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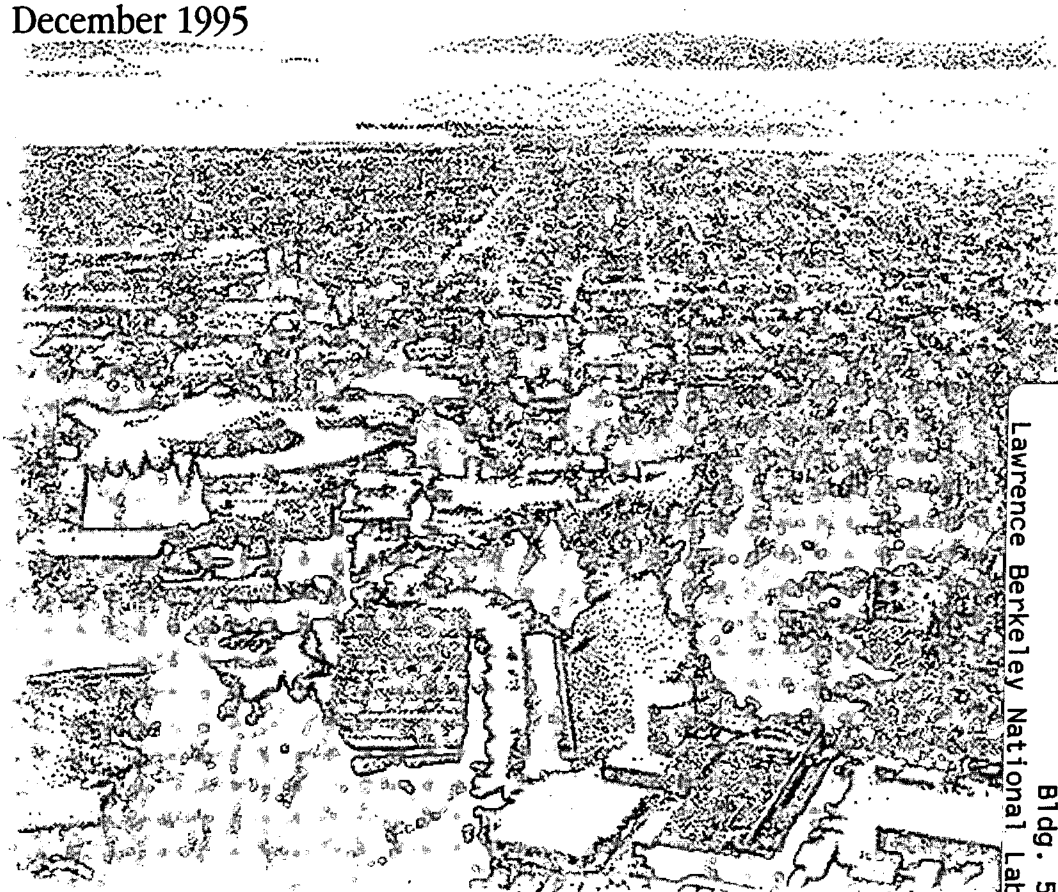

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RESIDENTIAL SECTOR END-USE FORECASTING WITH EPRI-REEPS 2.1: SUMMARY INPUT ASSUMPTIONS AND RESULTS

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ABSTRACT

This paper describes current and projected future energy use by end-use and fuel for the U.S. residential sector, and assesses which end-uses are growing most rapidly over time. The inputs to this forecast are based on a multi-year data compilation effort funded by the U.S. Department of Energy. We use the Electric Power Research Institute's (EPRI's) REEPS model, as reconfigured to reflect the latest end-use technology data.

Residential primary energy use is expected to grow 0.3% per year between 1995 and 2010, while electricity demand is projected to grow at about 0.7% per year over this period. The number of households is expected to grow at about 0.8% per year, which implies that the overall primary energy intensity per household of the residential sector is declining, and the electricity intensity per household is remaining roughly constant over the forecast period. These relatively low growth rates are dependent on the assumed growth rate for miscellaneous electricity, which is the single largest contributor to demand growth in many recent forecasts.

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1. INTRODUCTION

Energy end-use forecasting models characterize the long-term structure of energy consumption in homes under differing assumptions, scenarios, and policies. At the national level, end-use forecasting models facilitate the analysis of energy conservation programs and policy initiatives that are broad in scope, such as residential standards and national energy policy initiatives. In addition, utilities rely on end-use forecasting models to do long-term forecasting, assess market trends for new technologies, and to develop demand-side management (DSM) programs.

