is shown in Figure 9.2. Note that the efficiencies for gas units are given in terms of lbs/kWh, where the gas energy is converted to kWh at 3412 Btu/kWh (these figures do not include the electrical energy consumption of the dryer motor). The average efficiency of new electric units sold has changed only marginally since 1972, while the elimination of pilot lights has improved the efficiency of new gas dryers.

Cost vs. Efficiency for New Equipment

Estimates of cost vs. efficiency for new standard clothes dryers are shown in Figure 9.3. The values are based on estimates in the U.S. DOE appliance standards analysis (US DOE 1990b), adjusted to 1995$. Efficiency improvements are relatively minor except for the major new technologies which may become available for electric clothes dryers. Most of the dryer energy savings comes from reducing the time required to dry clothes, which can be achieved by clothes washer technologies that reduce remaining moisture content, or RMC (see previous chapter).

Product Lifetimes

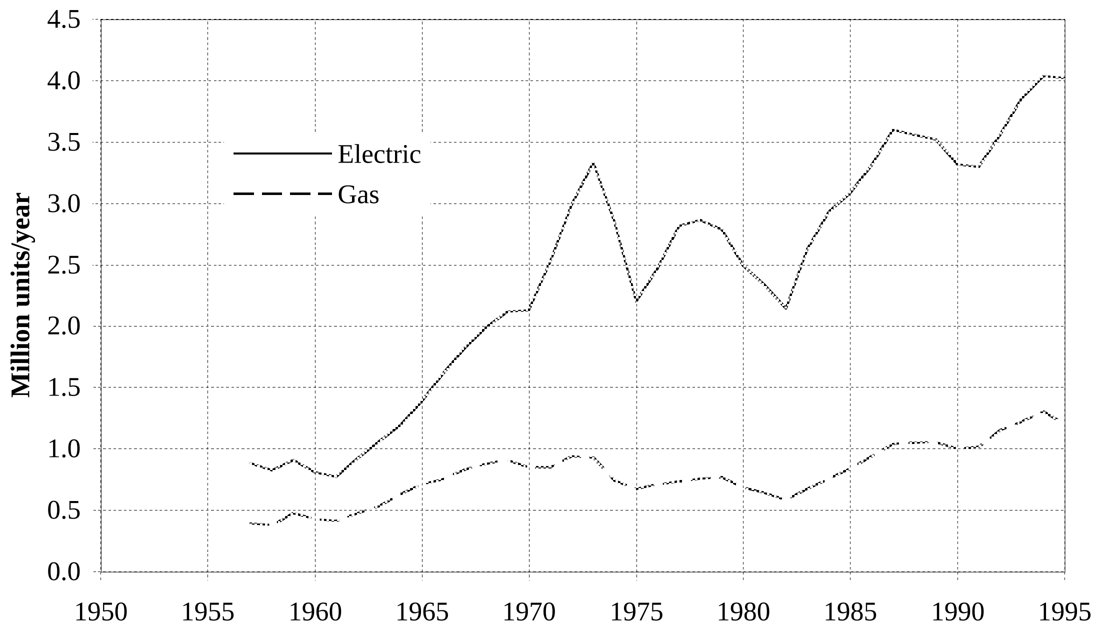
Table 9.2 shows three different estimates of the lifetimes of clothes dryers.

Table 9.2. Estimates of Residential Dryer Lifetimes

		Lifetime in Years	
Source		Gas Dryer	Electric Dryer
Appliance	Low	12	11
	Avg	14	13
	High	15	16
Lewis/Clark	Low	13	13
	Point	15	15
	High	18	18
LBNL/REM	Low	n/a	n/a
	Avg	17	17
	High	n/a	n/a

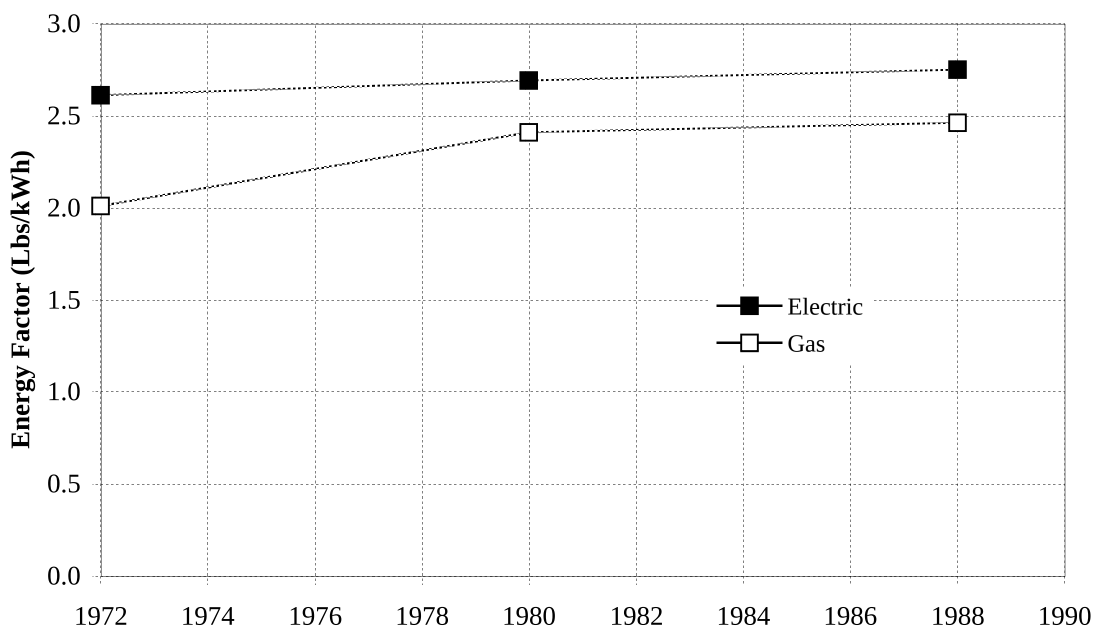
Sources: Appliance 1996 (first owner lifetime only); Lewis and Clarke 1990; LBNL-REM 1991.

Figure 9.1. Annual Clothes Dryer Shipments, 1957-1995



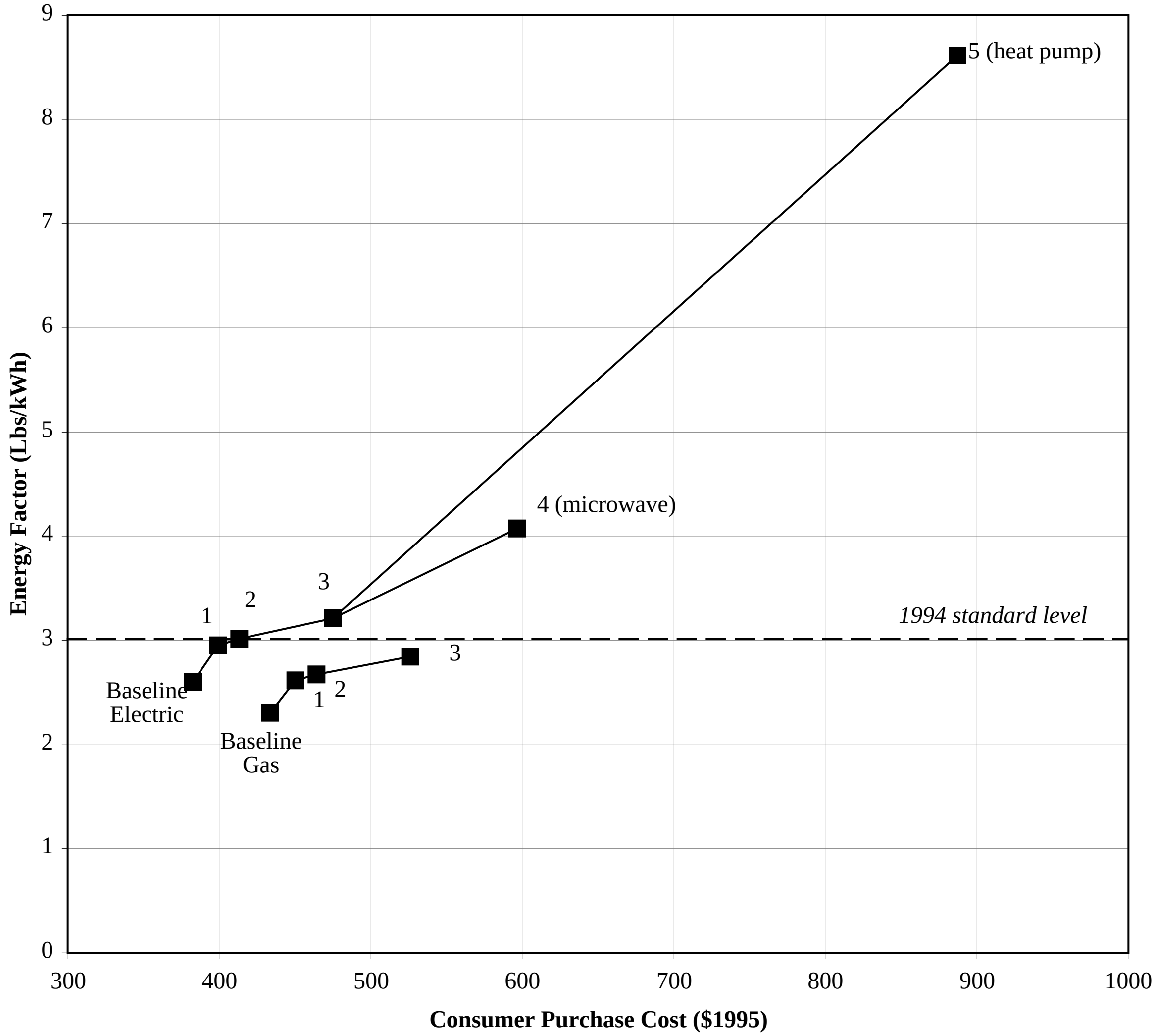
Source: US DOE 1990b (1951-1975); Appliance Magazine (1976-96).

Figure 9.2. Shipment-Weighted Efficiency for Clothes Dryers, 1972-1988



Source: AHAM 1991. Gas energy converted to kWh @ 3412 Btu/kWh to calculate energy factor.

Figure 9.3. Cost Versus Efficiency for New Dryers



Source: USDOE 1990b. Costs adjusted from $1988 using the chain type price index for personal consumption expenditures of 1.276. Gas energy factor represents gas consumption converted to kWh @ 3413 Btu/kWh. Test procedure uses 7 lbs/cycle and the test is run until the moisture content of the test load is between 2.5 and 5.0% of the bone dry weight of the test load.

Option	Description
Baseline	Standard Electric Dryer. 5.9 cubic feet. 359 cycles/year.
1	Automatic termination
2	1 + insulation
3	2 + recycle exhaust
4	2 + microwave
5	2 + heat pump
Baseline	Standard Gas Dryer. 5.9 cubic feet. 359 cycles/year.
1	Automatic termination
2	1 + insulation
3	2 + recycle exhaust

9.4. Market Shares

National stock market shares for electric and gas dryers by housing type are derived from the RECS data (US DOE 1982a, 1986, 1989a, 1993b, 1995b). Market shares in new buildings are derived for buildings built during the previous 5 to 7 years from the RECS data (for example, market shares in new construction in 1993 are derived from the 1993 RECS data for buildings built between 1988 and 1993). Some of these data are shown in Figures 9.4 and 9.5. Figure 9.4 shows that clothes dryer market shares are increasing slightly overall, with the growth coming from electric dryers. Market shares in new buildings are approximately 70% for electric clothes dryers, whereas the electric dryer stock share is 56%, so increases in the stock may be due primarily to dryers in new buildings.

9.5. Standards

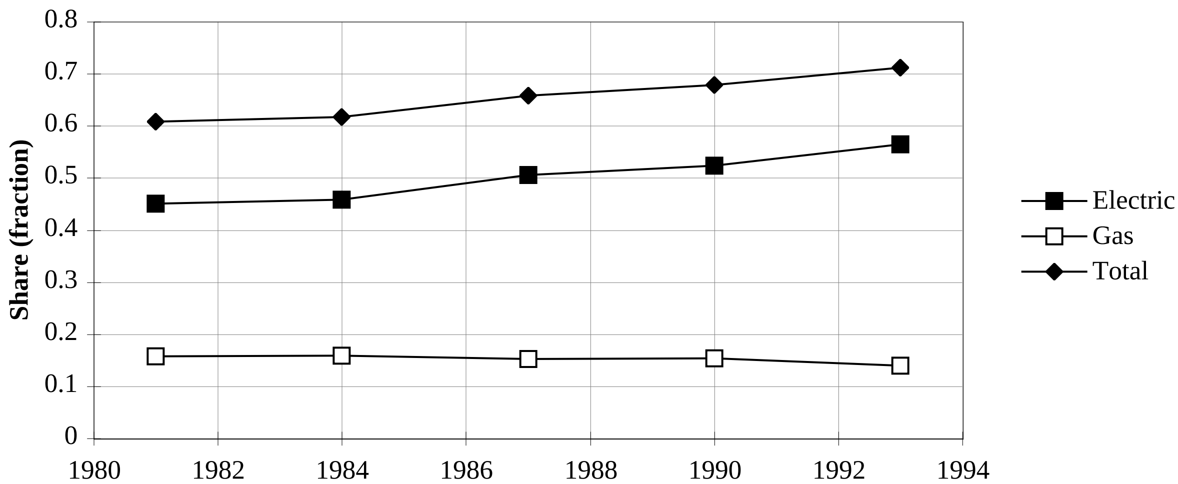
Efficiency standards for clothes dryers were first enacted in 1988 under the National Appliance Energy Conservation Act (NAECA), and required only that gas clothes dryers not have a constantly burning pilot light. Table 9.3 shows minimum efficiency standards for residential dryers.

Table 9.3. Minimum Efficiency Standards for Residential Dryers

Type	Fuel	Database Code	Year Effective	Min. EF	Total UEC
Standard	Electric	DR	1994	3.01	2.33 kWh/cycle
Compact (120V)	Electric	DR	1994	3.13	0.96 kWh/cycle
Compact (240V)	Electric	DR	1994	2.90	1.03 kWh/cycle
Standard	Gas	DR	1994	2.67	8.95 kBtu/cycle

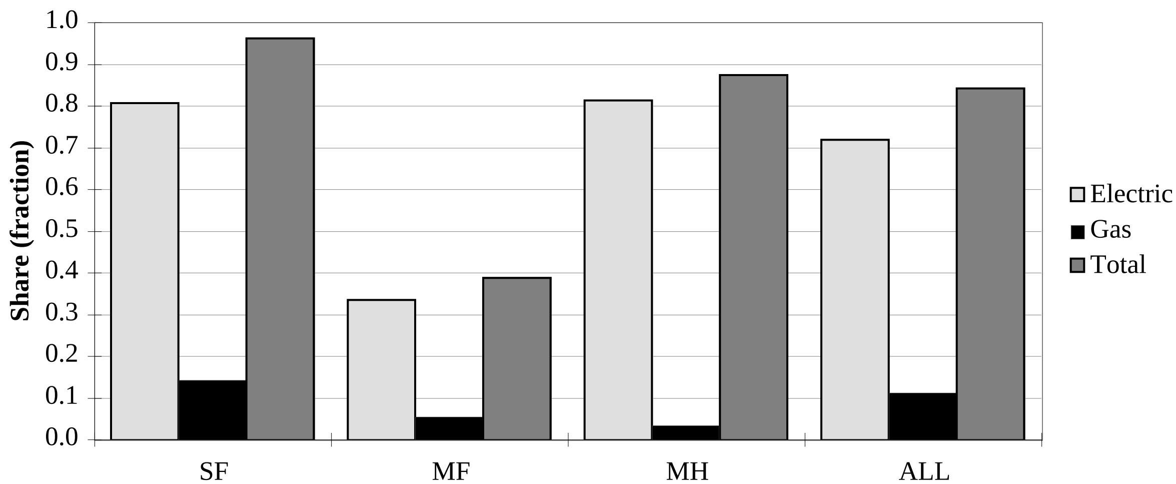
1) Effective date is May 14 of year indicated.
2) Standards specified in NAECA 1987 and effective starting 1988 for gas dryers required that gas dryers shall not be equipped with a pilot light. 1994 standards levels from US DOE 1990b.
3) EF units are lbs/kWh. Gas dryer EF are also lbs/kWh at a conversion of 3412 Btu/kWh.
4) UEC per cycle calculated as capacity (lbs)/EF, using 7 lbs for standard dryers and 3 lbs for compact size.

Figure 9.4. Clothes Dryer Fuel and Total Ownership Shares by Housing Type, 1981-1993



Source: US DOE 1982a, 1986, 1989a, 1992, 1995.

Figure 9.5. Clothes Dryer Fuel and Total Ownership Shares for New Construction by Housing Type



Source: US DOE 1995 data for buildings built between 1988 and 1993.

10. LIGHTING END-USE DATA

Residential lighting accounts for about 9% of residential electricity consumption (US DOE 1995b, US DOE 1996c, US DOE 1996d), and is thus a major end-use. However there has only recently been an effort by researchers, utilities, and policymakers to characterize the lighting end-use in the residential sector (for example Atkinson et al 1992 and Vorsatz et al 1997). In this section, we present data from a study large enough to allow detailed disaggregation of energy use in residences.

Average energy use for lighting in the building stock is difficult to measure by metering because of the spatially diffuse nature of lighting. It is also difficult to estimate UECs from other statistical techniques. In the UEC database, there is only one metered estimate for lighting and 2 conditional demand estimates (Appendix A).

Residential lighting exhibits a great deal of diversity in usage and equipment size (i.e., wattage of bulbs). This situation is further complicated by the fact that the usage level affects the service life of the device. For instance, an incandescent bulb used one hour per day will last approximately three years, while the same bulb operated three hours per day will last less than one year. The usage level is important because it largely influences the cost-effectiveness of energy-efficient lighting technologies.

We use the results of a detailed lighting metering study conducted in Washington state (Tribwell and Lerman 1996), which monitored lighting usage using light loggers and surveyed the wattages of all monitored sockets. We create incandescent bulb UECs by both hours of usage and bulb wattage. Using this breakdown, we calculate total electricity use and use per household for residential lighting. We also present a summary of costs and lifetimes for standard incandescent bulbs and their more efficient replacements.

10.1. Baseline Lighting Usage

We divide the current stock of indoor and outdoor light sockets into six usage bins: less than 1 hour, 1 to 2, 2 to 3, 3 to 4, 4 to 5, and greater than 5 hours per day. Table 10.1 shows the average usage in hours per day (second column) and the fraction of sockets (third column) assigned to each usage bin. We assume, in the absence of better data, that this usage distribution is representative of residential lighting usage in the U.S.

10.2. Distribution of Installed Wattage

We focus mainly on incandescent lamps because they comprise the vast majority of lighting in the residential sector. The Washington survey reports fixture wattage, which is the total wattage of all bulbs installed in each fixture. We calculate bulb wattage by dividing the fixture wattage by the number of bulbs per fixture. Because all bulbs in some fixtures are not of the same wattage, the derived bulb wattages occasionally are not whole numbers, or do not match wattages available. For this reason, Table 10.1 shows the distribution of bulbs by wattage bins; the bins are constructed to be centered around the most popular bulb wattages (25, 40, 60, 75, 100, and 150 watts). The second row of Table 10.1 shows the average wattage of each wattage bin, while the third row shows the overall distribution of bulbs by wattage.

10.3. Energy Consumption per Socket

Table 10.1 also shows the average socket UEC, based on the usage and wattage distributions discussed above. Each combination of lamp wattage and daily usage leads to a unique annual socket UEC, ranging from 4 to 552 kWh per socket per year. The overall average UEC per socket is 49.8 kWh/socket/year (bottom right corner of Table 10.1). The column and row marked "% of total" show the percent of total incandescent lighting energy consumption attributable to each usage bin and wattage bin, respectively.

Table 10.1: Usage and Wattage Distributions for Incandescent Sockets in Single Family US Residences

		Wattage bin	<35	35-50	50-67	67-85	85-125	125-160	>160	*Wtd avg*	
		Avg watts in bin	23	40	60	75	100	150	252	75.5	
		% of total bulbs	5%	11%	42%	17%	15%	7%	3%		
Daily Usage (Hrs/day)	*Mean in Bin (Hrs/day)*	*Bulb Fraction (% of total)*	*Electricity use per socket by usage bin and wattage bin (kWh/yr)*							*Wtd avg*	*% of total*
0-1 hrs	0.4	57%	4	5	8	9	13	15	31	9.2	*10%*
1-2 hrs	1.4	17%	13	21	32	40	51	80	130	40.3	*14%*
2-3 hrs	2.5	9%	24	36	53	66	93	133	211	70.4	*13%*
3-4 hrs	3.5	5%	28	50	75	92	128	189	353	97.7	*9%*
4-5 hrs	4.5	3%	33	65	99	123	167	249	359	133.7	*9%*
>5 hrs	9.3	9%	71	146	211	236	338	458	552	241.3	*44%*
Wtd Avg	1.8	100%	15.4	28.3	39.9	47.1	69.8	103.1	127.4	49.8	*100%*
% of total			*1%*	*7%*	*34%*	*16%*	*21%*	*14%*	*7%*	*100%*	

Source: Tacoma Public Utility data cited in Tribwell and Lerman, 1996. Lamp wattages calculated using fixture wattage / number of lamps per fixture.

10.4. Energy Consumption per Household

Table 10.2 converts the socket-level UEC (from Table 10.1) to a whole-house UEC estimate. We rely on a 1990 PG&E survey (Kelsey and Richardson 1992) for assumptions on installed wattage per square foot (1.25 for single-family and mobile home, 1.18 for multi-family) and the fraction of all wattage that is incandescent rather than fluorescent (88%). We believe that this survey is the best source on the characteristics of the overall lighting stock because it has the largest sample size of any lighting survey (over 1,000 homes) and covered a wide variety of houses (the 1993 RECS is not adequate for this purpose because it did not include sockets with very low usage). Table 10.2 uses national data on house type mix and floor area (US DOE 1995b), and the per-socket incandescent UEC and average incandescent usage from Table 10.1. National annual incandescent UECs range from 643 kWh/year (multi-family) to 1444 kWh/year (single-family), with an overall average of 1200 kWh/year. Table 10.2 also compares our national estimates with the California estimates from the PG&E survey; which found an overall average incandescent UEC per household of 1098 kWh/year.

10.5. Total Energy Consumption by Housetype

Table 10.3 shows total incandescent electricity consumption in US residences, disaggregated by house type, usage bin, and wattage bin. Total annual consumption for residential incandescent bulbs is 112 TWh. If the PG&E survey's estimate of fluorescent (not compact fluorescent) penetration per household accurately reflects households throughout the nation, electricity use for fluorescent lamps in residences would add another 15 TWh to this total. Our total (including fluorescents) of 127 TWh is over 35% higher than DOE estimates of 1993 lighting energy use of 91 TWh (US DOE 1995c) and 94 TWh (US DOE 1995d); however, our estimate is very similar to the 122 TWh for 1990 calculated by Atkinson et al. (1992). About 80% of incandescent lighting energy is found in single-family homes, with most of the rest found in multi-family buildings.

Table 10.2: Calculation of National Lighting Consumption by House Type

	National Annual Consumption				*PG&E (1)*
	Housing Type				(all house
Parameter	Single-Family	Multi-Family	Mobile Homes	Total	types)
Percentage of 1993 households (2)	*69%*	*25%*	*6%*	*100%*	
Existing home heated floor area (sq ft) (3)	1,953	922	938	1,636	1,400
Installed incandescent watts (4)	2,148	957	1,032	1,785	1,552
Avg. incandescent usage (hr/day) (5)	1.84	1.84	1.84	1.84	1.94
Annual incandescent UEC (kWh/yr) (6)	1,444	643	693	1,200	1,098
Inc. UEC per socket (kWh/socket/yr) (7)	49.8	49.8	49.8	49.8	44.7
Sockets per house (8)	29	13	14	24	25

(1) Total lighting UEC is 1274 kWh/yr. Fluorescent UEC (156 kWh/yr) calculated assuming 3.2 lamps per house @ 41.1 Watts per lamp used 3.8 hours per day for 313 days per year (Kelsey & Richardson 1992). Incandescent (1118 kWh/yr) is net of tube fluorescent lamps.
(2) 1993 RECS (US DOE 1995c).
(3) U.S. heated floor area by house type from US DOE (1995c); PG&E floor area from Kelsey & Richardson (1992).
(4) Calculated assuming 1.25 Watts per square foot for single-family and mobile home and 1.18 Watts per square foot for multi-family, reduced by 12% to account for the fact that incandescent lamps are 88% of installed wattage (Kelsey & Richardson 1992). Total wattage for U.S. homes calculated as the product of PG&E wattage per square foot and national average floor area.
(5) U.S. value from Table 10.1; PG&E average usage based on customer-reported usage.
(6) Average usage * installed watts/1000
(7) U.S. incandescent UEC per socket from Table 10.1; PG&E from Kelsey & Richardson (1992).
(8) U.S. value for sockets per house calculated by dividing annual UEC (6) by UEC per socket (7); PG&E value based on Kelsey & Richardson (1992).

Table 10.3: 1993 Residential Incandescent Lighting Electricity Use by House Type, Usage Bin, and Wattage Bin (TWh/yr)

	Bulb wattage bin								
	<35W	*35-50W*	*50-67W*	*67-85W*	*85-125W*	*125-160W*	*>160W*	*Sum*	*Percent of total*
Single family									
0-1 hrs/day	0.2	0.6	3.4	1.6	2.0	1.1	0.9	10	*9%*
1-2 hrs/day	0.2	0.8	4.3	2.1	2.4	1.7	1.1	13	*11%*
2-3 hrs/day	0.2	0.7	3.9	1.9	2.4	1.6	1.0	12	*11%*
3-4 hrs/day	0.1	0.5	2.8	1.3	1.7	1.1	0.8	8	*7%*
4-5 hrs/day	0.1	0.5	2.7	1.3	1.6	1.1	0.6	8	*7%*
>5 hrs/day	0.6	2.9	15.3	6.7	8.8	5.4	2.5	42	*38%*
Sum	1.4	5.9	32.4	14.9	19.0	12.0	6.8	92	*82%*
Multi-family									
0-1 hrs/day	0.0	0.1	0.6	0.3	0.3	0.2	0.1	1.7	*1%*
1-2 hrs/day	0.0	0.1	0.7	0.4	0.4	0.3	0.2	2.1	*2%*
2-3 hrs/day	0.0	0.1	0.7	0.3	0.4	0.3	0.2	2.0	*2%*
3-4 hrs/day	0.0	0.1	0.5	0.2	0.3	0.2	0.1	1.4	*1%*
4-5 hrs/day	0.0	0.1	0.5	0.2	0.3	0.2	0.1	1.3	*1%*
>5 hrs/day	0.1	0.5	2.6	1.1	1.5	0.9	0.4	7.1	*6%*
Sum	0.2	1.0	5.5	2.5	3.2	2.0	1.2	16	*14%*
Mobile home									
0-1 hrs/day	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.4	*0%*
1-2 hrs/day	0.0	0.0	0.2	0.1	0.1	0.1	0.0	0.5	*0%*
2-3 hrs/day	0.0	0.0	0.2	0.1	0.1	0.1	0.0	0.5	*0%*
3-4 hrs/day	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.3	*0%*
4-5 hrs/day	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.3	*0%*
>5 hrs/day	0.0	0.1	0.6	0.3	0.3	0.2	0.1	1.6	*1%*
Sum	0.1	0.2	1.3	0.6	0.7	0.5	0.3	4	*3%*
Total									
0-1 hrs/day	0.2	0.7	4.2	2.0	2.5	1.4	1.1	12	*11%*
1-2 hrs/day	0.2	0.9	5.2	2.5	2.9	2.1	1.3	15	*14%*
2-3 hrs/day	0.2	0.9	4.8	2.3	3.0	1.9	1.2	14	*13%*
3-4 hrs/day	0.1	0.6	3.4	1.6	2.1	1.4	1.0	10	*9%*
4-5 hrs/day	0.1	0.6	3.2	1.6	2.0	1.3	0.7	10	*8%*
>5 hrs/day	0.7	3.5	18.6	8.1	10.6	6.5	3.0	51	*45%*
Sum	2	7	39	18	23	15	8	112	*100%*

(1) Total 1993 households (97 million) from 1993 RECS (US DOE 1995c).
(2) Total TWh calculated using number of households by house type and usage/wattage breakdowns from Tables 10.1 and 10.2.

10.6. Costs of Efficiency Improvements in Lighting

Table 10.4 shows costs and lifetimes for typical incandescent bulbs and more efficient replacements for those bulbs.

Table 10.4: Cost and Lifetimes for Incandescent and Compact Fluorescent Bulbs

Lamp type	Style	Lamp Wattage	Approximate Incandescent Equivalent Watts	Rated Life Hours	Lamp Cost 1990 $
Incandescent	General service	60	60	1000	$0.48
		75	75	750	$0.48
		100	100	750	$0.48
Compact Fluorescent	Capsule	15	60	9,000	$14
	Capsule	18	75	9,000	$20
	Globe	15	60	9,000	$14
	Twin Tube	7	40	10,000	$24
	Twin Tube	11	40+	10,000	$24
	Twin Tube	15	60	10,000	$24
	Twin Tube	20	75	10,000	$24
	Quad Tube	20	75+	9,000	$20
	Quad Tube	27	100	9,000	$22
Incandescent reflector	PAR 38 Flood	150	150	2,000	$3.66
Halogen reflector	PAR 38 Flood	90	150	2,000	$4.91

(1) Source for standard and reflector incandescents and halogens: Atkinson et al. 1992.
(2) Source for compact fluorescents: Koomey et al. 1994a.
(3) Prices are to the end-user, not including utility rebates.

11. COOKING END-USE DATA

Cooking, or the combined total for cooktops, ovens, and microwave ovens, accounts for about 7% of residential electricity consumption, 4% of natural gas consumption, and 10% of LPG consumption. The primary consideration for forecasting of cooking energy use may be changes in usage as people cook more with microwave ovens and utilize more prepared foods. Both of these structural changes could decrease residential energy use for cooking over time. We include data on three classes of cooking appliances: cooktops, ovens and microwaves. The cooking end-use is made more complicated by the smaller devices such as toaster ovens and coffee makers. UECs for these miscellaneous devices are provided in Table 13.1 in Chapter 13, Miscellaneous End-Use Data.

11.1. Cooking UECs

Cooking UECs for new cooktops, ovens, and microwaves are measured using a laboratory test procedure from U.S. DOE. The UEC of a cooking appliance in the field will be directly proportional to the amount the appliance is used.

Average energy use for cooking appliances in the stock is estimated by utilities and other groups through direct metering or statistical techniques. In the UEC database, there are 6 metered estimates for electric cooking, 3 for microwaves, and only 1 for gas cooking. However, there are 57 derived from statistical techniques. In only a few cases are the cooking UECs split between cooktops and ovens (Appendix A).

Stock UECs

Our UEC estimates for cooking are 822 kWh/yr for electric cooktops and ovens, 5.6 MMBtu/yr for gas and LPG cooktops and ovens, and 132 kWh/yr for microwave ovens. These are taken from weighted averages of the records in the UEC database (Appendix A).

New UECs

New UECs are assumed to be the same as for the existing stock.

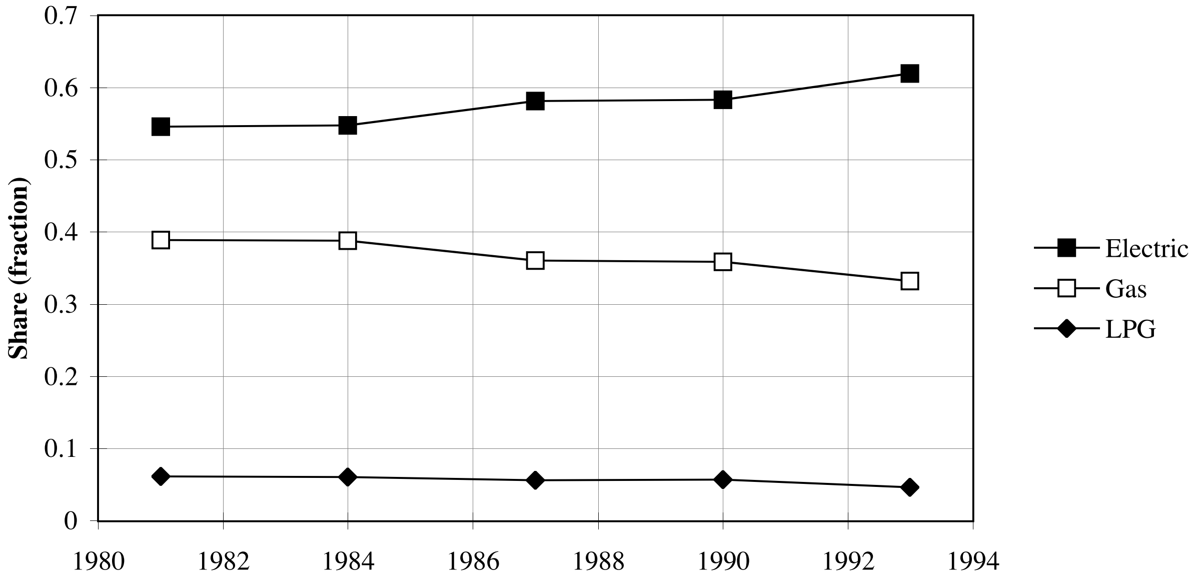
11.2. Cooking Technology Data

There is very little data currently available on the technology characteristics of cooktops, ovens, and microwaves.

Historical Efficiency Data

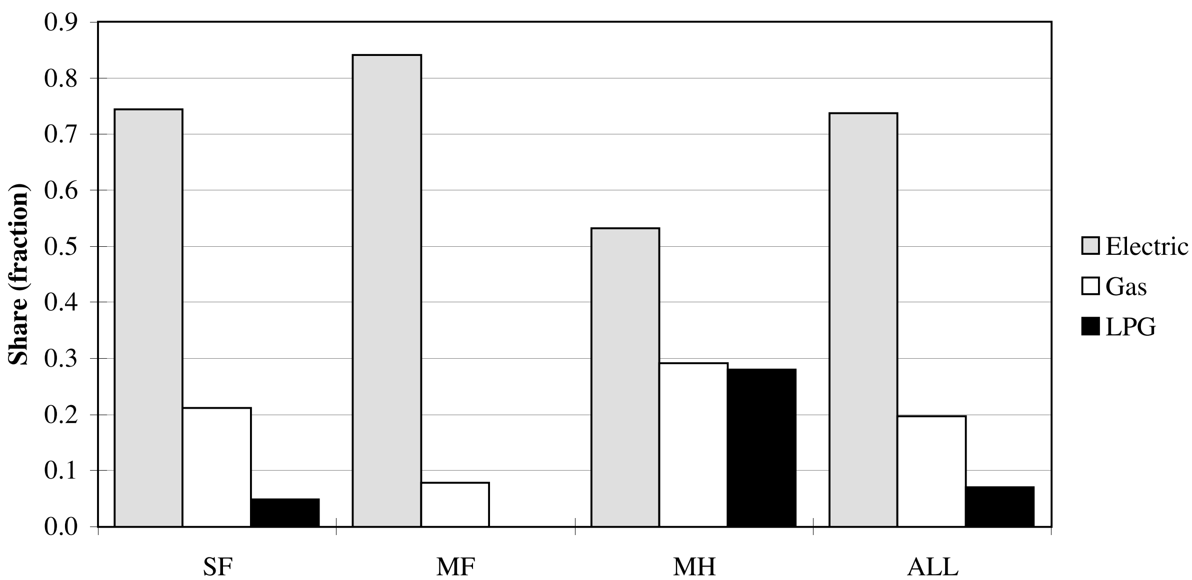
No data on historical efficiency for cooking appliances are available. Historical shipment data are shown in Figure 11.1 for cooking ranges, Figure 11.2 for cooktops, and Figure 11.3 for microwave ovens.

Figure 11.11. Cooking Fuel Shares in Total Housing Stock, 1981-1993



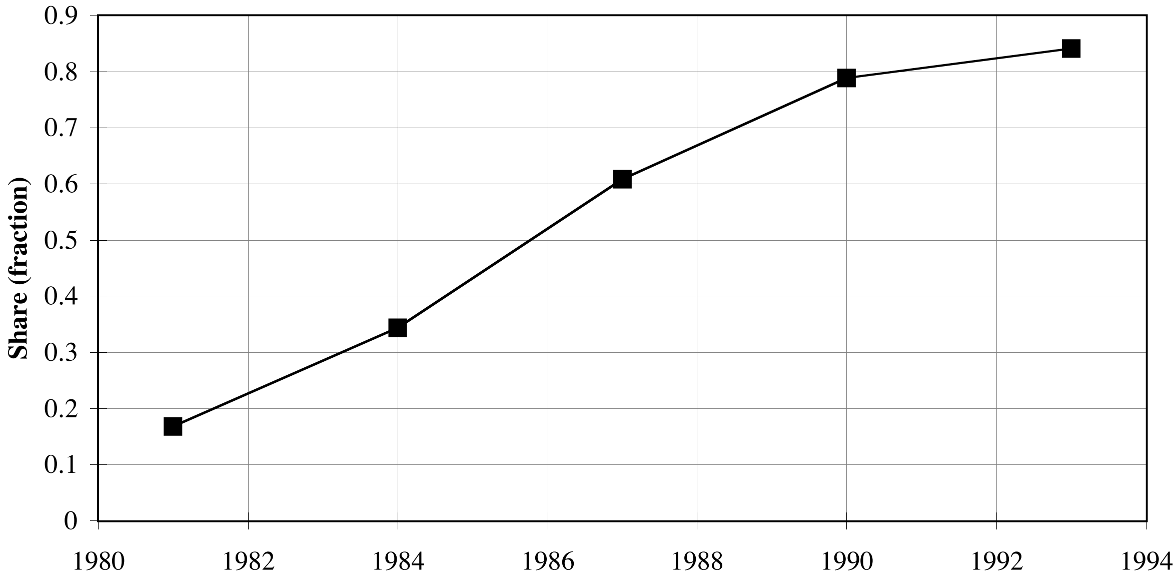
Source: US DOE 1982a, 1986, 1989a, 1992, 1995.
Fuel shares are for "main cooking fuel" only. Not all houses will have both rangetops and ovens.

Figure 11.12. Cooking Fuel Shares for New Construction by Housing Type



Source: US DOE 1995 data for buildings built between 1988 and 1993.
Fuel shares are for "main cooking fuel" only. Not all houses will have both rangetops and ovens.

Figure 11.13. Microwave Oven Shares in Total Housing Stock, 1981-1993



Source: US DOE 1982a, 1986, 1989a, 1992, 1995.

Cost vs. Efficiency for New Equipment

Estimates of cost vs. efficiency for new electric cooktops (coil element), gas cooktops, electric and gas ovens (non self-cleaning as well as self-cleaning), and microwave ovens are provided in Figures 11.4 through 11.10. The values are based on estimates in the U.S. DOE appliance standards analysis (US DOE 1996a).

Product Lifetimes

Three estimates of the lifetime of cooking equipment are shown in Table 11.1.

Table 11.1. Estimates of Residential Cooking Equipment Lifetimes

Source		Lifetime in Years		
		Gas Range	Electric Range	Microwave Ovens
Appliance	Low	11	10	7
	Avg	18	15	10
	High	24	20	12
Lewis/Clark	Low	15	15	
	Point	15	15	
	High	20	20	
LBNL/REM	Low	16	16	7
	Avg	18	18	10
	High	21	21	13

Sources: Appliance 1996 (first owner lifetime only); Lewis and Clarke 1990; LBNL-REM from Fechtel et al 1980.

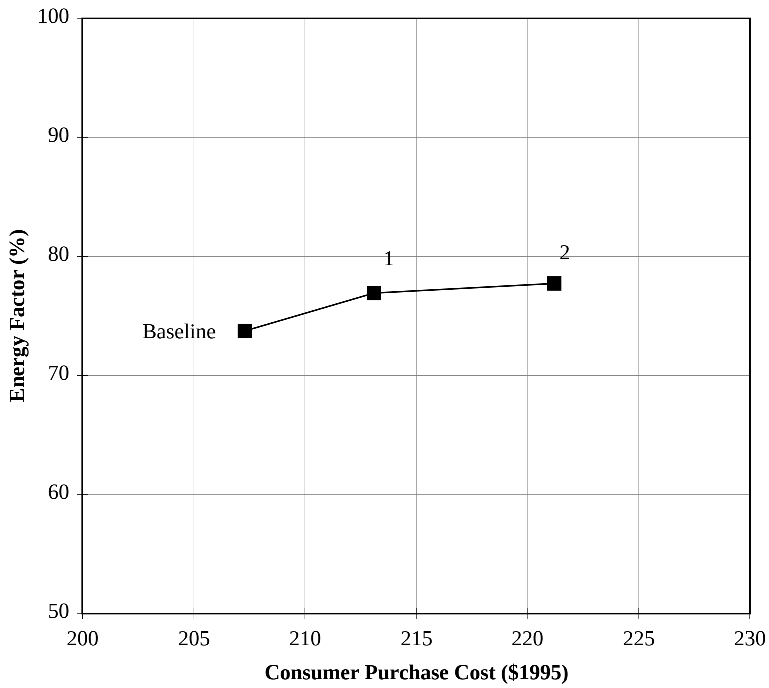
11.3. Market Shares

National stock market shares by main cooking fuel for standard cooking appliances, by housing type, are derived from the RECS data (US DOE 1982a, 1986, 1989a, 1993b, 1995b). Market shares in new buildings are derived for buildings built during the previous 5 to 7 years from the RECS data (for example, market shares in new construction in 1993 are derived from the 1993 RECS data for buildings built between 1988 and 1993). Some of these data are shown in Figures 11.11 and 11.12. There is a clear movement towards electric cooking in both the building stock and in new construction. Figure 11.13 shows that microwave ovens have reached almost an 85% share in the housing stock, and as shown in the shipments data, may have saturated the market.

11.4 Efficiency Standards

Starting in 1990, gas cooktops and ovens with electric cords were no longer allowed to have a constantly burning pilot light. Thus, most new gas cooktops and ovens must have electric or electronic ignition systems, which will decrease gas usage and increase electricity usage for gas ranges.