The Residential End-Use Energy Planning System (REEPS 2.1)[1], developed by the Electric Power Research Institute (EPRI), is a forecasting model that allows users to define customized models for various energy end-uses in the residential sector, including appliances and heating, ventilation, and air conditioning (HVAC) equipment. The model for each end-use can be configured with its own structure, data, and functional relationships. Using the modeling framework provided by the Appliance and HVAC modules in REEPS, researchers at the Ernest Orlando Lawrence Berkeley National Laboratory (LBNL) have developed individual forecasting models for refrigerators, freezers, clothes dryers, water heaters, clothes washers, dishwashers, lighting, cooking, and HVAC equipment.

This report summarizes the REEPS model framework and inputs described in Hwang et al. (1994) and Johnson et al. (1994), and presents the results of the baseline forecast for each end-use. Section 2 provides a basic overview of the REEPS model; Section 3 describes inputs to the model; Section 4 describes the decision models that are used to forecast the effect of different decisions made in the course of owning and operating residential appliances and HVAC equipment; Section 5 interprets the forecasting results; Section 6 discusses key issues raised by examination of the results; and Section 7 summarizes our conclusions. In addition, Appendix A provides tables of forecasting results; Appendix B provides an itemized list of ways that the current HVAC module has changed since it was described in Johnson et al. (1994) (an earlier report detailing the HVAC module of the REEPS model) and Appendix C lists the variables that affect various decision models in REEPS.

2. OVERVIEW OF THE REEPS MODEL

The REEPS model incorporates the basic features of residential end-use forecasting into a generalized modeling framework in which the user has considerable control over the algorithms and model structure. All users of the REEPS forecasting system use a common software framework that allows them to focus on the substantive aspects of analysis and avoid potential programming errors introduced by changes in the software source code. The REEPS framework allows for greater flexibility than traditional forecasting models, which are "hardwired" for particular formulations of residential-sector energy use. Rather than relying on a fixed set of equations and/or parameters, the user can customize the equations used to forecast future appliance, HVAC equipment, and housing characteristics. Both the functional form and the parameters included in these equations can be modified by the user. This allows the user to model a wide range of scenarios and policies, at varying levels of disaggregation, without ever changing the computer program's source code (McMenamin et al. 1992).

The flexibility of the REEPS model, however, requires the user to assume a large responsibility for configuring the input data. Each distinct set of data and parameters results in a different model;

[1] Throughout this report, we use the acronym REEPS to refer to the EPRI-REEPS 2.1 model.

thus, there can be considerable variation in forecast results even when exogenous variables remain the same. In effect, the "model" consists of the structure, data, and algorithms developed by the user, and the REEPS computer program functions as a modeling shell that imparts a higher level of structure and consistency to the analysis. The individual appliance and equipment end-use models in REEPS derive their higher-level structure from the common set of exogenous and housing stock input variables shown in **Figure 2.1.** Data from these input sets are used as drivers in forecasting the characteristics and usage of the appliance and HVAC equipment stock. Inputs to the model are described in detail in Section 3.

REEPS uses a state-based approach to forecasting in which consumer purchase decisions are modeled based on the "state" of the decision maker (e.g., household characteristics and household ownership of appliances and HVAC equipment). Base-year (1990) data are used to characterize the existing stock of appliances and HVAC equipment and the homes in which they are used. Empirical values of unit energy consumption (UEC), ownership, efficiency, and size/capacity in the control year (1991) are used to calibrate decision models within the end-use models. Based on this control-year data, the model creates a set of calibration factors that remain in place for the duration of the forecast. **Table 2.1** lists the HVAC equipment and appliances for which forecasts are made. These basic categories are referred to throughout this report as "generic technologies". Figure 2.1 lists the primary forecasting outputs of the model; these outputs are described in greater detail in Section 5.

As described in the REEPS manual (McMenamin et al. 1992), the three primary steps of forecast execution for each forecasted year are:

1) Accounting for changes in stock, based on equipment decay;
2) Execution of equipment purchase models; and
3) Updating of equipment stock and computation of energy sales.