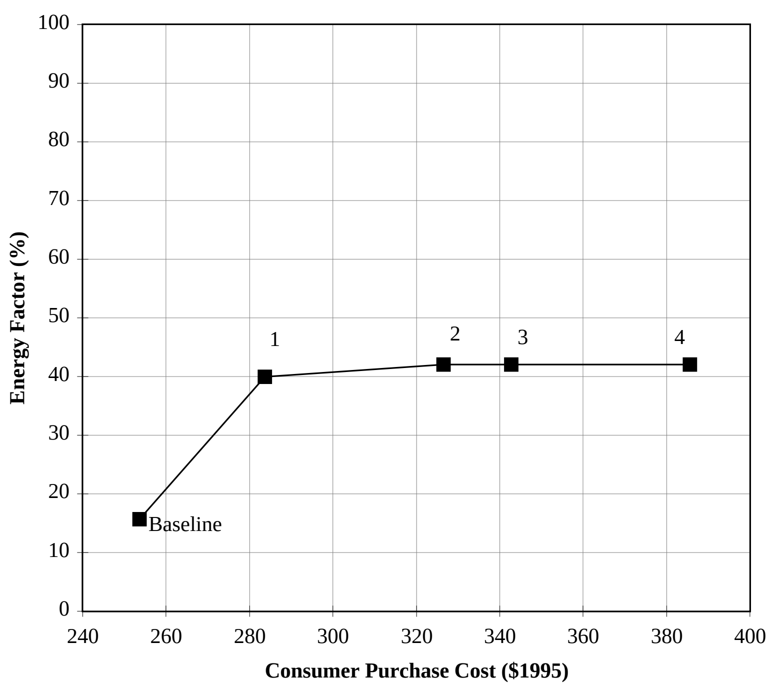
Figure 11.4. Cost Versus Efficiency for New Electric Cooktops with a Coil Element



Option	Description
Baseline	Electric Coil Cooktop
1	0 + Improved Contact Conductance
2	1 + Reflective Surfaces

Source: US DOE 1996a. Efficiency based on anticipated updates to proposed DOE test procedure (Federal Register 60(56), March 23, 1995). Costs converted from $1990 using the chain type price index for personal consumption expenditures of 1.158.

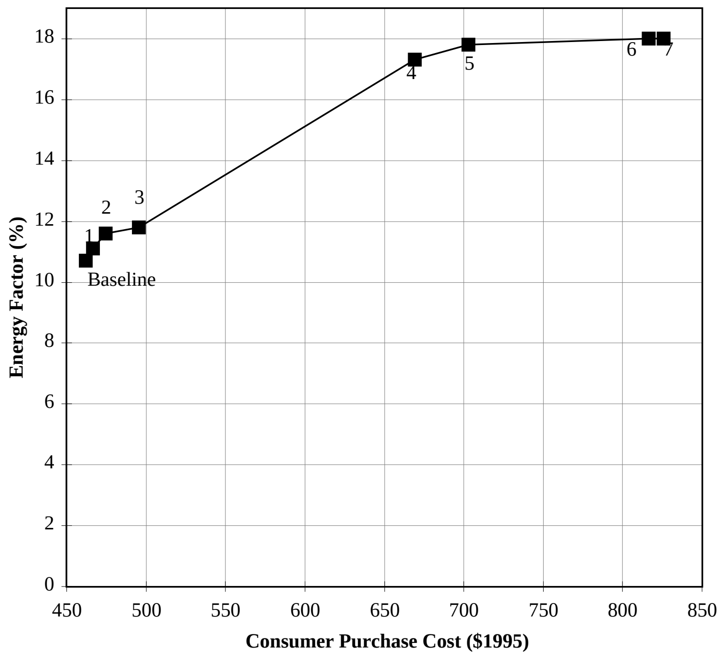
Figure 11.5. Cost Versus Efficiency for New Gas Cooktops



Option	Description
Baseline	Conventional Gas Cooktop
1	0 + Electronic Ignition
2	1 + Sealed Burners
3	2 + Reflective Surfaces
4	3 + Thermostatically Controlled Burners

Source: US DOE 1996a. Efficiency based on anticipated updates to proposed DOE test procedure (Federal Register 60(56), March 23, 1995). Costs converted from $1990 using the chain type price index for personal consumption expenditures of 1.158.

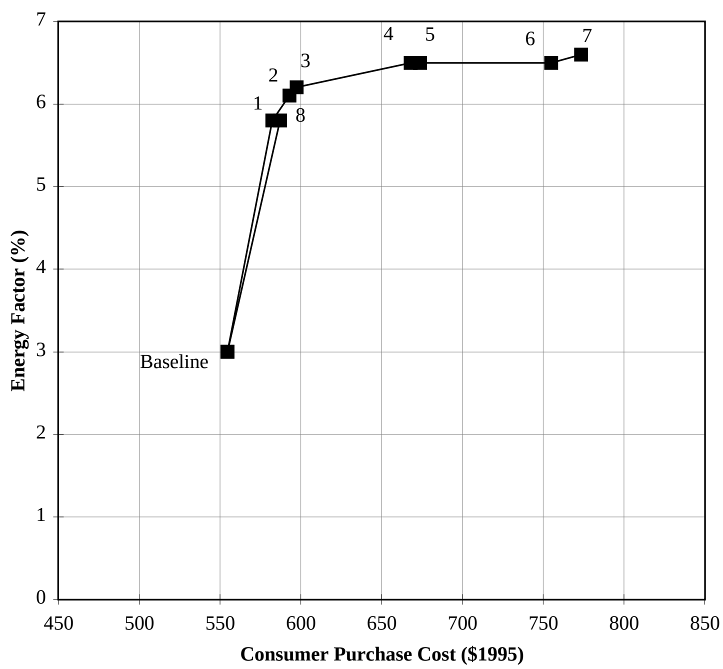
Figure 11.6. Cost Versus Efficiency for New Electric Ovens (Non Self-Cleaning)



Option	Description
Baseline	Electric Oven, Non Self-Cleaning
1	0 + Reduced Vent Rate
2	1 + Improved Insulation
3	2 + Improved Door Seals
4	3 + Bi-Radiant Oven
5	4 + Oven Separator
6	5 + Forced Convection
7	6 + Reduced Conduction Losses

Source: US DOE 1996a. Non self-cleaning ovens represent 45% of new electric oven sales. Efficiency based on anticipated updates to proposed DOE test procedure (Federal Register 60(56), March 23, 1995). Costs converted from $1990 using the chain type price index for personal consumption expenditures of 1.158.

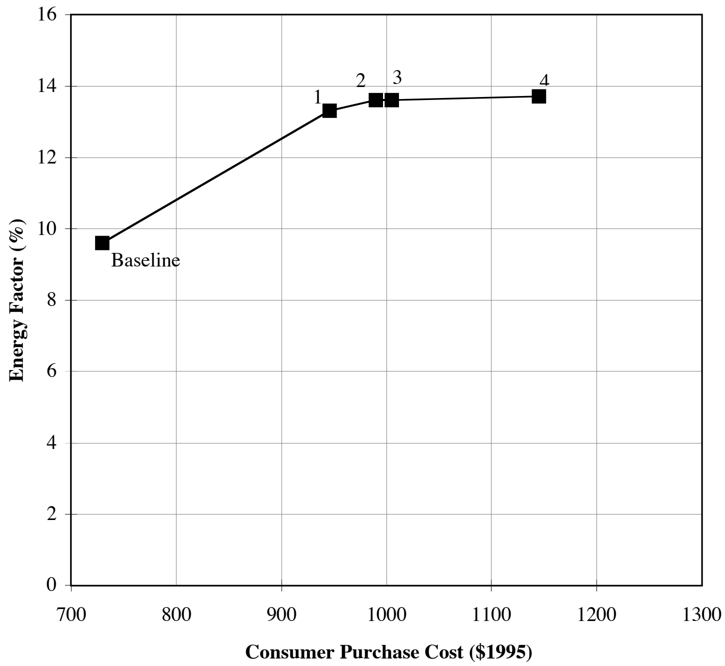
Figure 11.7. Cost Versus Efficiency for New Gas Ovens (Non Self-Cleaning)



Option	Description
Baseline	Gas Oven, Non Self-Cleaning
1	0 + Electric Glo-bar Ignition
2	1 + Improved Insulation
3	2 + Improved Door Seals
4	3 + Forced Convection
5	4 + Reduced Vent Rate
6	5 + Oven Separator
7	6 + Reduced Conduction Losses
8	0 + Electronic Spark Ignition

Source: US DOE 1996a. Non self-cleaning ovens represent 75% of new gas oven sales. Efficiency based on anticipated updates to proposed DOE test procedure (Federal Register 60(56), March 23, 1995). Costs converted from $1990 using the chain type price index for personal consumption expenditures of 1.158.

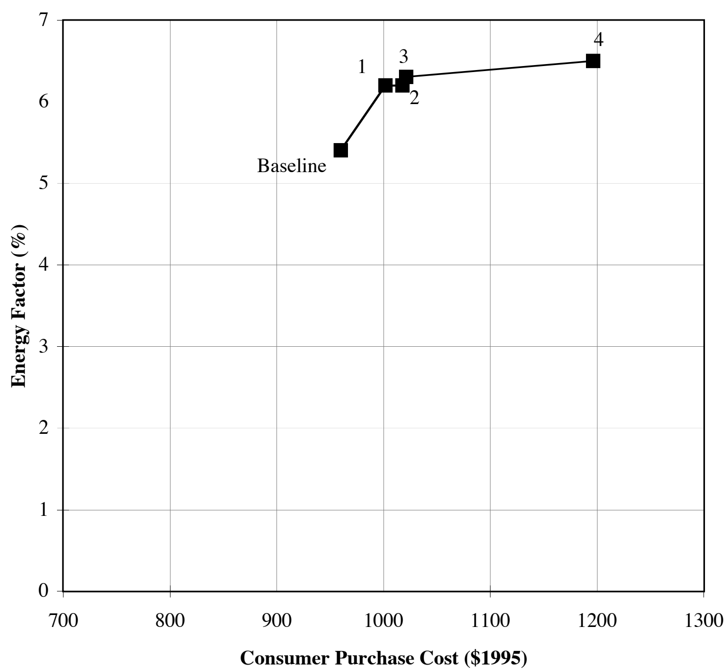
Figure 11.8. Cost Versus Efficiency for New Electric Ovens (Self-Cleaning)



Option	Description
Baseline	Electric Oven, Self-Cleaning
1	0 + Bi-radiant Oven
2	1 + Oven Separator
3	2 + Reduced Conduction Losses
4	3 + Forced Convection

Source: US DOE 1996a. Self-cleaning ovens represent 55% of new electric oven sales. Efficiency based on anticipated updates to proposed DOE test procedure (Federal Register 60(56), March 23, 1995). Costs converted from $1990 using the chain type price index for personal consumption expenditures of 1.158.

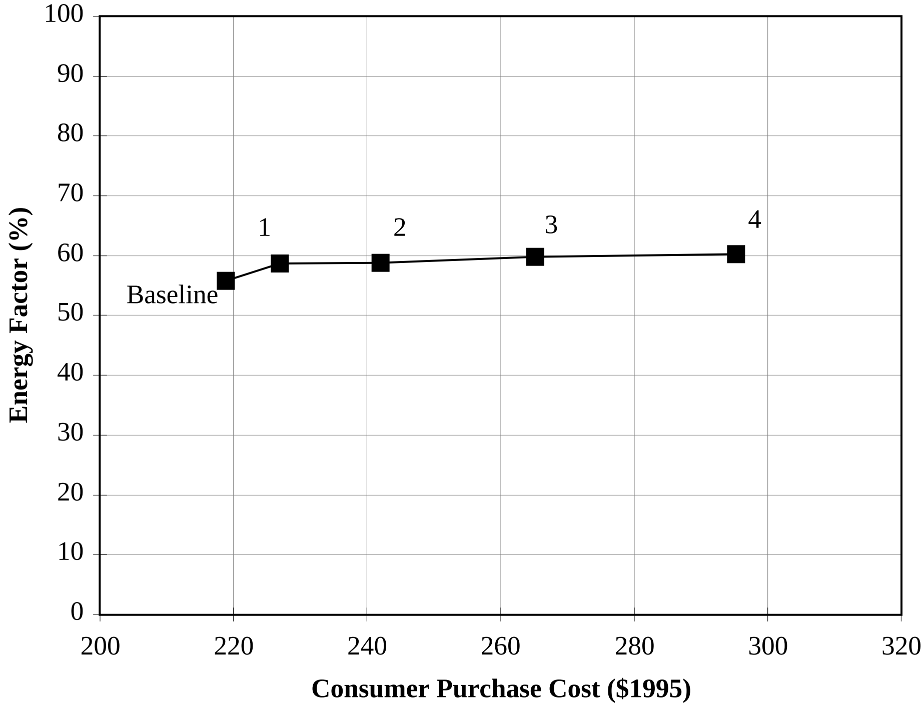
Figure 11.9. Cost Versus Efficiency for New Gas Ovens (Self-Cleaning)



Option	Description
Baseline	Gas Oven, Self-Cleaning
1	0 + Forced Convection
2	1 + Reduced Conduction Losses
3	2 + Improved Door Seals
4	3 + Oven Separator

Source: US DOE 1996a. Self-cleaning ovens represent 25% of new gas oven sales. Efficiency based on anticipated updates to proposed DOE test procedure (Federal Register 60(56), March 23, 1995). Costs converted from $1990 using the chain type price index for personal consumption expenditures of 1.158.

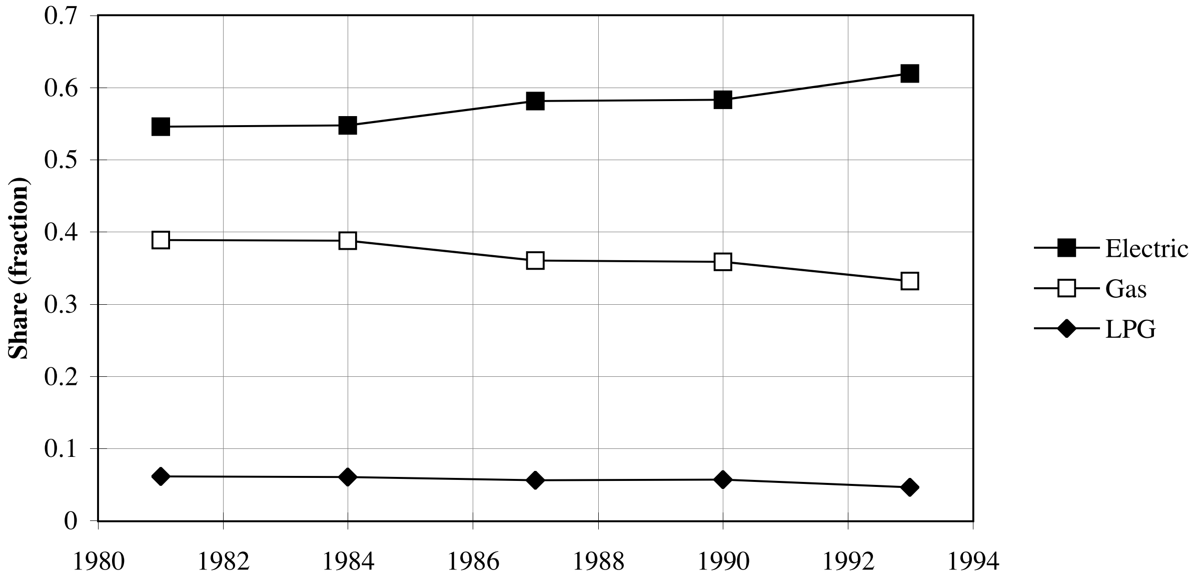
Figure 11.10 Cost Versus Efficiency for New Microwave Ovens



Source: US DOE 1996a. The energy factor is calculated by dividing the microwave power output by the electric power input. Costs adjusted from $1990 using the chain type price index for personal consumption expenditures of 1.158.

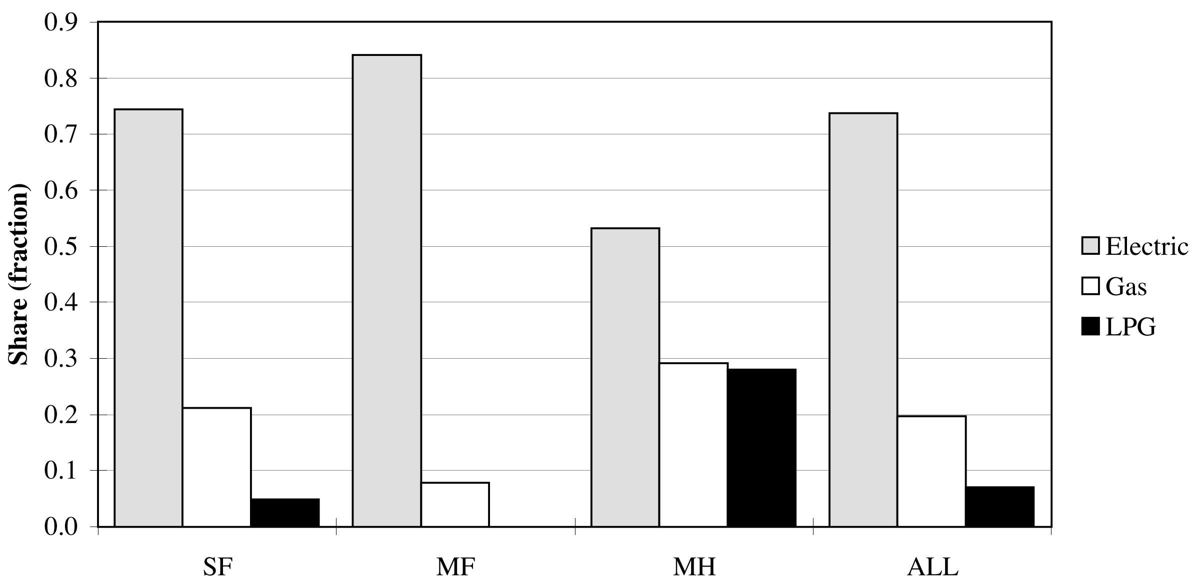
Option	Description
Baseline	Microwave oven
1	0 + More Efficient Power Supply
2	1 + More Efficient Fan
3	2 + More Efficient Magnetron
4	3 + Reflective Surfaces

Figure 11.11. Cooking Fuel Shares in Total Housing Stock, 1981-1993



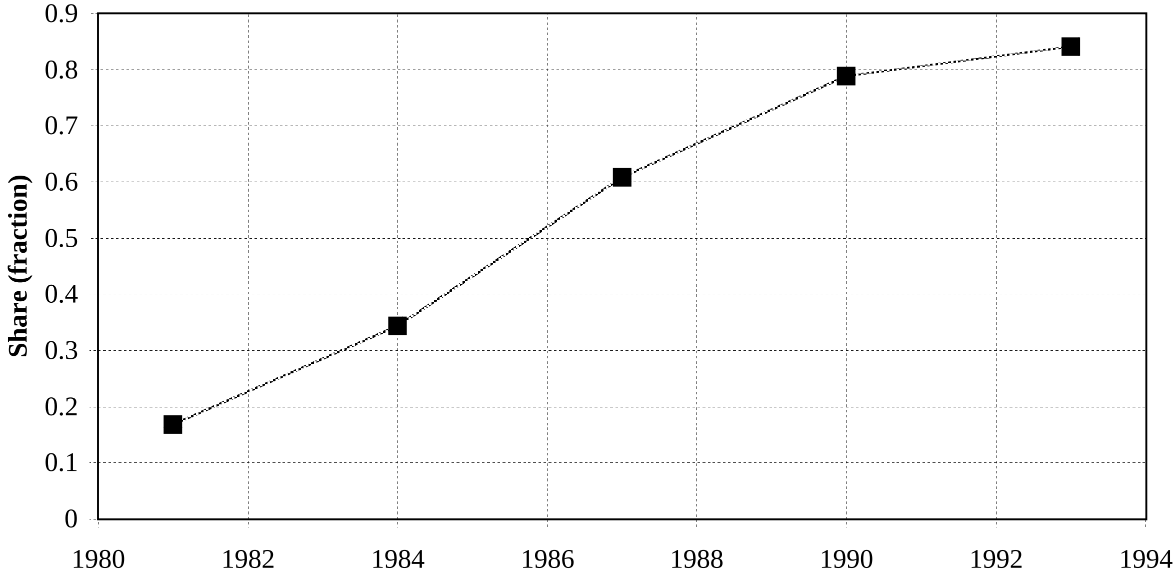
Source: US DOE 1982a, 1986, 1989a, 1992, 1995.
Fuel shares are for "main cooking fuel" only. Not all houses will have both rangetops and ovens.

Figure 11.12. Cooking Fuel Shares for New Construction by Housing Type



Source: US DOE 1995 data for buildings built between 1988 and 1993.
Fuel shares are for "main cooking fuel" only. Not all houses will have both rangetops and ovens.

Figure 11.13. Microwave Oven Shares in Total Housing Stock, 1981-1993



Source: US DOE 1982a, 1986, 1989a, 1992, 1995.

12. TELEVISION END-USE DATA

Televisions account for about 5% of total electricity usage in the residential sector because of the large number of sets in use and the large number of daily hours of usage per set. Televisions have been studied as part of the U.S. DOE appliance standards process.

12.1. Television UECs

Television UECs for new units are measured using a laboratory test procedure from U.S. DOE. The UEC of a television in the field will be directly proportional to the amount the appliance is used. Television energy consumption is directly related to screen size, with larger picture tubes consuming more energy. In general, a monochrome (black and white) set uses one-third the energy of a comparably sized color set.

Average energy use for televisions in the stock is estimated by utilities and other groups through metered estimates or statistical techniques. In the UEC database, there are no metered estimates for televisions but more than 40 derived from statistical techniques. Typically, these UECs estimate the total household UEC for televisions and not UEC per television set (Appendix A).

UEC Equation

Energy usage by television sets is a function of the "on-time" and the "off-time". Televisions typically consume power while off, which is termed the standby load. This relationship is as follows (US DOE 1993c):

UEC: $\text{kWh/yr} = P_T * \text{hours on} + P_s * \text{hours off}$

where: $P_T =$ total power ($P_O + P_S$)

$P_o =$ operating power (kW)

$P_s =$ standby power (kW)

hours on and hours off are in (hr/yr), and

hours on + hours off = 8760 hours per year.

For the U.S. DOE appliance standards analysis, it is assumed that the set is on 2200 hours per year (roughly 6 hours per day) and the set is off 6560 hours per year (roughly 18 hours per day).

Stock UECs

The average UECs for televisions in the residential forecasting database are 513 kWh/yr for color and 191 kWh/yr for black and white. These are taken from weighted averages of the records in the UEC database, and represent household usage for televisions, not usage per set. A 1988 analysis of 54 electronically tuned color television models found average annual energy use of 161 kWh for 13- and 14-inch sets, 199 kWh for 19- and 20-inch sets, and 276 kWh for 25- to 27-inch sets (US DOE 1993c). The higher per household UECs can be attributed to households owning several sets and/or using each set more than 6 hours per day.

New UECs

Since televisions have not been subject to energy efficiency standards, the UECs for new televisions are assumed to be the same as for stock units. However, to the extent that average screen sizes of new shipments increases, new UECs likely will also increase.

12.2. TELEVISION USAGE

The average household has at least one television set in operation over 7 hours per day (Neilsen 1987).

12.3. Television Technology Data

The main difference between different television technologies is between color and black and white television sets. Clearly, color televisions are the most important, since black and white televisions are becoming much less prevalent. The sourcebook includes shipments of color and black and white televisions, technology data for standard sizes of televisions, and market shares of each type and the average number of televisions per household. Changes in the technologies on the market, such as increasing numbers of projection televisions or other large units, may affect the energy use of televisions in the future but are not addressed here.

Historical Efficiency Data

There are no historical efficiency data for televisions available; historical shipments are shown in Figure 12.1.

Cost vs. Efficiency for New Equipment

Estimates of cost vs. efficiency for new color and black and white televisions are shown in Figures 12.2 and 12.3. The values are based on estimates in the U.S. DOE appliance standards analysis (US DOE 1988, 1993c) adjusted to $1995. The usage values are based on 2200 hours of operation per year.

Product Lifetimes

Estimates of average lifetimes for televisions are shown in Table 12.1.

Table 12.1. Estimates of Residential Television Lifetimes

Source		Lifetime in Years: Black and White	Color
Appliance	Low	6	10
	Avg	8	11
	High	10	12
US DOE 1993c (19” and 20” units)	Avg		11.5

Sources: Appliance 1996 (first owner lifetime only); US DOE 1993c.

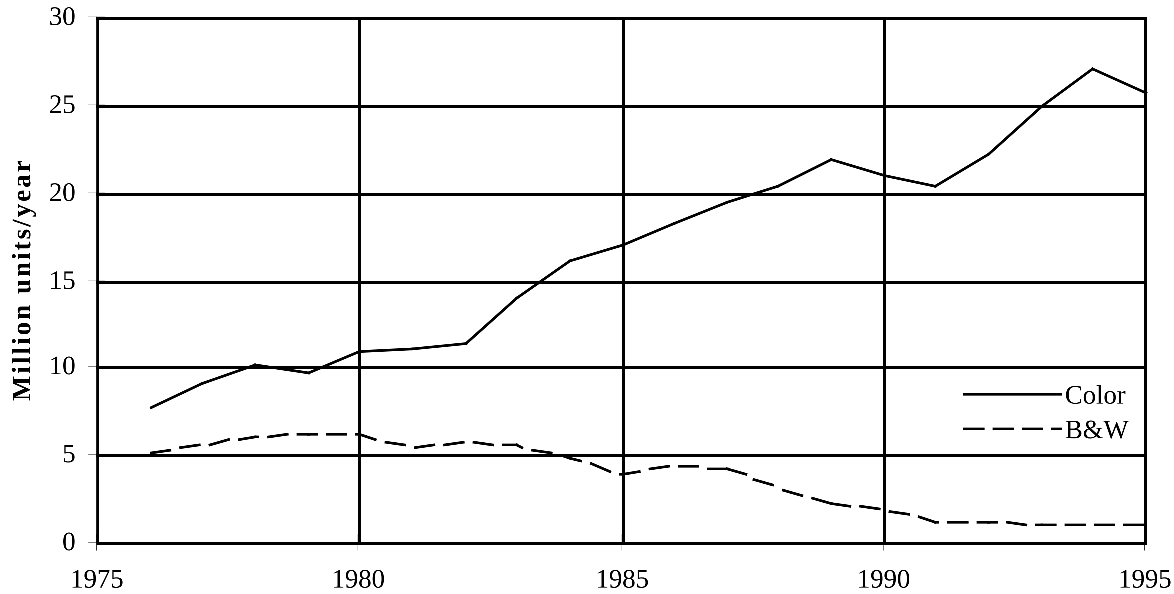
12.4. Market Shares

National stock market shares for color and black and white televisions, by housing type, are derived from the RECS data (US DOE 1982a, 1986, 1989a, 1993b, 1995b). Market shares in new buildings are derived for buildings built during the previous 5 to 7 years from the RECS data (for example, market shares in new construction in 1993 are derived from the 1993 RECS data for buildings built between 1988 and 1993). The market shares of televisions in the housing stock are shown in Figure 12.4. Clearly, the penetration of color televisions is almost 100%, while the share of households with black and white televisions is dropping. In addition, Figure 12.5 shows that the number of color televisions per household is increasing to almost 2 per household.

12.5. Standards

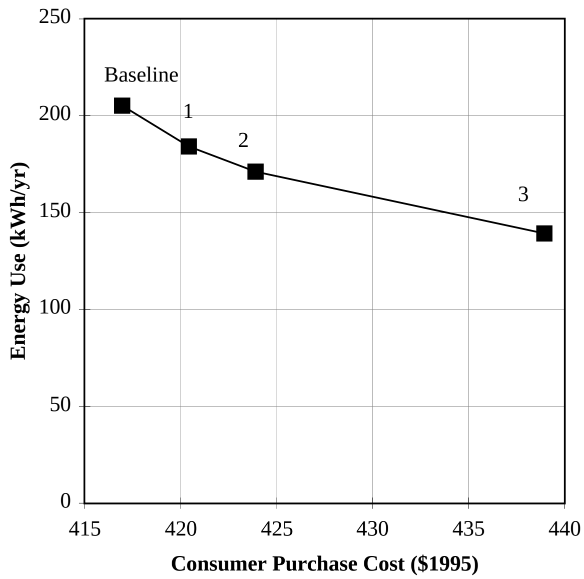
None applicable at this time.

Figure 12.1. Annual Television Shipments, 1976 to 1995



Source: Appliance Magazine 1996. Includes LCD units, and combination TV/VCRs after 1989.

Figure 12.2. Cost Versus Energy Use for New Color Televisions

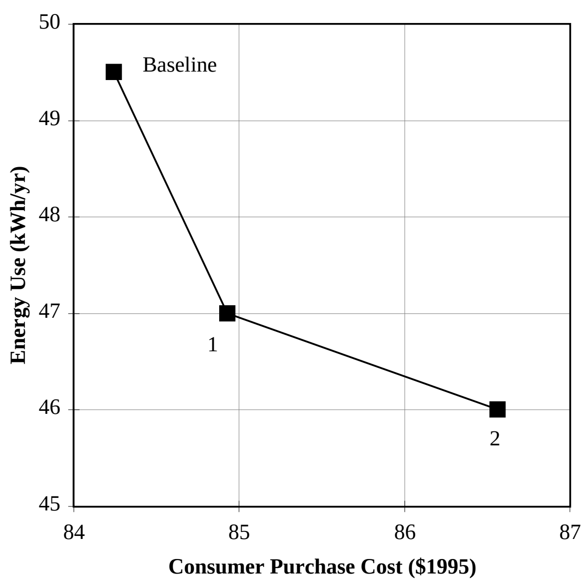


COLOR TELEVISION

Option	Description
Baseline	19 to 20 inch color television.
1	0 + Reduce standby power to 2W
2	1 + Reduce screen power by 6W
3	2 + Reduce screen power by 73/41W

Source: US DOE 1993c. Energy use calculated using 2200 hours of operation and 8760 hours of standby per year. Costs adjusted from $1990 using the chain type price index for personal consumption expenditures of 1.158.

Figure 12.3. Cost Versus Energy Use for New Black and White Televisions

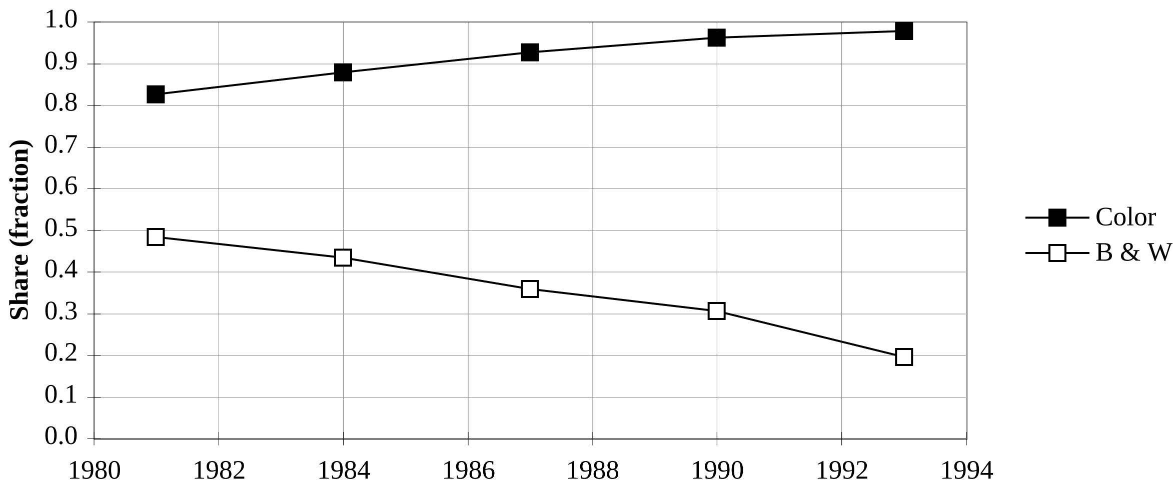


BLACK AND WHITE TELEVISION

Option	Description
Baseline	13 to 14 inch monochrome TV
1	Reduce screen power by 5%
2	Reduce screen power by 7%

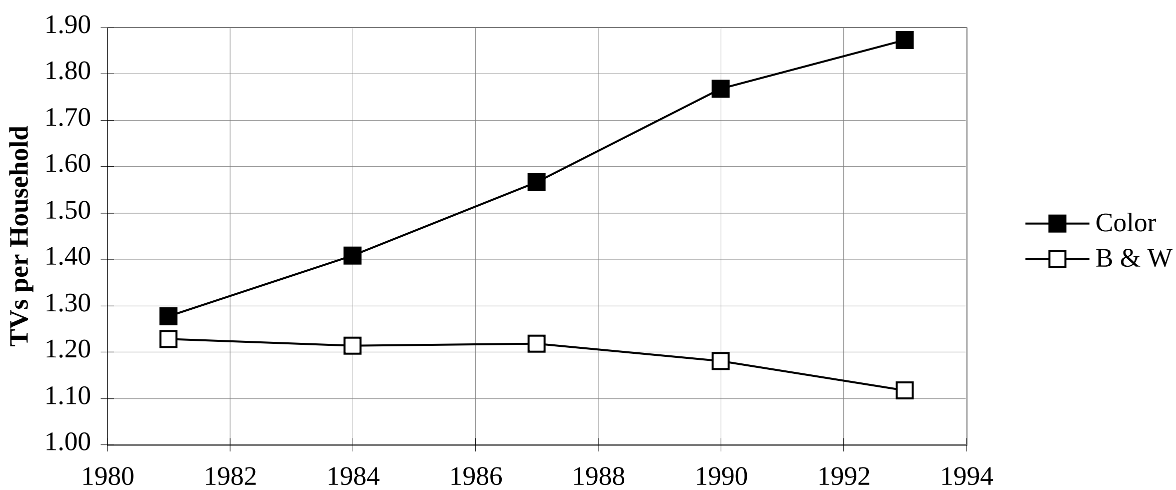
Source: US DOE 1988. Energy use calculated using 2200 hours of operation and 8760 hours of standby per year. Costs adjusted from $1988 using the chain type price index for personal consumption expenditures of 1.276.

Figure 12.4. Television Ownership Shares, 1981-1993



Source: US DOE 1982a, 1986, 1989a, 1992, 1995.
Data is fraction of households with at least one television of the type indicated.

Figure 12.5. Average Number of Televisions for Houses with Televisions, 1981-1993



Source: US DOE 1982a, 1986, 1989a, 1992, 1995.
Data is average number of television sets for those with televisions for the type indicated.

13. MISCELLANEOUS END-USE DATA

About one-quarter to one-third of residential electricity consumption comes from unspecified, or "miscellaneous," end-uses (US DOE 1995b, US DOE 1996c). Table 13.1 shows estimates of stocks, UECs, and national energy consumption for these miscellaneous end-uses (Sanchez 1997). National energy consumption of these end-uses nearly doubled from 96 TWh in 1980 to 180 TWh in 1995. Since the table assumes that UECs and usage of each type of device are constant over time, this increase in miscellaneous end-use energy is attributable to increasing saturations of these products. Devices with motors account for most of the 1995 consumption of miscellaneous end-uses, followed by heating and electronics products. Four devices, furnace fans, waterbed heaters, torchiere lamps, and cable boxes, account for about a third of all miscellaneous energy use in 1995. (We include torchiere lamps as a miscellaneous, rather than lighting, end-use, because they are not typically included in lighting or energy surveys such as RECS.)

Table 13.1 Stocks, UECs, and National Energy Consumption of Miscellaneous Electric End-Uses

	Stock (millions of units)				UEC	National Consumption (TWh)			
End-Use	1980	1985	1990	1995	(kWh/yr)	1980	1985	1990	1995
Motors									
Furnace Fan	33	36	42	43	500	16.6	18.2	21.0	21.4
Ceiling Fan	8	36	97	140	50	0.4	1.8	4.9	7.0
Pool Pump	1	2	5	4	1500	1.9	3.0	7.6	6.4
Well Pump	13	13	14	12	400	5.0	5.4	5.7	4.8
Dehumidifier	8	8	8	11	400	3.1	3.2	3.4	4.4
Aquariums	4	5	5	8	548	2.4	2.6	2.8	4.2
Evaporative Cooler	2	3	4	3	1183	2.9	3.1	4.4	3.2
Vacuum Cleaner	80	86	92	96	31	2.5	2.7	2.9	3.0
Mounted Air Cleaner	1	2	3	5	500	0.6	1.1	1.7	2.5
Humidifier	5	9	12	13	100	0.5	0.9	1.2	1.3
Air Cleaner Electric, not mounted	0	0	11	22	55	0.0	0.0	0.6	1.2
Hand-Held Rechargeable Vacuum	0	14	34	21	43	0.0	0.6	1.5	0.9
Electric Lawn Mower	6	6	6	6	100	0.6	0.6	0.6	0.6
Blender	50	62	71	80	7.3	0.4	0.5	0.5	0.6
Exhaust Fan	29	32	37	36	15	0.4	0.5	0.6	0.5
Garbage Disposer	31	30	38	41	10	0.3	0.3	0.4	0.4
Sump/Sewage Pump	8	9	9	10	40	0.3	0.3	0.4	0.4
Whole House Fan	8	9	9	4	80	0.6	0.7	0.8	0.3
Electric Toothbrush	3	3	6	12	26	0.1	0.1	0.2	0.3
Window Fan	4	9	10	15	20	0.1	0.2	0.2	0.3
Floor Fan	22	39	35	36	8.1	0.2	0.3	0.3	0.3
Bottled Water Dispenser	1	1	1	1	300	0.2	0.3	0.3	0.3
Desk Fan	6	19	28	32	8.1	0.1	0.2	0.2	0.3
Stand Fan	0	0	4	28	8.1	0.0	0.0	0.0	0.2
Can Opener	50	57	63	66	3.3	0.2	0.2	0.2	0.2
Hand Mixers	20	41	64	89	1.5	0.0	0.1	0.1	0.1
Hand-Held Electric Vacuum	0	2	8	20	3.9	0.0	0.0	0.0	0.1
Compactor	2	2	2	1	50	0.1	0.1	0.1	0.1
Food Slicer	0	29	46	42	0.9	0.0	0.0	0.0	0.0
Stand Mixers	7	12	17	22	1.3	0.0	0.0	0.0	0.0
Electric Knife	30	33	36	38	0.7	0.0	0.0	0.0	0.0
Central Vacuum	0	0	0	1	24	0.0	0.0	0.0	0.0
Men's Shaver	28	31	38	38	0.5	0.0	0.0	0.0	0.0
Hand Held Massager	4	7	10	12	0.3	0.0	0.0	0.0	0.0
Women's Shaver	10	8	9	10	0.2	0.0	0.0	0.0	0.0
Juicer	0	0	2	4	0.4	0.0	0.0	0.0	0.0
Foot Massager	0	0	0	0	6.8	0.0	0.0	0.0	0.0
Subtotal, Motors						*39.4*	*46.8*	*62.5*	*65.5*
Lighting									
Torchiere Lamps	0	0	1	30	394	0.0	0.0	0.3	11.9
Grow Lights	0	0	0	0	800	0.3	0.3	0.4	0.4
Subtotal, Lighting						*0.3*	*0.3*	*0.7*	*12.3*

Table 13.1 (cont.) Stocks, UECs, and National Energy Consumption of Miscellaneous Electric End-Uses

End-Use	Stock (millions of units) 1980	1985	1990	1995	UEC (kWh/yr)	National Consumption (TWh) 1980	1985	1990	1995
Heating									
Waterbed Heaters	7	10	14	15	900	6.5	9.4	12.6	13.2
Automatic Drip Coffeemaker	40	53	68	81	116	4.7	6.1	8.0	9.4
Crankcase Heater	24	26	28	29	200	4.8	5.2	5.6	5.8
Iron	80	86	84	86	53	4.2	4.6	4.4	4.5
Spa/Hot Tub	2	2	2	2	2300	3.7	4.0	4.3	4.5
Electric Blankets	44	44	37	29	120	5.3	5.3	4.4	3.5
Toaster	81	87	79	85	39	3.1	3.3	3.1	3.3
Hair Dryer	40	68	81	85	35	1.4	2.4	2.9	3.0
Toaster Oven	16	28	36	40	50	0.8	1.4	1.8	2.0
Percolator Coffeemaker	14	25	23	17	65	0.9	1.7	1.5	1.1
Slow Cooker	34	62	68	59	16	0.5	1.0	1.1	0.9
Waffle Iron/Sandwhich Grill	24	26	28	33	25	0.6	0.6	0.7	0.8
Hot Plate	20	21	22	24	30	0.6	0.6	0.7	0.7
Auto Engine Heaters	2	2	2	2	250	0.4	0.4	0.5	0.5
Deep Fryer	8	21	19	15	20	0.2	0.4	0.4	0.3
Heat Tape	2	3	3	3	100	0.2	0.3	0.3	0.3
Hair Setter	21	19	22	27	10	0.2	0.2	0.2	0.3
Heating Pads	20	42	61	68	3.4	0.1	0.1	0.2	0.2
Automatic Griddles	22	23	25	26	5.5	0.1	0.1	0.1	0.1
Espresso Maker	0	0	2	7	19	0.0	0.0	0.0	0.1
Electric grill	2	1	1	1	180	0.3	0.3	0.2	0.1
Air Corn Popper	13	22	29	20	6.1	0.1	0.1	0.2	0.1
Electric Kettle	0	0	1	1	75	0.0	0.0	0.1	0.1
Instant Hot Water	0	0	0	0	160	0.1	0.1	0.1	0.1
Curling Iron	28	28	39	54	1.0	0.0	0.0	0.0	0.1
Hot Oil Corn Popper	7	13	16	11	2.5	0.0	0.0	0.0	0.0
Subtotal, Heating						*39.0*	*47.7*	*53.4*	*55.1*
Electronics									
Cable Boxes	16	32	50	58	175	2.8	5.6	8.8	10.2
Video Cassette Recorder	2	29	89	133	57	0.1	1.6	5.1	7.6
Compact Audio	42	47	46	53	81	3.4	3.8	3.8	4.3
Rack Audio System	31	39	50	55	55	1.7	2.1	2.8	3.0
Doorbell	57	61	65	68	44	2.5	2.7	2.9	3.0
Computers	4	9	13	21	130	0.5	1.1	1.7	2.8
Clock	81	87	93	97	26	2.1	2.3	2.5	2.6
Answering Machine	2	10	45	66	35	0.1	0.3	1.6	2.3
Home radio, small/clock	156	149	133	105	18	2.8	2.7	2.4	1.9
Cordless Phone	0	15	32	61	26	0.0	0.4	0.8	1.6
Video Games	0	3	36	64	24	0.0	0.1	0.9	1.5
Boom Box	15	56	78	73	19	0.3	1.1	1.5	1.4
Laser Printer	0	0	2	5	249	0.0	0.0	0.4	1.4
Garage Door Opener	23	24	26	27	44	1.0	1.1	1.2	1.2
Security Systems	0	6	13	19	43	0.0	0.3	0.6	0.9
Ink jet Fax	0	0	1	3	216	0.0	0.1	0.2	0.6
Printers	3	7	9	12	45	0.1	0.3	0.4	0.5
Satellite Dish	0	1	2	5	96	0.0	0.1	0.2	0.5
Home Medical Equipment	0	0	0	0	400	0.2	0.2	0.2	0.2
Copiers	0	0	1	2	25	0.0	0.0	0.0	0.0
Subtotal, Electronics						*17.6*	*25.8*	*37.7*	*47.5*
Total						***96***	***121***	***154***	***180***

Source: Sanchez 1997. End-uses already included in other sections of this report (TVs, clothes washers, dishwashers, and microwave ovens) have been excluded here.