In the first step, equipment decay is used to account for changes in the average stock efficiency due to retirements and replacements of equipment. In the second step, ownership, efficiency, and equipment size/capacity are calculated for replacement purchases, equipment conversion purchases, and purchases for installation in newly constructed houses. In the third step, the characteristics of the equipment stock are updated based on the results of the purchase decisions identified in the second step.

Special Issues for the HVAC Equipment Module

As mentioned above, HVAC equipment is treated differently from appliances in REEPS because of the complex physical and economic interactions that characterize HVAC systems. HVAC equipment is therefore modeled as a combination of heating, cooling, and distribution system components, so that an HVAC *system* is chosen by the model. In addition, the energy use of an HVAC system is largely dependent on the thermal shell of the house in which it is installed. Consequently, as indicated in Figure 2.1, engineering data on building thermal shells are incorporated into the HVAC equipment module.

In the HVAC module, there are 10 primary heating technologies and two primary cooling technologies (see Table 2.1). Secondary sources (such as Room AC and wood stoves) are considered to be supplements to primary sources and are modeled in less detail in the REEPS modeling framework. The three distribution systems in the model are hydronic, forced-air, and "none". The combination of a heating technology, cooling technology, and distribution system defines a discrete HVAC system in REEPS. Sixteen unique systems of heating and cooling equipment are modeled; these systems are tracked independently throughout the model.

Figure 2.1 General Structure of the REEPS 2.1 Model

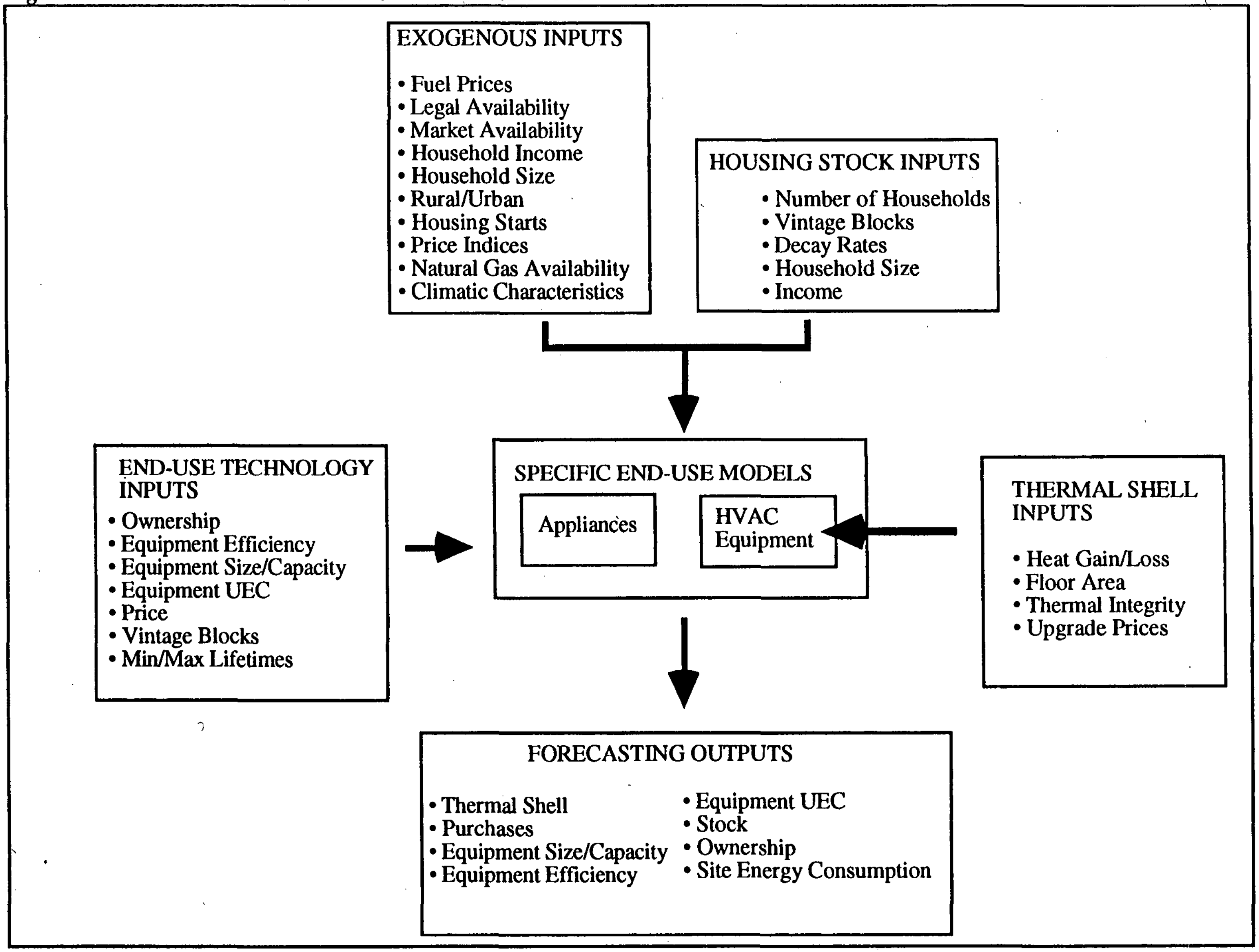

Table 2.1: Generic Technologies Modeled in REEPS

End-Use	Generic Technology
Heating	Electric Furnace Gas Furnace LPG Furnace Oil Furnace Electric Heat Pump Gas Boiler Oil Boiler Electric Room Heater Gas Room Heater Wood Stove (secondary) Other (wood)
Cooling	Central AC Electric Heat Pump Room AC (secondary)
Freezers	Electric
Refrigerators	Electric
Water Heaters	Electric Gas Oil
Dishwashers	Electric
Clothes Washers	Electric
Clothes Dryers	Electric Gas
Cooking	Electric Gas Oil
Lighting	Electric
Miscellaneous	Electric Gas Oil

Three separate models have been developed for HVAC systems -- one for the northern region of the U.S., one for the southern region of the U.S., and one for the country as a whole.[2] For the regional models, most input data are region-specific. In this report, unless otherwise noted, we refer to the national HVAC model. The regional models were developed in an effort to understand the impact of different weather conditions on HVAC use; the models are described briefly in Section 6 below.

Because floor area is an important element of HVAC purchase decisions, single-family (SF) housing in the two-region HVAC module is broken out into two single-family house types (small [≤ 1800 square feet] and large [> 1800 square feet]). The national HVAC module has just one single-family house type. Both versions of the model have multifamily (MF) and mobile home (MH) house times as well.

[2]The North region is composed of Federal Regions 1, 2, 3, 5, 7, 8, and 10, and the South Region is composed of Federal Regions 4, 6, and 9. For a map of these regions and details on their associated climate characteristics, see Johnson et al. (1994).

3. INPUTS TO THE MODEL

Data Sources

Because REEPS requires information at the household level, the modeling framework is particularly data-intensive. Data are obtained from multiple sources including:

- R.S. Means Co.: Building construction cost data;
- U.S. Energy Information Administration (EIA) 1995 Annual Energy Outlook (AEO);
- 1990 Residential Energy Consumption Surveys (RECS) conducted by EIA;
- Cost-efficiency option data developed for the U.S. Department of Energy (DOE) in support of the federal standards for appliance efficiency;
- U.S. Bureau of the Census;
- Association of Home Appliance Manufacturers (AHAM);
- Air conditioning and Refrigeration Institute (ARI);
- Gas Appliance Manufacturers Association (GAMA);
- National Association of Home Builders (NAHB);
- Appliance manufacturers; and
- Energy-related surveys by utilities as well as other organizations.

Inputs to the model can be described by four general categories: (1) Exogenous, (2) Housing Stock, (3) End-Use Technology, and (4) Thermal Shell. As indicated in Figure 2.1, the exogenous and housing stock data are fundamental inputs used in the models for both appliances and HVAC end-uses; the End-Use Technology inputs are specific to each end-use; and the Thermal Shell inputs are used only in the HVAC model.

Unless otherwise stated, exogenous inputs are taken from the U.S. Department of Energy's Annual Energy Outlook (US DOE 1995a). All other inputs are taken from the detailed data compilations documented in Johnson et al. (1994) and Hwang et al. (1994), except where noted.

Exogenous Inputs

The exogenous inputs to the model consist of time-series data for 1990 through 2030 and are listed in **Table 3.1** below. Exogenous inputs include fuel prices for each type of fuel used in the model projections; availability of appliances and HVAC equipment as constrained by efficiency standards and market processes; average income per household; average number of persons per household; percentage of rural versus urban households; number of houses built in a given year; historical inflation rates; the percentage of the housing stock having piped natural gas service; and climate characteristics. These exogenous inputs are used to forecast the general macroeconomic circumstances under which the energy- and technology-specific projections occur.