By 2015 annual miscellaneous energy use is expected to increase by another 100 TWh; 60 TWh of this increase is expected to come from increased saturation of one product, torchiere lamps (Sanchez 1997) (although some of the growth in torchiere energy use may be offset by decreases in other lighting energy use).

14. DEMOGRAPHIC AND PRICE DATA

Table 14.1 provides other data related to residential sector forecasting, including 1990 data on housing stocks, housing starts, and energy prices, and forecasts for 1990 through 2015.

Table 14.1. Residential Sector Forecasting Demographic and Price Data, 1990 through 2015

	1990	1995	2000	2005	2010	2015
Households (millions)						
Single family	64.36	68.66	72.66	76.85	80.93	85.07
Multi-family	24.42	24.56	25.53	26.98	28.67	30.45
Mobile homes	5.21	5.83	6.30	6.64	6.89	7.12
Total	93.99	99.10	104.40	110.50	116.50	122.60
Housing Starts (millions)						
Single family	0.90	1.08	1.05	1.08	1.03	1.09
Multi-family	0.30	0.28	0.36	0.42	0.48	0.48
Mobile homes	0.19	0.34	0.29	0.29	0.28	0.29
Total	1.39	1.70	1.70	1.80	1.79	1.86
Energy prices (1995$ per MBtu)						
Electricity	26.88	24.67	24.09	23.49	22.88	22.28
Natural Gas	6.46	6.01	5.63	5.49	5.27	5.18
Distillate Fuel	9.20	6.24	7.03	7.28	7.45	7.33
Liquified Petroleum Gas	12.56	10.29	11.29	11.40	11.85	11.57

Source: US DOE 1994 for 1990 (1992$ values converted to 1995$ using chain type price index for personal consumption expenditures of 1.076); US DOE 1996c for all other years.

15. FUTURE WORK

We have identified several areas that need further work in order to fully support our residential sector analyses. The greatest need is for a database of calibrated building prototypes complete with an analysis of shell measure savings based on real-life conditions and applicable building technologies. We have building models that have been compared to measured data showing fairly good agreement (e.g. the LBNL/GRI prototypes), but the analytical work to estimate the impact of potential thermal shell improvements on these buildings has not been done. Building shell measure conservation potential databases developed at LBNL and other places have made no attempt to calibrate the models to actual residential sector energy consumption data, and typically have been used in analyzing design energy use in new construction.

This report does not update the data or methodology used to estimate heating and cooling UECs (in Chapter 3), in part because later RECS surveys do not provide as detailed information on shell-related efficiency measures as the 1987 RECS. Analysis of this end-use could be improved by using updated building prototypes. Other data that have not been included in this sourcebook, such as housing demolitions, shell characteristics of new housing construction, sales of solar water heaters, etc., could improve our overall analysis of end-use energy consumption.

Finally, many of the UECs used in this report are simply weighted averages of UECs from several different types of studies, which can vary greatly in terms of sample size, methodology, and quality. In addition, studies may contain information only for certain appliance classes, housing types, vintages, or regions, and may have been performed in different years. As explained in Appendix A, we attempted to qualitatively account for differences in study methodology and data quality; our hope was to eventually build a database large enough so that biases introduced by individual studies would be minimized. Unfortunately, recent developments in the utility industry have reduced the effort to regularly collect data on end-use energy consumption by end-use, which will inhibit data compilations like this one in the future (Vine 1996).

16. SUMMARY

This report updates the Lawrence Berkeley National Laboratory (LBNL) residential forecasting database (originally Hanford et al 1994). The sourcebook consists of several spreadsheets on building shell characteristics, heating and cooling loads, and other parameters to estimate HVAC energy consumption; shipments, average energy factors, and cost vs. efficiency curves for several classes of new appliances; and a large database of stock unit energy consumption factors (UECs) for a variety of end-uses. Much of the data from the earlier report have been updated to 1995, and corrections have been made where necessary. We did not update the thermal shell and heating and cooling loads (Chapter 3) because of the difficulty of recalculating these parameters within the timeframe and funding constraints for the revisions. Energy analysts can use this report as a sourcebook for both "back of the envelope" calculations and inputs to computer models that forecast US residential energy consumption by end-use. The report can be downloaded from the Web at http://enduse.lbl.gov/Projects/RED. Future updates to the report, errata, and related links, will also be posted at this address.

APPENDIX A. UEC DATABASE DESCRIPTION

INTRODUCTION

The purpose of this appendix is to review and assimilate all available estimates of Unit Energy Consumption values (UECs) for the major residential end-uses. This project is part of a larger effort to develop baseline data for use in residential sector energy demand forecasting models and to document the source of each element within a database structure. UECs are among the most important inputs to forecasting models and thus require careful examination and documentation.

Data on UECs have traditionally come from a variety of sources, including sub-metering of individual appliances, conditional demand regression analyses, engineering estimates, previous model inputs, and other utility and industry figures. Our analysis shows that these methods can produce UEC estimates of vastly different magnitudes. Further problems in estimating UECs from available data occur when considering regional data, end-uses that interact with other end-uses, appliances or equipment that use different technologies within the same end-use, vintage of equipment, and different housing types that suggest different usage patterns. Not surprisingly, different researchers tend to use UEC inputs that vary widely.

The primary goal of this project is to collect and systematically analyze existing data on residential end-use unit energy consumption and to derive UEC estimates based on those data. A secondary goal is to understand the level of uncertainty in UEC estimates for the various residential end-uses. The results of this analysis will be used to critically assess the UEC inputs in the residential energy demand forecasting models used at Lawrence Berkeley National Laboratory (LBNL) and to suggest improvements in these UEC inputs. Lastly, the database allows us to compare UEC estimates from the different analysis techniques described above and to make observations about the applicability of those techniques for specific end-uses. We present the results of the analysis in this report, along with conclusions about the nature of the data and the best UEC estimates based on the collected data. A bibliography including all data sources in the UEC database is provided.

DATA COLLECTION AND ANALYSIS METHODOLOGY

The data collection effort consisted of gathering all published data, as well as some unpublished data, collected by various researchers at LBNL over the last several years. We did not attempt to obtain a representative distribution of sources across utilities, regions, house types, or study types. The sources include only those known to researchers at LBNL. In total, over 1400 UEC records were extracted from over 150 sources. While the data may not be statistically representative, they include the majority of the available information.

We entered each of the UEC estimates into an Excel spreadsheet. Each record contains the UEC estimate along with documentation of the source, other information from the study useful in understanding the reliability of the estimate, and an indicator of the quality of the estimate as well as other notes. Our goal was to organize the data so that we could analyze it at different levels of disaggregation, depending on the number of records for a given end-use category.

For example, data on UECs come from a variety of different sources including sub-metering of individual appliances, conditional demand regression analyses, engineering estimates, previous model inputs, and other utility and industry figures. In addition, studies may contain information only for certain appliance classes, housing types, vintages, or regions, and may have been performed in different years. Previous attempts at UEC aggregation have either failed to account for these differences at all or have not examined their effects systematically. Thus, we retain as much information about each study as is necessary to understand the methodology and applicability of the data for further analysis. We summarize the important fields in the UEC database in Table A.1 below and discuss how we make use of these supporting data in the following sections.

Table A.1. Description of UEC Database Fields

Field	Description
End Use	a code for one of the seventeen end-uses included in the database (e.g. heating, cooling, water heating)
Class	the appliance class or technology under consideration, if specified (e.g. auto-defrost vs. manual defrost refrigerators, central vs. room air conditioning)
Study Type	one of six categories, including metered, conditional demand, engineering, model or other previously aggregated value, utility, or industry (defined in detail below)
Vintage	representative of either *stock* or *new* appliances, equipment, or buildings
House type	single-family, multi-family, manufactured home, or all/not-specified
Year	the year in which the data were collected or the estimate made
Region	area of the U.S. that the data represent
Quality	a subjective rating of data quality assigned to each record
Source	the report's authors and title, or other documentation
Notes	anecdotal information about the piece of data

We developed procedures for selectively aggregating the observations. Where appropriate, weighting factors were used in the analysis based on data quality, historical efficiency trends and the study type. By weighting and disaggregating as much as possible, we sought to generate 1990 *stock* UECs that best represent the data in the database. Because we had little UEC data for the *new* vintage (e.g. recently purchased refrigerators or heating energy use in recently constructed buildings), the results presented in this paper include only those for the *stock* vintage. Data for *new* vintage equipment, appliances and buildings will not be discussed further.

End Use and Appliance Class

The 17 end-use and fuel type combinations included in the UEC database are gas and electric heating, cooking, water heating, and clothes drying; electric air-conditioning; refrigerator-freezers; stand-alone freezers; clothes washers; dishwashers; microwaves; lighting; and color and black-and-white TVs. Additionally, we subdivide several of these end-uses into their most important product classes wherever energy use varies significantly between classes and the data allow for it. The end-uses and appliance classes are summarized in Table A.2 (estimates of per cycle energy use for clotheswashers, clothesdryers, and dishwashers are included in the database, but not shown in the table). Updated estimates from the LBNL REM and REEPS forecasting models, as well as more recent data from DOE's Residential Energy Consumption Survey (RECS), are also shown in Table A.2.

Table A.2. UEC Database Contents by End Use and Class (stock UECs only)
Electric UECs in kWh/yr, gas UECs in MMBtu/yr

				Records in Database					Model Estimates		Conditional Demand	
					Low	High	Unweighted	Weighted	REM	REEPS	RECS	RECS
End Use	Code	Class	Code	N	UEC	UEC	Average	Average	1990	1990	1990	1993
Air Conditioning	EAC	all/not-specified	ALL	19	567	2550	1445	1489	1769			
		central air	CAC	98	651	7935	2495	2233	2340	2338	3231	2858
		heat pump	HP	34	750	4360	2278	2308	2862	2472		
		room air	RAC	77	230	5597	993	854	809	759		762
Black-White TV	EBW	all/not-specified	ALL	25	50	1325	263	193				
		solid state/electronic	SDS	3	99	100	100	99				
		tube/manual	TUB	3	220	288	243	259				
El. Cooking	ECK	total cooking	ALL	74	310	2138	887	829	498	600		
		oven only	OVN	4	334	667	433	440	276			
		range only	RNG	7	299	820	506	536	222			
Clotheswasher	ECW	total=motor+h2o	ALL	15	403	1135	687	623				
		cycle data only	CYC	6								
		motor only †	MOT	30	-69	449	113	120	103	102		
El. Clothes Dryer	EDR	all dryers	ALL	67	304	2059	995	1002	883	920		
		cycle data only	CYC	2								
Dishwasher	EDW	total=motor+h2o	ALL	24	287	1836	1149	1055				
		cycle data only	CYC	2								
		motor only	MOT	39	93	2562	470	400	156	178		
Freezer	EFZ	all/not-specified	ALL	53	288	2274	1177	1029	1039	1027		
		manual defrost	MND	15	497	1880	1084	924				
		upright auto defrost	UAD	15	1043	3336	1685	1453				
El. Heating	EHT	all/not-specified	ALL	74	765	14155	6038	5988	7393		3604	4541
		central furnace	CTL	23	1460	32400	8342	7584	6557	6159		
		heat pump	HP	65	798	19659	6363	6068	4720	4968		
		all elec. res. (CTL + RM)	RES	52	741	18311	6800	6682				
		room electric	RM	12	326	9660	4562	4649	8309	7768		
Lighting	ELT	all lighting	---	11	857	4405	1312	1016				
Microwave	EMW	all microwaves	---	28	78	1132	268	209				
Refrigerator	ERF	all/not-specified	ALL	57	748	3033	1374	1157	1155	1273	1301	1350
		manual defrost	MND	12	700	1800	1116	928				
		side-by-side no TTD	SDN	1	1734	1734	1734	1734				
		top-mount auto def	TAD	28	1352	2555	1753	1403				
Color TV	ETV	all/not-specified	ALL	41	214	1792	600	527				
		solid state/electronic	SDS	3	320	360	333	343				
		tube/manual	TUB	3	528	540	532	535				
El. Water Heater	EWH	all el. water heaters	---	105	1902	9000	3795	3633	5192	4292	2797	2713
Gas Cooking	GCK	total gas cooking	ALL	11	2.05	17.80	6.33	5.66	5.23	5.00		
		oven only	OVN	3	1.00	4.00	2.33	3.33	2.35			
		range only	RNG	3	1.00	2.00	1.67	2.00	2.88			
Gas Dryer	GDR	all gas dryers	ALL	10	3.31	5.90	4.24	4.25	3.50	4.00		
		cycle data only	CYC	1								
Gas Heating	GHT	all gas heating *	---	56	30.90	136.60	65.14	63.02	62.27	67.00	64.50	73.70
Gas Water Heater	GWH	all gas water heaters	---	31	16.20	51.29	24.92	24.83	29.65	24.00	23.10	25.80
TOTAL RECORDS				1242								

†negative value from poor regression specification
*REEPS estimate based on gas furnaces only
Notes: Low/high UECs are reported values. Weighted average and RECS 1993 UECs are based on UECs normalized to 1990 efficiency using historical efficiency factors in Figure A.1.

The appliance and equipment classes that we distinguish are central, room and heat pump air-conditioning and electric heating systems, manual and auto-defrost refrigerators and freezers, and solid-state/electronic and tube/manual color and black-and-white TVs. Auto-defrost refrigerators are further sub-divided into top-mounted (TAD), through-the-door feature equipped (TTD), and other side-by-side (SDN) models. Electric heating records which distinguish electric resistance heating from heat pump systems but do not separate room from central heating are grouped together in a resistance heating (RES) category. Partial UECs for dish- and clothes washer motor use and for range and oven energy use in cooking are tracked independently, similarly to equipment classes.

For end-uses where class data are kept, a separate category is also included for data records that do not specify a particular class or that explicitly combine sub-estimates for the different classes. This "ALL" class is therefore not a sum of ALL records, but a separate class category for estimates that at least claim to include all the classes of the given end-use.

Study Type

For purposes of analysis, the UEC studies have been grouped into six study type classifications: metered, conditional demand, engineering, model/aggregate, utility estimate and industry estimate.

Metered studies are those in which individual appliances are measured for their energy use under actual or simulated domestic usage conditions. These include utility sub-metering and monitoring studies of field energy usage, as well as a few laboratory tests of appliances that are typically based on a standardized test procedure intended to replicate field usage patterns.

Conditional demand studies, including national-level regression analyses, represent attempts by utilities and others to apportion whole-house energy use data to specific end-uses, based on statistical correlation with saturation surveys, weather data and other variables. There is a great deal of variation in both statistical methodology and level of end-use detail among conditional demand studies.

Engineering estimates are studies that base energy consumption estimates on engineering formulas and certain usage and building characteristics assumptions. Examples are building simulation program estimates of space conditioning energy use and gallons x ΔT estimates of water heating energy use. The U.S. Department of Energy (DOE) appliance standards analysis Technical Support Documents (see US DOE 1989b, for example) fall into the engineering category because they use computer models to determine energy consumption for various design options in new equipment.

Forecasting models generally include UEC data collected and corrected over time, from a variety of undocumented sources. For this reason, we put *model* data in its own study type, together with other *aggregate* estimates of UEC use, such as averages of conditional demand studies and utility trade association figures.

Estimates from individual utilities that do not disclose a source or methodology --often simply the best guesses of utility personnel -- are kept in the *utility* category, and equipment manufacturers' figures, primarily the new product data from standardized appliance tests, are classified in the *industry* study type (see AHAM 1990).

UECs from three new sources, Residential Energy Consumption Surveys (RECS) done in 1990 and 1993 by the U.S. DOE Energy Information Administration (EIA), and the American Gas Association's 1995 Residential Natural Gas Market Survey, have been added to the database. These UECs have been included in the analyses in this appendix. Updated estimates from the

REM (LBNL) and REEPS (EPRI, with adjustments made by LBNL) forecasting models have not been included in the updated version of the database, since the 1990 baseline values for these models were in part developed based on information from the previous version of this report. However, the updated model values are shown in various tables and figures here for comparison with the database values.

In this analysis, we investigate the variability of UEC estimates within and across study types where the data allow. This gives important insight into the relative range of UEC estimates derived from different analysis techniques. We use observations gained from these comparisons to give weights to average UECs by study type when calculating best estimates for each end-use UEC.

House Type

When the data source specifies the house type from which the data are derived, we record those data in the database as either single-family, multi-family, or manufactured home. These distinctions are obviously important when analyzing space conditioning UECs. For these end-uses, we also collected the conditioned floor area of the sample and heating or cooling degree days of the climate under consideration. However, there were few entries for these parameters other than building simulation program estimates of heating and cooling UECs.

House type may be an important factor for other UECs that are influenced by occupancy levels, usage patterns, and appliance and equipment sizes that are related to the type of dwelling. Both the LBNL Residential Energy Model (REM) and the REEPS 2.0 forecasting models allow for different end-use UECs for each house type. Thus, we attempt to find significant distinctions between UECs by house type in the data.

Data Year and Historical Efficiency Normalization

For each UEC record, we post the year in which the data were collected or the estimate made. The database includes stock UEC estimates that range as far back in time as the mid-1970s. Thus, comparing these estimates with more recent stock data does not account for changes in UEC values over time. As shown in the equation below, UECs are a function of appliance size or capacity, level of usage and efficiency:

$$\text{UEC} = \frac{\text{capacity X usage}}{\text{efficiency}}$$

Any of these parameters can change over time. The most significant factor, and the one we account for in this analysis, is the change in efficiency of the appliance stock. The process of *normalizing* the data to 1990 stock efficiency levels is necessitated by the enormous changes taking place in the market for certain appliances. For example, new refrigerators and freezers have increased markedly in efficiency since 1972. Without normalizing to a common efficiency level, it would be meaningless to compare refrigerator stock UEC data from, for instance, a 1976 and a 1986 study. The background trend of efficiency improvement would largely obscure any other differences one attempted to examine.

To calculate average stock efficiency for each year, we take a shipment-weighted sum of the new unit efficiencies (available from manufacturers' data) in the preceding product lifetime. Shipments and Shipment-Weighted Efficiency Factors (SWEFS) of new units for the years 1972-95 are shown in Tables A.3 and A.4. The calculation assumes that the stock of equipment in any given year is made up of all the new units which have been purchased recently enough to still be in service, on average. The efficiencies are normalized to the 1990 efficiency level; this means that reported 1990 UECs are unchanged, while stock UECs from earlier years are reduced (and UECs from later years increased) by the appropriate factor to account for efficiency improvements in new units. The end-uses for which historical factors are used are gas heating, room and central air-conditioning, electric and gas water-heating, refrigerators, freezers, clothes washers, and dishwashers. The historical factors for refrigerators and freezers are based on data for all product classes, and are applied to all records for those appliances in the database. UECs for other end-uses, including not specified heating or cooling technologies and motors for dishwashers and clotheswashers, are assumed to remain constant with respect to efficiency over time. The calculated normalization factors are shown graphically in Figure A.1. (The normalization factors for some end-uses in the previous version of this report were incorrect; all end-uses were erroneously assumed to have the same average lifetime. The correct factors are shown in Figure A.1). For each record in the UEC database, the value normalized for historical efficiency is provided, as well as the initial reported value.

The effect of the historical normalization can be seen in Figures A.2 and A.3. Figure A.2 shows the distribution of refrigerator UEC estimates, unadjusted for historical efficiency trends. Figure A.3 shows the same data, adjusted to 1990 stock efficiencies using the historical weighting (but not the quality rating which eliminates outlying data). The effect of the normalization is twofold -- it reduces the average UEC to its approximate 1990 level, and it decreases the standard deviation, as variation due to the age of the different data sources is reduced.

Region

For the space-conditioning and water heating end-uses, regional climate and price effects are strongly correlated with energy use. Data records for these end-uses are coded with both federal and census region codes. Where records are for multi-state regions that overlap more than one federal or census area, we make a determination based on a subjective judgment of the largest population-weighted portion of the data group, and the data are assigned to a single region in each coding. Data from some regions are scarcer than others due to the vagaries of interest in data collection across regions of the U.S. Where the data are sufficient, we compare UEC estimates across regions.

Quality Rating

Subjective quality ratings are given to all records on a five-point scale, where a one is the highest ranking and a five represents a zero-weighted study that is included just for the sake of documentation. We assume that all records with ratings one through four have some value, but that studies that are better designed or more detailed yield more reliable estimates of UECs and should be weighted more heavily into aggregate averages. The criteria used to determine the ratings are sample size for metered studies, complexity of methodology, reasonableness of output, and level of end-use detail. Quality ratings are assigned only on the basis of a record's value within its study type. Comparisons across study types are made later, at the aggregate level.