Housing Stock Inputs

Households are the basic unit of REEPS decision-making. **Table 3.2** lists the inputs that are used in REEPS to project future housing trends in terms of different housing types (single-family, multi-family, and manufactured housing) for both new and existing houses (some of these inputs are also listed above under exogenous variables). These inputs include the number of houses occupied in the base year; vintage blocks; housing stock decay rates; and average household income. Base-year (1990) housing stock data is entered into REEPS, and projections are made through 2030.

Table 3.1: Exogenous Inputs to the REEPS Model

Exogenous Inputs for 1990 to 2030	Description
Fuel Prices	Prices for oil, gas, electricity, liquid petroleum gas (LPG), and wood
Legal Availability	Availability of appliances and HVAC equipment as a result of efficiency standards; specifies which lower-efficiency appliances and equipment are not available on the market in a given year.
Market Availability	Availability of appliances and HVAC equipment as a result of the market; accounts for new products coming on to the market in a given year.
Household Income	Average income per household (disposable income; constant-year dollars)
Household Size	Average number of persons per household
Rural/Urban	Percentage of rural versus urban households
Housing Starts	Projection of the number of houses built in a given year, by house type
Price Indices	Historical inflation rates for adjusting input prices
Natural Gas Availability	Projection of the percentage of housing stock having piped natural gas service
Climate Characteristics	Heating degree days and cooling degree days (these degree days are used by the model when estimating heating and cooling loads within the REEPS default thermal shell model, but not with the LBNL data set, which is based on component loads derived as described in Johnson et al. (1994)

Table 3.2: Housing Stock Inputs to the REEPS Model

Housing Stock Inputs	Description
Housing Stock	Number of houses occupied in the base year, by house type. Housing stock after the base year is calculated within the model using 1990 stock, decay rate, and housing starts; projected changes to the housing stock are calibrated to match AEO 95 projections through 2010. The 2000-2010 growth rate is extrapolated through 2030.
Vintage Blocks	Houses existing in 1990 versus houses built after 1990
Decay Rates	Rate at which existing houses are removed from the housing stock, by house type. The projected decay rate is calibrated so that the housing stock projection matches AEO 95 projections.
Household Size	Average number of persons per household, by house type.
Household Income	Average household income in the base year, by house type.

End-Use Technology Inputs

The end-use technology inputs describe the type of appliances and HVAC equipment in existing homes in the base year (1990). These inputs are: ownership, efficiency, size/capacity, unit energy consumption, price, vintage block shares, and minimum and maximum lifetimes. Control-year (1991) data are also included for ownership, efficiency, and size/capacity. Base-year data is the average over the entire housing stock; control-year data represent only what was added in 1991 (new houses and replacements) and are used to calibrate the decision models. Efficiency, unit energy consumption, and price are technology-specific values for most appliance end-uses and average values for the remaining appliance and HVAC end-uses. The end-use inputs are defined in **Table 3.3**.

Table 3.3: End-Use Technology Inputs to the REEPS Model

End-Use Technology Inputs for the Base Year (1990), by house type	Description
Ownership	Percentage of existing households (i.e., market shares) in the base year (1990) that own a generic appliance technology or HVAC system (by fuel type). *New home* market shares data are input for the control year (1991).
Efficiency	Measure of energy output compared to energy input. New Home efficiency data are input for the control year (1991).
Size/Capacity	For refrigerators, freezers, and HVAC equipment, size/capacity are input in the base year and are modeled explicitly in the forecast. For all other technologies, the size/capacity is normalized to 1.0 in the base year and does not change throughout the forecast. *New home* refrigerator, freezer, and HVAC data are also input for the control year (1991).
UEC	Average annual energy use of a single appliance or piece of HVAC equipment.
Purchase Price	Average purchase price of specific technologies; for reduced-form, average purchase price is calculated based on size/capacity and efficiency.
Vintage Block Share	The share of the existing stock that was purchased in one of several time periods.
Min./Max. Lifetimes	Typical minimum and maximum lifetimes of appliances and HVAC equipment.