Table A.3. Historical Shipments

Millions of Units Shipped

End Use	avg. life (yrs)	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
GHT	23	1.57	1.57	1.85	2.15	1.81	1.33	1.11	1.09	1.32	1.42	1.16	1.66	1.85	1.82	2.11	2.07	2.09	2.16	1.95	2.06	2.11	2.59	2.70	2.60
RAC	15	3.97	4.11	3.74	2.40	2.96	3.27	4.04	3.75	3.20	3.69	2.76	2.00	3.10	3.02	2.82	3.80	4.64	5.09	4.15	2.81	2.91	3.08	4.12	4.30
CAC	12	1.76	2.05	1.77	1.10	1.51	1.60	1.80	1.68	1.37	1.42	1.15	1.75	2.05	1.99	2.08	2.44	2.58	2.82	2.44	2.42	2.35	2.57	3.13	3.27
EWH	13	2.27	2.59	2.49	2.18	2.62	2.70	2.68	2.66	2.45	2.46	2.72	3.13	3.48	3.45	3.39	3.40	3.33	3.37	3.23	3.17	3.40	3.61	3.90	3.92
GWH	13	3.16	3.08	2.57	2.65	3.11	3.07	2.92	2.89	2.82	2.79	3.04	3.17	3.50	3.53	3.73	3.95	3.96	4.13	3.91	3.94	4.24	4.47	4.75	4.45
ERF	19	6.32	6.77	5.98	4.58	4.82	5.71	5.89	5.71	5.12	4.94	4.36	5.48	5.99	6.08	6.51	6.97	7.23	7.10	7.10	7.27	7.76	8.11	8.65	8.67
EFZ	21	1.58	2.42	3.22	2.46	1.54	1.60	1.52	1.94	1.76	1.61	1.34	1.34	1.28	1.24	1.22	1.26	1.35	1.22	1.30	1.41	1.64	1.61	1.69	1.69
ECW	14	5.16	5.50	4.95	4.23	4.49	4.93	5.35	5.26	4.82	4.28	3.96	4.55	5.05	5.28	5.77	6.00	6.19	6.25	6.19	6.20	6.52	6.79	7.04	6.90
EDW	13	3.20	3.70	3.32	2.70	3.14	3.36	3.56	3.49	2.74	2.48	2.17	3.12	3.49	3.58	3.92	4.03	3.91	3.67	3.64	3.57	3.82	4.10	4.58	4.55

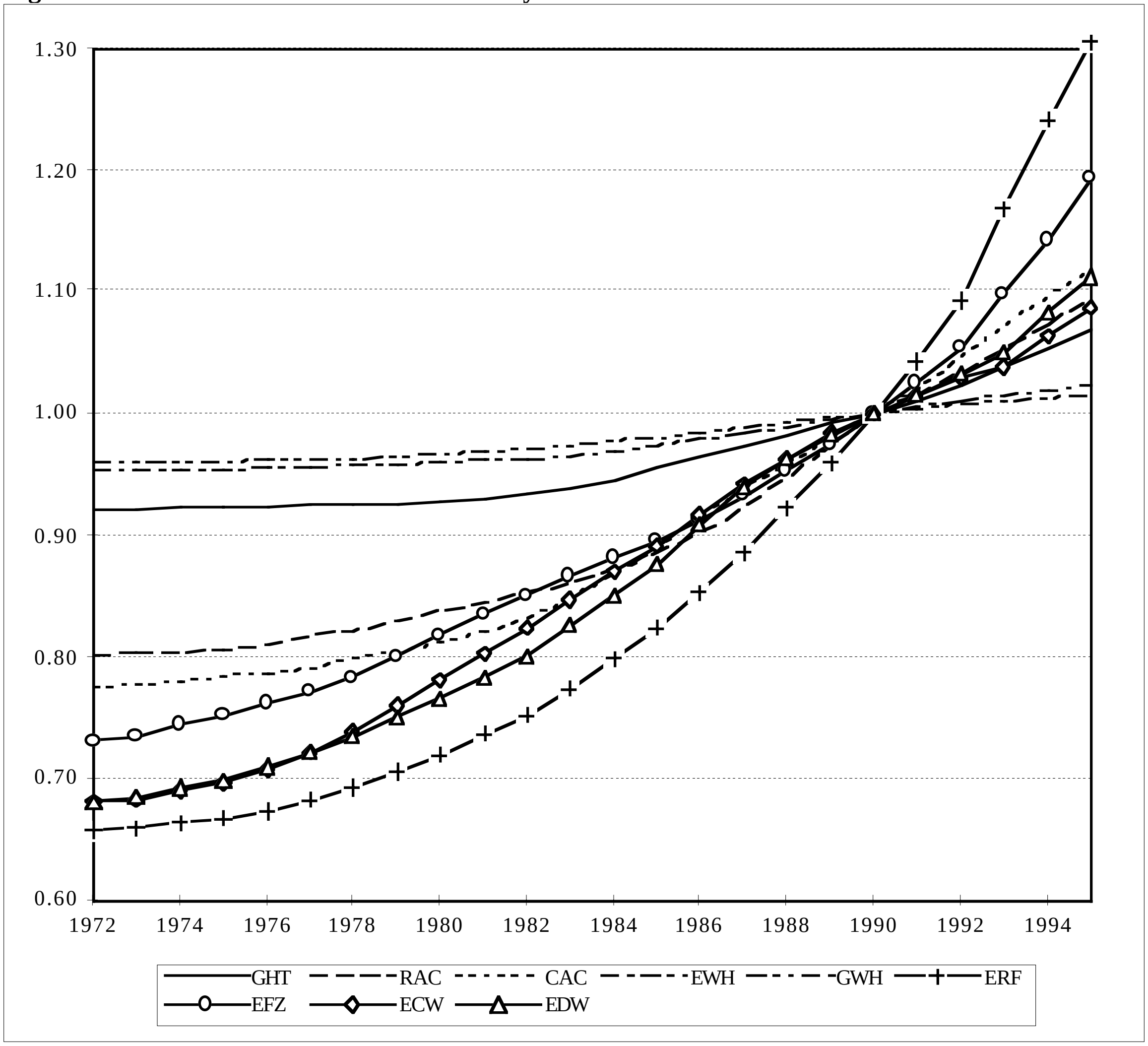
Source: Product lifetimes from LBL-REM; shipments from AHAM

Table A.4. Shipment-Weighted Efficiency Factors (SWEFs) for New Units

End Use	Unit	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
GHT	AFUE%	62.7	62.7	62.7	62.8	62.8	62.8	62.9	63.0	63.1	63.3	63.5	63.9	64.4	65.0	65.6	66.2	66.9	67.5	68.0	68.6	69.6	70.7	71.7	72.8
RAC	EER	5.98	5.99	6.01	6.03	6.06	6.09	6.14	6.20	6.25	6.31	6.37	6.42	6.51	6.62	6.73	6.89	7.08	7.28	7.46	7.58	7.71	7.85	8.02	8.17
CAC	SEER	6.66	6.68	6.70	6.72	6.75	6.79	6.85	6.91	6.97	7.04	7.14	7.28	7.45	7.64	7.85	8.06	8.23	8.42	8.58	8.75	8.98	9.19	9.41	9.58
EWH	%	79.8	79.8	79.8	79.9	79.9	80.0	80.1	80.2	80.3	80.4	80.6	80.9	81.2	81.5	81.9	82.3	82.8	83.2	83.7	84.2	84.6	85.0	85.4	85.7
GWH	%	47.4	47.4	47.4	47.5	47.5	47.6	47.6	47.7	47.8	47.9	48.0	48.1	48.3	48.4	48.6	48.8	49.0	49.2	49.4	49.6	49.8	49.9	50.0	50.1
ERF	cu.ft./kwh/day	3.84	3.85	3.87	3.90	3.94	3.99	4.05	4.13	4.21	4.31	4.40	4.53	4.67	4.82	4.98	5.18	5.40	5.61	5.84	6.10	6.39	6.83	7.26	7.63
EFZ	cu.ft./kwh/day	7.29	7.32	7.41	7.51	7.59	7.69	7.81	7.98	8.16	8.33	8.48	8.63	8.78	8.93	9.09	9.29	9.50	9.72	9.96	10.22	10.50	10.94	11.38	11.88
ECW	cu.ft./kwh	0.64	0.64	0.65	0.66	0.67	0.68	0.70	0.72	0.73	0.75	0.77	0.80	0.82	0.84	0.86	0.88	0.91	0.92	0.94	0.95	0.97	0.98	1.00	1.02
EDW	load/kwh	0.24	0.24	0.24	0.25	0.25	0.25	0.26	0.26	0.27	0.28	0.28	0.29	0.30	0.31	0.32	0.33	0.34	0.35	0.35	0.36	0.36	0.37	0.38	0.39

Source: AHAM, GAMA, ARI, and DOE SWEF data, interpolated for missing years

Figure A.1. Normalized Stock Efficiency Factors



Formulas for calculating the Stock Efficiency Factor (SEF) in year Y:

$$SEF_Y = \frac{\sum_{Y-lifetime}^{Y} SWEF_{yr} \times shipments_{yr}}{\sum_{Y\text{-}lifetime}^{Y} SWEF_{yr}}$$

$$Normalized\ SEF_Y = \frac{SEF_Y}{SEF_{1990}}$$

Formula for calculating the historically-weighted UEC:

$$UEC_{1990} = UEC_Y \times SEF_Y$$

Figure A.2. Distribution of Unweighted "ALL" Class Refrigerator UECs

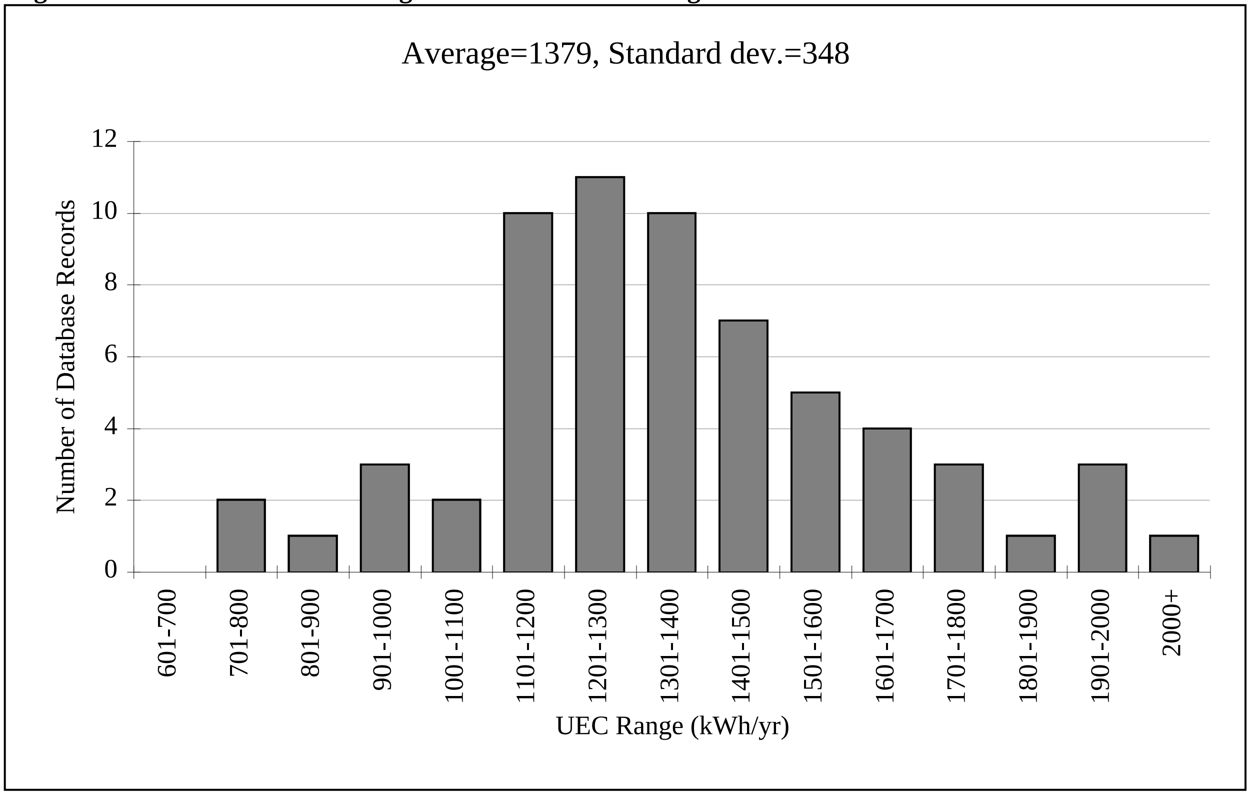
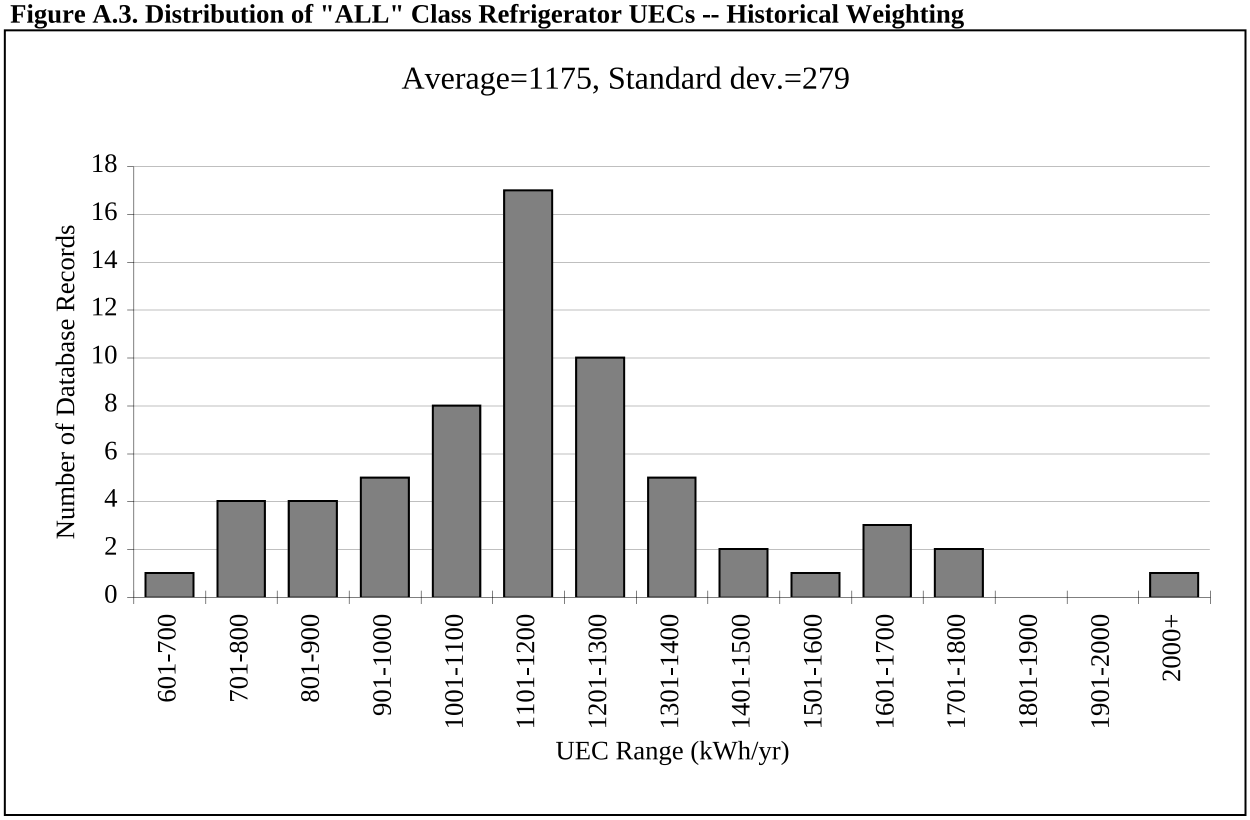


Figure A.3. Distribution of "ALL" Class Refrigerator UECs -- Historical Weighting



During our analysis, we tried several different types of weighting schemes. However, the results varied little between these different formulations. In the analysis that follows, we weight the records in each disaggregated group according to a factor of (5-QR). Thus, a record with a rating of one will be weighted four times as strongly as a record with a rating of four, twice as strongly as a three, and four-thirds as strongly as a two. Since these weightings are performed within each disaggregated group, a category with only one record will not be adjusted for quality, as there is nothing to weight it against. These single record categories are marked by italics on the tables that follow.

Other Documentation

The database contains information on the source of each record which refers to a separate database of bibliographical entries. A list of all the sources is included in the bibliography. Additionally, each record is supported by a “notes” field which holds any additional remarks or other data from the study which did not fit into the standard fields of the database. Entries that are included in the database but are not assessed in this study include per cycle estimates of dishwasher, clothes washer and dryer UECs, floor-space and climate characteristics for some space-conditioning estimates, and capacity figures for refrigerators and water heaters. These data were too limited and incomplete to permit any further analysis.

OVERVIEW OF DATA SOURCES

In all, the UEC database contains 1242 separate records of stock UEC estimates taken from 143 different sources (see Table A.2). The attached bibliography lists the data sources. The largest contributors are two UEC comparison studies from the Electric Power Research Institute (EPRI), each of which provides several hundred records of national and regional conditional demand and engineering estimates. National average space heating, cooling and water-heating UECs also include the conditional demand estimates made over several years for the Residential Energy Consumption Survey (RECS) by the U.S. DOE Energy Information Administration (EIA).

The widest range of UEC values in almost every end-use comes from conditional demand studies, where estimates frequently vary by as much as a factor of 5 or 10 within the same end-use. The most extreme of these estimates represent outliers and are almost certainly the results of flawed statistical methodology and hidden variables. For example, the highest estimate of 1132 kWh/yr for microwave oven use would represent about 3 hours of on time, every day of the year, for a typical 1000W microwave -- a high usage level for any household and patently absurd for a regional average. It is likely in this case that microwave consumption is affected by an income correlation or other hidden variable which has not been otherwise accounted for in this particular regression analysis.

Appliance sub-metering may be the ideal method for obtaining accurate end-use data for simple home appliances. Metering studies are expensive undertakings, however, and tend to be performed only rarely, limiting the quantity and sample size of the available data. Metered data in the database are predominantly from the Bonneville Power Administration (Pratt et al. 1989), Pacific Gas and Electric Co. (Brodsky et al. 1986), and Consumers Power Company (1984) studies.

Industry data in the database come from trade association and manufacturer reports. Industry data represent the best information we have about the state of new equipment entering the market, since these data are typically derived from standardized appliance testing procedures, performed identically on each manufacturer’s product line. As estimates of actual energy use in real households, standardized testing procedures are probably highly artificial (see Meier and Heinemeier 1990 and Lambert Engineering, Inc. 1990). However, because usage variation is controlled for by the testing procedure, industry estimates are extremely useful for tracking equipment efficiency over time, as we have employed them in the normalized historical weightings.

National forecasting models tend to be very complete, providing a high level of regional and vintage segment detail, but often contain data that are at best only second-hand. We include database records for some end-uses from existing residential demand forecasting models and projects, including the work of LBNL (LBNL-REM), EPRI (REEPS version 2.0), EIA (PC-AEO), the Gas Research Institute (GRI), EPA (EGUMS), and others (as discussed earlier, updated UECS from LBNL REM and REEPS have not been included in the database, but are provided in the tables and figures here for comparison with the values in the database). Model data can often be limited by data manipulations and hidden assumptions. EGUMS, the EPA emissions forecasting study, for example, uses appliance UECs that are averaged together from a small arbitrary sample of utility and laboratory studies, uncorrected for differences in appliance class, data year, and housing vintage. We include other data of this type, where several different estimates have been aggregated together to arrive at a model input, in the model category.

By definition, UEC records from utility estimates are not well documented. The figures range from simple guesses based on home auditing experience to more explicit calculations of average equipment wattages and usage levels, but are most often presented for use by the residential consumer, in as simplistic a form as possible, with little or no reference to data methodology. Utility estimates come from Edison Electric Institute, Memphis Light, Gas and Water Division, Public Service Company of New Mexico, Pacific Gas & Electric Company, and many other utilities and related agencies.

Engineering studies are often good estimators of UECs, but may suffer from unknown variables used in the calculations, particularly estimates of usage. Simulations of building heating and cooling energy consumption are examples of UEC sources in the engineering category. Also included are estimates of energy consumption for new product designs such as those used in the U.S. DOE appliance standards procedure. Engineering models are perhaps the simplest method for determining UECs for new vintage appliances, equipment, and buildings. However, as previously noted, UECs for *new* vintages are not included in this analysis.

RESULTS

In the analysis, we separate the end-uses into space conditioning and non-space conditioning. We assume that, based on the degree of variability within the data, variations in UEC across climates will not be apparent for simple residential appliances. Therefore, non-space conditioning end-uses are analyzed only by study type and house type. Space conditioning end-uses are analyzed by region, and by house type and study type for national average heating and cooling estimates. Water heating is analyzed as both a space conditioning and a non-space conditioning end-use; that is, both with and without regional disaggregation.

Non-Space Conditioning UECs

Non-space conditioning records were analyzed by study type and by house type. As shown in Table A.5, information on house type for the non-space conditioning UECs is scarce outside of the single-family and all/not-specified categories. With the possible exception of water heaters, there are not enough data to make any meaningful statement about the relationship of UEC to house type for these end-uses. Differences between single-family and all/not-specified are small, in general, and mostly reflect underlying differences in study type and data quality, rather than actual phenomena related to house type. In general, only the most detailed studies produce separate UECs for single-family houses. This is readily apparent for the freezer sub-classes (upright auto-defrost and manual defrost), where only the best conditional demand studies produce estimates for single-family dwellings, while other, less-detailed studies (including many utility estimates) generate “all” house type UECs for these classes.

For both gas and electric water heaters, there are enough estimates of multi-family and manufactured home UECs to observe a pattern. However, all of these records come from various years of RECS conditional demand analyses. While the data show expected trends -- that water heating energy use is greater in single-family homes because of higher number of occupants, etc. -- the RECS estimates are lower, on average, than other data in the database, suggesting that the RECS methodology may produce lower UEC estimates for all house types. Furthermore, water heating estimates for the “all” house type category tend to run higher than the estimates for specific house types, again probably due to differences in data quality and study type. Because of the small climate dependence of water heater energy use, this comparison is repeated later in Table A.8 with only the national-level estimates.

UEC values specific to each house type are not readily available from the database for non-space conditioning end-uses. However, the different study types are well populated and provide an interesting avenue for comparison. Figures A.4 to A.7 show the range of raw (or unadjusted) UEC estimates for three of the end-uses with large numbers of database records -- cooking, refrigeration, and water heating -- broken down by study type. Our weighted averages, which include both historical and quality rating factors, are shown by the mid-box crossbars and numerical labels. The large size of the range boxes demonstrates the wide variations that exist in UEC estimates, while the difference between averages shows the biases of the different methodologies. Table A.6 shows the results of the same analysis in tabular form for all non-space conditioning UECs. The final column averages together records of different study types, with an additional “Study Type Quality Rating” factor assigned to each study type on the basis of its apparent consistency and reliability for the given end-use. The result is a “Best Weighted Average” UEC for each end-use, which makes the best use of the available data. In the figures, the estimates are compared with the appropriate data estimated in the updated versions of LBNL REM and REEPS, as well as the two most recent years of RECS data. The results for each end-use are discussed below.

Refrigerator data do not show great variability across study types, although metered data are generally higher than other sources. Sample size may be an important issue here, because of the differing UEC levels of the refrigerator sizes and classes. For example, a small metered sample might contain a greater proportion of side-by-side or through-the-door featured models, which have considerably higher UECs. We calculate a “best” 1990 stock UEC for refrigerators of 1144 kWh/yr.

Both black-and-white and color TV UECs show good consistency across study types, although conditional demand figures for color TVs may be slightly higher than for other study types. The weighted-average estimates are about 190 kWh/yr for black-and-white and 500 kWh/yr for color TVs. These averages are considerably higher than other estimates for these end-uses (Meier and Heinemeier 1990, US DOE 1989a) that have previously been used to develop model inputs. Most of the data we consider comes from conditional demand studies, which may assign too much consumption to the television end-use, or, on the other hand, may be capturing real usage habits of television owners.

Table A.5. Non-Space Conditioning UECs by House Type

Electric UECs in kWh/yr, gas UECs in MMBtu/yr

All numbers for stock vintage normalized to 1990 efficiencies and averaged using (5-QR) weighting (except italicized)

		HOUSE TYPE							
		All/Not Specified		Single-Family		Multi-Family		Manufactured Home	
End Use	Class	N	UEC	N	UEC	N	UEC	N	UEC
Black/White TV	ALL	22	198	3	164				
Electric Cooking	ALL	54	808	18	919	1	*501*	1	*565*
	OVN	3	482	1	*334*				
	RNG	6	580	1	*322*				
Clotheswasher	ALL	12	663	3	463				
	MOT	24	127	4	93	1	*83*	1	*93*
El. Clothes Dryer	ALL	48	1047	17	906	1	*775*	1	*880*
Dishwasher	ALL	16	1054	8	1055				
	MOT	31	445	6	256	1	*235*	1	*235*
Freezer	ALL	41	1058	10	955	1	*818*	1	*933*
	MND	10	1047	5	693				
	UAD	11	1595	4	1121				
Lighting	---	10	1016	1	*4405*				
Microwave	---	22	202	6	234				
Refrigerator	ALL	39	1136	14	1207	2	1092	2	1240
	MND	10	972	2	749				
	TAD	26	1427	2	1191				
Color TV	ALL	34	500	7	647				
El. Water Heater	---	66	3804	29	3754	5	2207	5	2917
Gas Cooking	ALL	7	6.22	2	5.57	1	*4.24*	1	*4.70*
	OVN	3	3.33						
	RNG	3	2.00						
Gas Dryer	ALL	6	4.15	2	5.09	1	*3.31*	1	*3.70*
Gas Water Heater	---	15	27.80	6	25.12	5	19.73	5	21.79

Figure A.4. **Electric Cooking UECs by Study Type -- Range and Weighted Average**

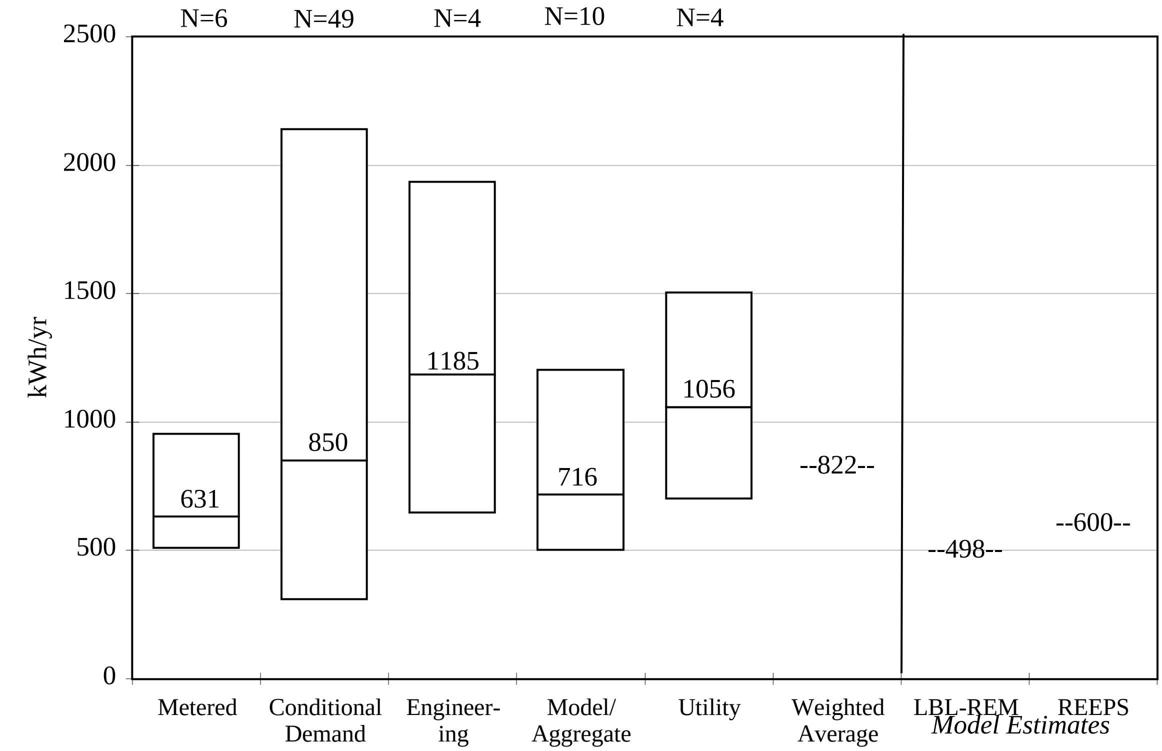
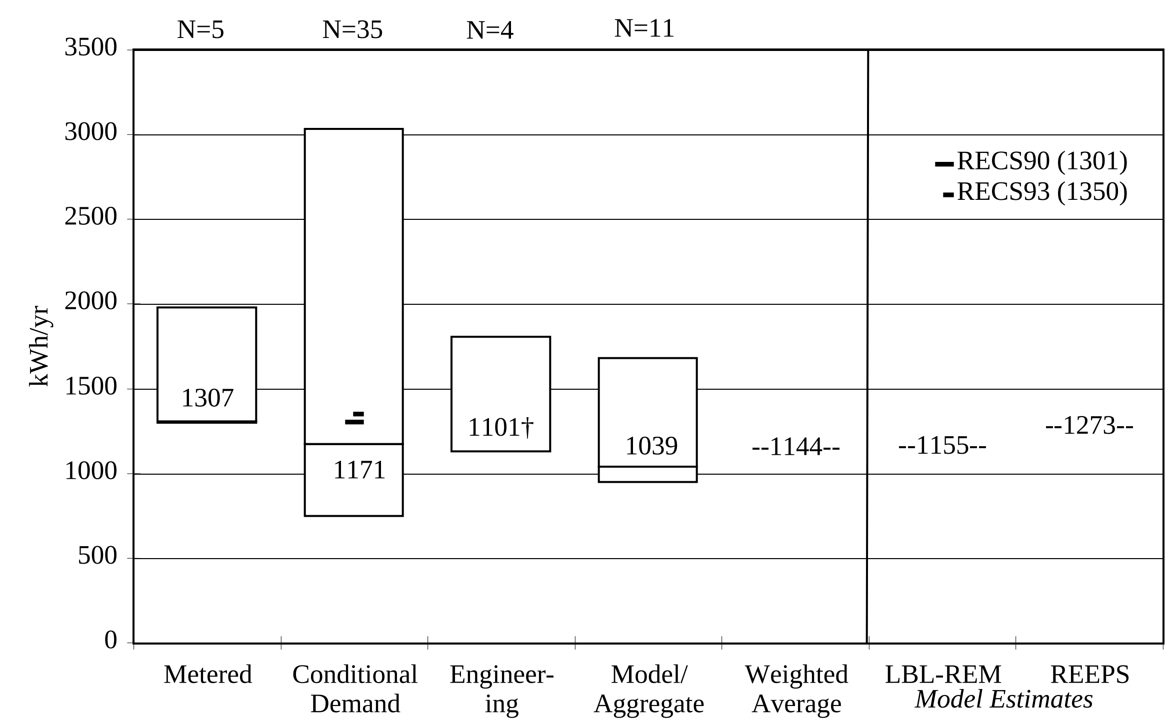


Figure A.5. **Refrigerator UECs by Study Type -- Range and Weighted Average**



†the weighted average is less than the lowest input value due to the strong historical efficiency weighting of the refrigerator end use

Figure A.6. Electric Water Heater UECs by Study Type -- Range and Weighted Average

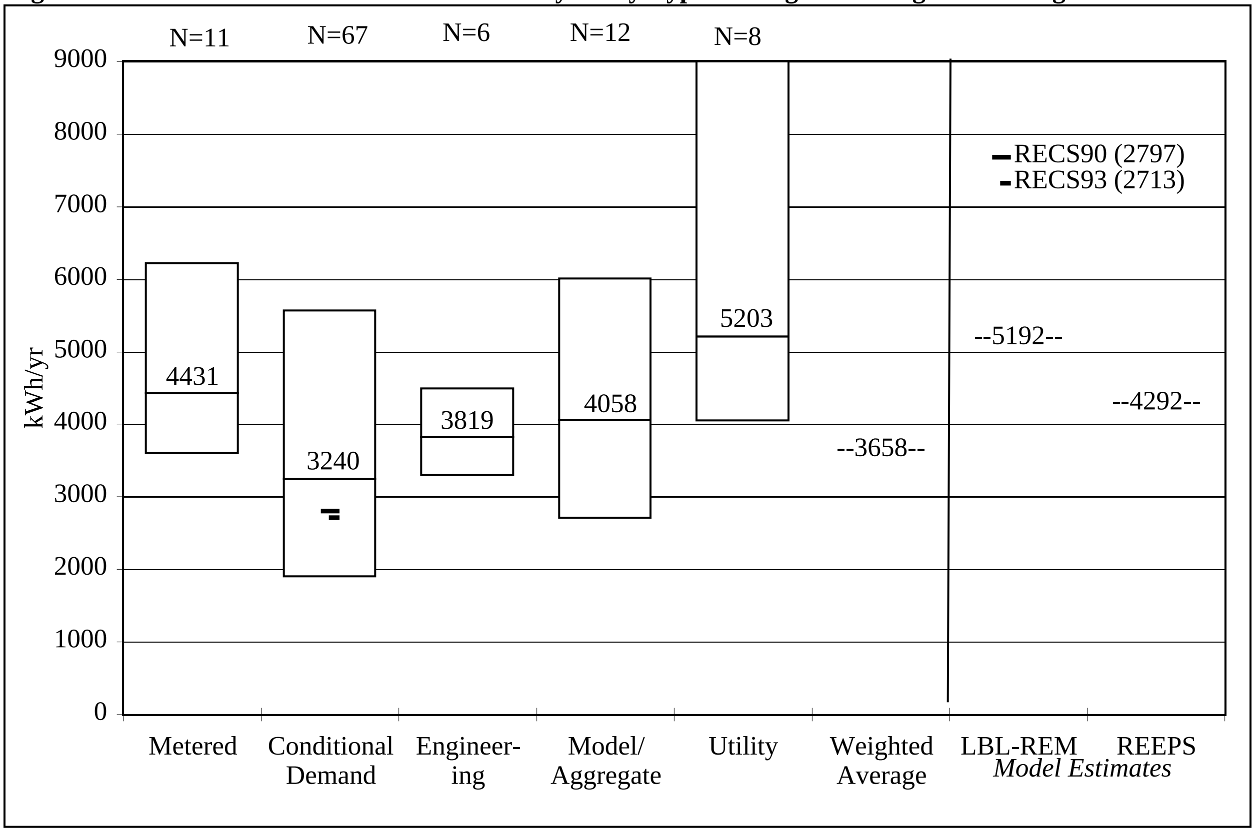


Figure A.7. Gas Water Heater UECs by Study Type -- Range and Weighted Average

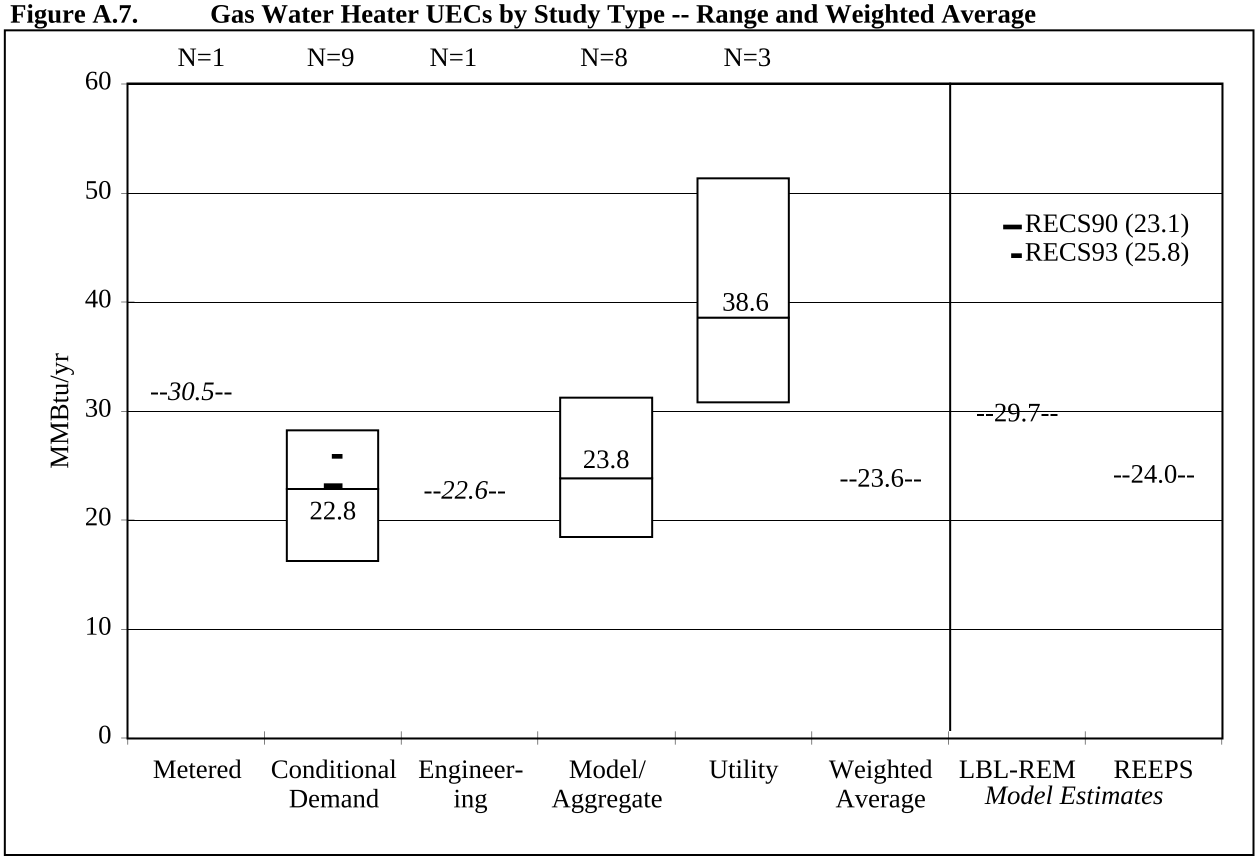


Table A.6. Non-Space Conditioning UECs by Study Type

Electric UECs in kWh/yr, gas UECs in MMBtu/yr

All numbers for stock vintage normalized to 1990 efficiencies and averaged using (5-QR) weighting (except italicized)

Industry UECs excluded

STQR=Study Type Quality Rating (1=highest, 5=lowest)

Best Weighted Average=

$$\frac{\Sigma\ N*UEC*(5\text{-}STQR)}{\Sigma\ N*(5\text{-}STQR)}$$

		STUDY TYPE															Best Weighted
		Metered/Monitored			Conditional Demand			Engineering			Model/Aggregate			Utility Estimate			Average
End Use	Class	N	UEC	STQR	N	UEC	STQR	N	UEC	STQR	N	UEC	STQR	N	UEC	STQR	UEC
Black/White TV	ALL				15	194	2	2	218	1	7	181	1	1	*182*	2	191
Electric Cooking	ALL	6	631	1	49	850	2	4	1185	3	10	716	1	4	1056	3	822
	OVN	1	*334*	1							1	*346*	1	2	572	4	386
	RNG	3	516	2	1	*299*	3				1	*399*	1	2	705	4	485
Clotheswasher	ALL				12	586	3	1	*641*	1	1	*564*	1	1	*926*	4	600
	MOT	6	94	1	8	163	5	4	94	1	9	106	1	3	105	1	100
El. Clothes Dryer	ALL	4	927	1	44	1030	1	2	977	1	13	930	1	4	981	1	1000
Dishwasher	ALL				18	962	1				2	1165	1	4	1286	3	1010
	MOT	2	128	1	22	522	5	2	242	2	9	279	1	3	361	5	250
Freezer	ALL	2	1224	1	37	1009	1	3	1103	1	10	1024	1				1026
	MND	2	875	1	8	881	1				1	*980*	2	4	1046	2	921
	UAD	1	*1238*	1	8	1411	1				2	1439	1	4	1597	3	1430
Lighting	---	1	*4405*	5	2	908	1	1	*1124*	1	5	998	1	2	1068	1	1006
Microwave	---	3	96	1	18	249	5				4	144	2	3	179	3	132
Refrigerator	ALL	5	1307	3	35	1171	1	4	1101	1	11	1039	1				1144
	MND				6	873	1							6	1009	4	901
	TAD	10	1216	4	9	1297	1				2	1377	1	7	1678	4	1338
Color TV	---				31	557	3	2	431	2	6	407	2	2	446	3	513
El. Water Heater	---	11	4431	1	67	3240	3	6	3819	2	12	4058	1	8	5203	5	3658
Gas Cooking	ALL	1	*5.71*	1							6	5.53	2	3	5.73	2	5.61
Gas Dryer	ALL	1	*4.04*	1							7	3.83	2	1	*4.45*	3	3.91
Gas Water Heater	---	1	*30.45*	1	17	22.80	3	1	*22.58*	1	8	23.82	1	3	38.56	5	23.64

Electric cooking estimates vary widely, with almost a factor of two difference between metering studies at the low end and engineering estimates at the high end. There are wide discrepancies in the definitions of the end-use that make comparison between studies difficult. For example, metering studies routinely include only cooktops and ovens, with other kitchen appliances excluded from measurement, while conditional demand studies and engineering models often base UECs on available figures for the whole kitchen circuit. There is even disagreement in the literature over the word “range,” which can mean either the rangetop elements alone or the whole oven and cooktop combination, depending on the study. However, the weighted average for the cooking end-use, about 825 kWh/yr, is in good agreement with the sum of the oven and cooktop figures.

Clothes washer estimates are in fairly close agreement across study types. About 100 kWh/yr goes to motor energy and another 600 to hot-water energy, assuming electric water heat. Clothes dryer UECs are also very consistent at about 1000 kWh/yr across all study types.

There is considerable disagreement about dishwasher energy use, particularly in the partial UEC for motor energy. Here the disagreement between metered and conditional demand estimates is especially striking (a factor of four). Conditional demand is a very crude tool for separating the motor and hot-water portions of dish- and clothes washer energy use, however, and it is reasonable to assume that the motor energy here is higher than for other study types. In fact, many conditional demand studies do not distinguish water heating from mechanical energy at all, in which case the estimates often appear as extreme outliers to the motor energy range including, quite obviously, the estimate of 2562 kWh/yr for dishwasher motors. Actual average energy use by dishwashers is likely to be about 1000 kWh/yr assuming electric water heating, with about 250 kWh/yr going to motors.

Freezers average 1000 kWh/yr, weighted between upright auto-defrost freezers at about 1600 kWh/yr and manual defrost (both upright and chest) freezers, which use about 1000 kWh/yr. This split may be important if there is any trend towards one or the other model in the long-term.

The few existing lighting UEC estimates are quite consistently around 1000 kWh/yr. Several of these figures represent simple guesses of residential lighting use, such as “ten 100 Watt bulbs x 3 hours a day per bulb x 365 days a year = ~1000 kWh/yr”. Microwave figures vary widely, with conditional demand coming in artificially high. Other estimates all average between 100 and 200 kWh/yr. Both lighting and microwave UECs could be improved with simple household log surveys, tracking domestic usage patterns over time, to provide better information on typical lighting and microwave cooking practices in homes.

Electric water-heating data are well populated for all study types and show some interesting variation. Conditional demand estimates are lower than the rest of the study population, showing the deficit left by potentially excessive estimates of dish- and clothes washer motor use. Recent analyses of utility sub-metering data indicate that the conditional demand methodology EIA uses to derive RECS UECS underestimates electric water heating UECs, and overestimates electric space heating and cooling UECs (Battles 1990, Battles 1994). Figure A.6 compares recent RECs electric water-heating UECs with those from other conditional demand analyses, and other sources. Neglecting the utility estimates, the remaining study types fall in the 3400 to 4500 kWh/yr range, with some limited variation perhaps due to regional climate. Our weighted average figure is 3650 kWh/yr.

The gas end-uses are not particularly well represented in the database due to limited end-use research for gas appliances. However, agreement is fairly good across study types for the available data. For cooking and clothes drying, most of the estimates are from existing forecasting models, yet these values are similar to those from other study types. Weighted average UEC estimates are 5.6 MMBtu/yr for gas cooking and 3.9 MMBtu/yr for gas clothes dryers.

For gas water heating, the agreement between the conditional demand estimates and model estimates is good, suggesting UECs used in models are reasonable compared to other estimates. The slightly lower estimate for conditional demand may reflect the accounting problems of appliance hot water energy, although the weaker conditional demand studies (which tend to make this mistake) tend not to study the gas end-uses. The best weighted average for gas water heating is about 24 MMBtu/yr.

Space Conditioning UECs

For space conditioning UECs, we account for differences in climate and house size by analyzing the data both by region of the country and house type, as well as by study type. Ideally, the comparison would be made based on degree days and conditioned floor area of the building or buildings under analysis. However, few studies outside of RECS or the engineering estimates include data on house size and local climate. Thus, we compare studies by federal region and house type to account for these differences.

Table A.7 shows the break-down of space conditioning UEC estimates by federal (DOE) region for houses of the all/not-specified house type. Data are primarily from utility conditional demand estimates and are concentrated in a few federal regions due to the geographic distribution of the utilities which have pursued UEC studies. The South Atlantic (region 4), Great Lakes states (region 5), Southwest (region 6), and Far West (region 9) are the best represented in the data. Water heater data are not included here. The differences between regions in the water heating end-use UEC data are obscured by differences in data quality and study type.

Between regions, a few intuitive, climate-related trends are readily discernible. The Southern regions (4 and 6) have the highest air-conditioning use for all classes of equipment, while the Northern regions (1, 2, 3, 5, 7, 8 and 10) are much lower. Region 9, comprised of California, Arizona and Nevada, is heavily weighted towards Northern California by the preponderance of data from Pacific Gas and Electric, and thus falls in line with the milder, Pacific climate. Heating figures, conversely, are highest in the North and lowest in the South and Northern California. Gas heating data at this level of disaggregation are scarce and do not entirely support the expected trends. In general, there are not enough records to create definitive results by region. We calculate national population-weighted space conditioning UECs, using UECs reported by census region and RECS census region populations, in Table A.8.

Estimates of national average household space conditioning and water heating energy use are tabulated by house type in Table A.9. The results for central air conditioning and gas space heating are presented in Figures A.8 and A.9; Figure A.8. demonstrates how RECS may be overestimating space cooling UECs. The national average estimates are dominated by national conditional demand estimates (e.g. RECS), survey results (e.g. American Gas Association), model inputs, and engineering estimates. For all heating and cooling systems, multi-family consumption levels are roughly half those in single-family dwellings. This is a result of the smaller exterior surface area in apartments and multi-plexes and the smaller amount of conditioned space in each unit. Manufactured home space conditioning energy use is generally between single- and multi-family levels.

Table A.7. Space Conditioning UECs by Region

Electric UECs in kWh/yr, gas UECs in MMBtu/yr

All numbers for stock vintage normalized to 1990 efficiencies (except unspecified/"ALL" AC technology) and averaged using (5-QR) weighting (except italicized)

All/not-specified house type only

		FEDERAL REGION																			
		1		2		3		4		5		6		7		8		9		10	
End Use	Class	N	UEC	N	UEC	N	UEC	N	UEC	N	UEC	N	UEC	N	UEC	N	UEC	N	UEC	N	UEC
AC	ALL			1	*955*															3	1007
	CAC	2	1313	2	1732	3	1935	5	3138	4	1821	5	3989	1	*1717*	1	*2667*	12	1446	3	1552
	HP					1	*1947*	3	4005			2	3821					5	1036		
	RAC	1	*386*	1	*214*	2	454	7	1917	4	539	4	1326	1	*701*	1	*1025*	9	476	2	400
el. heating	ALL	1	*5851*	4	9011	2	8989	1	*765*	1	*10140*	1	*1797*					8	3481	2	12250
	CTL							1	*2750*			2	2787					3	2643	1	*9806*
	HP	1	*11192*			2	7605	5	4264	2	14633	4	3329	1	*19659*	1	*14816*	7	3268	2	7253
	RES	1	*10012*	1	*5294*	2	7893	4	4235	2	13086	3	3321	1	*17575*	1	*13260*	7	2609	2	7375
	RM							1	*830*			2	1500					2	3214	1	*9660*
gas heating	---	1	*78.9*			1	*87.5*	1	*34.4*	2	83.0	2	41.3	1	*52.7*	1	*42.1*	1	*75.2*	1	*40.8*

Figure A.8. National Average Central Air Conditioner UECs by House Type Range and Weighted Average

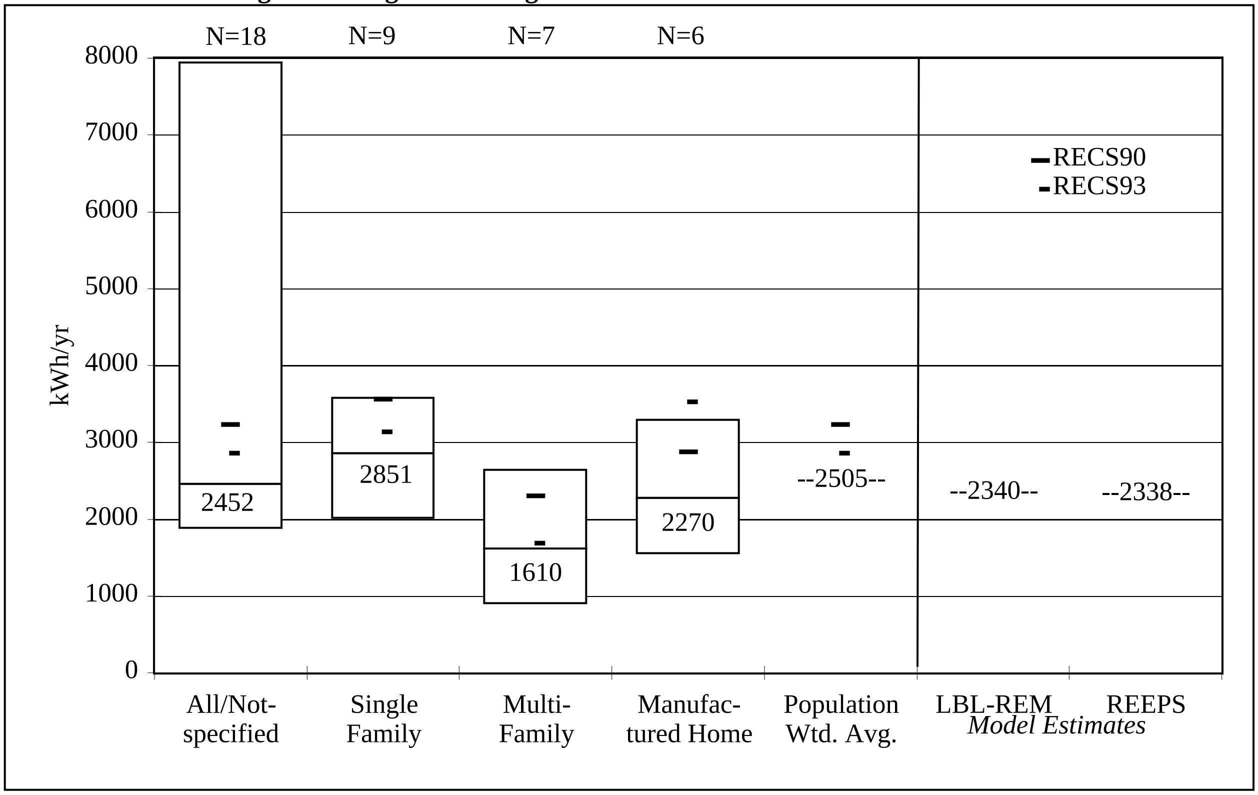


Figure A.9. National Average Gas Space Heating UECs by House Type Range and Weighted Average

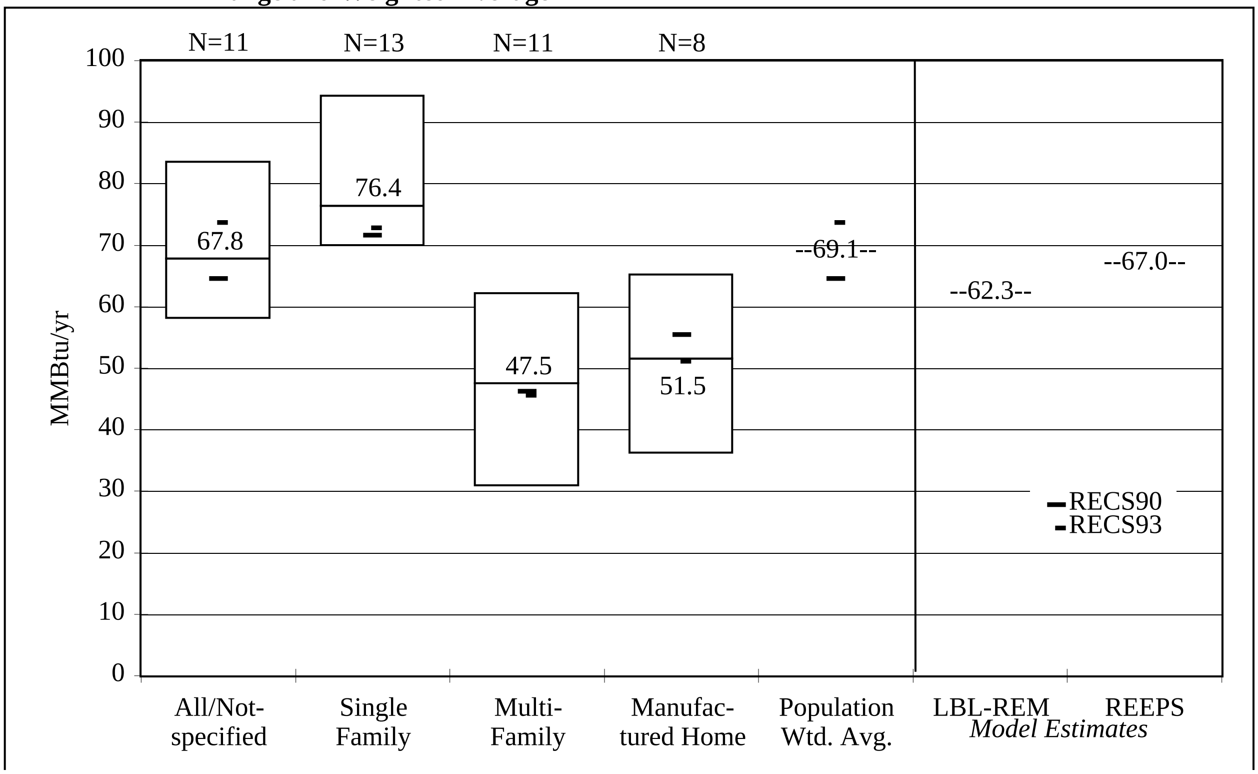


Table A.8. Space Conditioning UECs by Census Region

Electric UECs in kWh/yr, gas UECs in MMBtu/yr

All numbers for stock vintage normalized to 1990 efficiencies (except unspecified/"ALL" AC technology) and averaged using (5-QR) weighting (except italicized)

All/not-specified house type only

		CENSUS REGION																		*Population-weighted*
		1		2		3		4		5		6		7		8		9		
End Use	Class	N	UEC	N	UEC	N	UEC	N	UEC	N	UEC	N	UEC	N	UEC	N	UEC	N	UEC	*UEC*
AC	ALL			1	*955*											1	*964*	2	1028	
	CAC	2	1313	4	1662	4	1821	1	*1717*	3	2891	3	3008	3	4416	4	3326	14	1430	2647
	HP									1	*1947*	3	4005	1	*3859*	1	*3782*	5	1036	
	RAC	1	*386*	3	394	4	539	1	*701*	3	2518	4	1617	2	2098	3	865	11	465	1077
el. heating	ALL	1	*5851*	5	9687	1	10140			2	4063			1	*1797*	1	*3570*	9	5420	5247
	CTL											1	*2750*	1	*4113*	2	2427	3	5392	4116
	HP	1	*11192*	1	*10133*	2	14633	1	*19659*	3	4437	3	4663	3	4335	3	5916	8	3919	
	RES	1	*10012*	2	6806	2	13086	1	*17575*	3	4665	2	5098	2	4993	3	4912	8	3210	
	RM											1	*830*	1	*2673*	2	1188	2	6476	
gas heating	---	1	*78.9*	1	*88*	1	*82.4*	1	*52.7*	2	59.0			2	41.3	1	*42.1*	2	52.3	65.0

Census region populations (93 RECS) used to calculated national averages*

		1	2	3	4	5	6	7	8	9	Total
AC	CAC	0.6	3.2	6.7	3.8	11.1	3.4	6.9	1.7	3.5	40.9
	RAC	2	5.6	4.1	1.8	3.8	1.8	2.3	0.4	1.6	22.9
el. heating	ALL	1.0	3.1	3.5		10.7		4.8	2.0	6.3	31.4
	CTL						3.4	4.8	2.0	6.3	16.5
gas heating	---	1.6	7.9	13.0	4.1	4.9		6.3	3.5	9.0	50.3

*populations for regions without a UEC estimate are not shown or included in total

Table A.9. National Space Conditioning and Water Heating UECs by House Type

Electric UECs in kWh/yr, gas UECs in MMBtu/yr

All numbers for stock vintage normalized to 1990 efficiencies (except unspecified/"ALL" AC technology) and averaged using (5-QR) weighting (except italicized)

		DATABASE RESULTS								*Population-wtd. UECs: House Combinations*			
		All/Not Spec.		Single Family		Multi-Family		Manufactured Home		End Use Saturations (mill. units)			ALL
End Use	Class	N	UEC	N	UEC	N	UEC	N	UEC	SF	MF	MH	UEC
AC	ALL	5	1770	3	2134	3	972	3	1434	40.07	15.19	3.04	1795
	CAC	18	2452	9	2851	7	1610	6	2270	16.58	5.99	1.58	2505
	HP	3	3099	4	2908	3	1228	3	1970	4.49	2.23	0.24	2338
	RAC	20	787	4	933	5	644	4	809	18.99	6.97	1.23	854
el. heating	ALL	19	6775	8	7343	8	3717	8	5373	10.70	9.07	0.85	5667
	HP	6	8446	6	7423	4	3184	3	3533	4.43	2.23	0.23	5923
	CTL	3	8706	3	13826	3	4374	2	6050	6.27	6.84	0.63	8764
el. water heat	---	29	3653	5	3170	5	2207	5	2917	25.51	10.58	1.91	2889
gas heating	---	11	67.8	13	76.4	11	47.5	8	51.5	40.13	11.45	2.49	69.1
gas water heat	---	11	24.5	6	25.1	5	19.7	5	21.8	32.66	13.97	2.47	23.4

Population-weighted UECs:Technology Class Combinations

End Use	Class		Single Family	Multi Family	Manufactured Home
AC	ALL		1949	1110	1656
el. heating	ALL		11174	4082	5380

We have created national average UECs based on house type UECs and populations, shown in the second panel of Table A.9. Aggregations of the all/not-specified house type UECs agree with averages of the house type-specific records only for the air conditioning end-uses (except heat pumps) and central heating end-uses. The all/not-specified house type UECs are in even sharper disagreement with the average UECs weighted by census region population (shown in Table A.8); in particular, the central heating UEC from the census regions is half that of either of the two national estimates based on house type. National average water heater UECs by house type come solely from the RECS regression studies and are quite low compared to the national all/not-specified house type figures, which come from a wider variety of studies. As discussed earlier, recent research suggests the RECS water-heating UECs are underestimated.

The gas end-uses, space heating and water heating, give consistent results across house types. The national average for gas space heating in the "all" house category is 67.8 MMBtu/yr, which is almost identical to the population-weighted average across house types of 69.1 MMBtu/yr. The comparison for water heating is similar. As with electric water heating, the national average gas water heating UECs for particular house types are from the RECS conditional demand estimates for various years.

We also aggregate national average UECs across technology types for air conditioning and electric space heating to calculate average UECs by fuel. These are summed across house types at the bottom of Table A.9. For the most part, there is reasonable agreement between these summations and the data collected under the "all" technology class for air conditioning and electric heating. The exception is electric heating in single family homes, which is 50 percent higher than the "not specified" electric heating UEC. These results further highlight the overall inconsistencies among UEC estimates for electric space heating in the database.

Table A.10 shows a division of the national space conditioning and water heating records by study type, for records of the all/not-specified house type. At this level of disaggregation, there are not enough records to make any general conclusions about differences in study type for most space-conditioning end-uses. Figures for gas heating are consistent across study types, averaging 60 to 70 MMBtu/yr. For the most part, central and room air conditioning show consistency across study types, while estimates of national-average heating use show greater variation. Conditional demand water heating UECs are lower than other estimates, potentially due to the misallocation of dish- and clothes washer hot water use to motors.

Table A.10. National Space Conditioning and Water Heating UECs by Study Type

Electric UECs in kWh/yr, gas UECs in MMBtu/yr

All numbers for stock vintage normalized to 1990 efficiencies (except unspecified/"ALL" AC technology) and averaged using (5-QR) weighting (except italicized)

All/not-specified house type only

		Metered		Conditional Demand		Engineering		Model/Aggregate		Utility		Industry	
End Use	Class	N	UEC	N	UEC	N	UEC	N	UEC	N	UEC	N	UEC
AC	ALL			2	2040	1	*1392*	2	1661				
	CAC			11	2328	2	2567	4	2611	1	*3312*		
	HP			1	*4161*	1	*2666*	1	*2470*				
	RAC	1	*794*	11	769	2	799	4	823	1	*740*	1	*1187*
el. heating	ALL			14	6049	1	*14155*	3	9150				
	CTL			1	*6541*			2	10150				
	HP	1	*12901*	1	*7661*			4	7112				
	RES							2	8972				
	RM			1	*8329*								
el. water heat	---	1	*3862*	13	3068	5	4038	7	4588	2	4283	1	*4349*
gas heating	---			5	69.7			4	64.8			2	67.3
gas water heat	---			5	24.0	1	*22.6*	5	25.8				

CONCLUSIONS

The database of unit energy consumption (UEC) estimates is a useful tool for assessing the reliability of residential forecasting model inputs. The results provide the best estimates of UECs from the data collected. In the analysis of the data, this work goes beyond previous attempts at estimating UECs because we attempt to disaggregate the data by appliance class, housing type, and climatic regions where appropriate and we account for historical trends in UECs due to appliance turnover by calculating stock appliance efficiency and normalizing the data to the 1990 base year.

The analysis shows that there is significant variability in UEC estimates, both within and across study types. Some of this variability is due to random sampling error, resulting from the large underlying population variability in energy use habits. People use energy in very different ways and on widely different schedules, so that no reasonable size sample group can be perfectly representative of a regional or national average UEC. However, there is also a great deal of variability due to systematic error in estimation methodologies and study design. With this in mind, we analyze the data by study type, or UEC estimation methodology, and rate the quality of the differing methodologies for each end-use.

The analysis suggests two primary areas for future work in developing UECs for model inputs. First, most models allow for separate UECs for all end-uses by housing type. This sort of disaggregation is not well supported by measured data or conditional demand estimates, even though it is intuitive that differences in UECs between house types exist, because of different occupancy levels and equipment choices. Thus, model UEC inputs for appliances and water heating will need to be differentiated across housing types using assumptions about appliance usage and appliance size rather than any real measured data.

The second set of problems highlighted by this analysis is in the UECs for certain specific end-uses. The most problematic areas include appliance hot water usage and electric heating UECs. The hot water usage associated with clothes and dishwashers is difficult to estimate using the standard methodologies, and the accounting of the water-heating energy to those end-uses or to water heating appears to vary between studies. These differences in accounting will need to be assessed.

A more important area for future work, however, is in estimating UECs for electric heating technologies, including resistance furnace, room (or zonal) heating and heat pumps. The inconsistency in UEC data across study types and housing types for these end-uses is much greater than for gas heating or air-conditioning. Part of this problem must be due to the difficulty of separating electric heat from other household electric data in conditional demand estimation, a problem which is not as severe in the gas end-uses. Additionally, the small overall population and the localized nature of electrically heated homes may contribute to the confusion. Significant variation in space conditioning UECs may actually be the result of regional differences in electricity prices.

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