Thermal Shell Inputs

The thermal shell refers to the physical properties of a building that affect the flow and distribution of heat, without considering building occupants or their behavior. Characteristics of the thermal shell are important variables when forecasting the energy use of HVAC systems, and an advantage of REEPS is its modeling of the interaction between the thermal shell and HVAC equipment. The thermal shell inputs to the REEPS model include heat gain and loss characteristics of thermal shell components; home size; and upgrade prices. The thermal shell is modeled separately from the HVAC systems. The shell inputs are defined in **Table 3.4**.

Table 3.4: Thermal Shell Inputs to the REEPS Model

Thermal Shell Inputs for the Base Year (1990)	Description
Heat Gain/Loss Characteristics	Annual thermal load attributable to a unit area of shell component of a given thermal integrity level (e.g., R-value) in a particular climate.
Home Size	Average base-year floor area by house type.
Thermal Integrity	Base-year market share of several shell packages, each defined as a unique combination of shell component thermal integrity levels. Thermal shell shares for new homes are input for the control year (1991).
Upgrade Prices	Base-year prices for different thermal shell upgrades (insulation, efficient windows, sealing) in new houses.

4. DECISION MODELS

REEPS uses decision models to forecast the effect of different decisions made in the course of owning and operating residential appliances and HVAC equipment. The decision models determine the value of four key variables for appliances and HVAC equipment throughout the course of the forecast: ownership, efficiency, usage, and size/capacity. When combined with an exogenous forecast of the number of households, fuel prices, and household income, these variables determine the residential sector energy consumption of the generic technologies listed in Table 2.1. These five variables are related through the fundamental energy demand identity used in REEPS:

$$Energy_a = \sum_h \frac{Usage_{a,h} \bullet Size_{a,h}}{Efficiency_a} \bullet Ownership_{a,h} \bullet Number\,of\,Households_h \qquad (1)$$

In Equation 1, "Energy$_a$" is the total energy consumption of an appliance or piece of HVAC equipment and is specified for each generic technology "a"; "h" represents house type.

Table 4.1 lists the four decision models that are central to REEPS energy end-use calculations. These decision models provide the values of the endogenous variables in Equation 1. For details on the order of execution of these models, see McMenamin et al. (1992). Each model is discussed below.

Table 4.1: Decision Models in the REEPS Model

Model	Description	Model Type (1)
Ownership Model	Forecasts the percentage of households that will own a generic type of appliance or HVAC equipment as well as what type of fuel the appliance or HVAC equipment uses. Also forecasts purchase type in terms of new homes, replacement, or acquisition of a new appliance where it did not exist before.	Default or LBNL (see Table 4.2 for details)
Efficiency-Choice Model	Forecasts the level of efficiency chosen by the consumer for a particular type of appliance or HVAC equipment.	LBNL
Usage Model	Forecasts the intensity of usage of appliances and HVAC equipment (e.g., for HVAC equipment, this would be the hours of operation; for a clothes washer, it would be loads per year)	Default
Equipment Sizing Model	Forecasts the average size/capacity of refrigerators, freezers, and HVAC equipment in a given year.	LBNL for refrigerators, freezers, and HVAC; no sizing model for others.

(1) The Default Model is intrinsic to REEPS. The LBNL Model refers to cases in which we used different parameters or changed the functional form in order to better characterize an end-use.

The Ownership Model

The Ownership decision model forecasts the percentage of households that will own a generic type of appliance or HVAC equipment. **Table 4.2** details by end-use the functional forms of the Ownership and Efficiency models.

Household ownership of appliances is estimated using a discrete choice model. As described in Hwang et al. (1994) and Johnson et al. (1994), and summarized in Table 4.2, a multinomial logit equation is used to choose among different generic technologies. Each generic technology is characterized by utility functions based on household characteristics, technology characteristics, and exogenous variables. See Appendix C, Table C.1, for a breakdown by end-use of the variables upon which the ownership calculation depends.

For HVAC equipment, the ownership model compares discrete HVAC systems (defined by a heating technology, cooling technology, and distribution system) using a two-tiered, or nested, logit function. This logit function uses two separate sets of utility functions, one for heating technology purchase and operating costs (including the cost of the associated distribution system) and another for the cooling technology purchase and operating costs. Secondary heating and cooling (wood stove and room AC) ownership are modeled using a simplified (reduced-form) equation (Johnson et al. 1994).

For most appliances and all HVAC equipment, there are two user-specified states that can lead to a purchase decision: (1) new home construction, where an appliance or piece of HVAC equipment is purchased for a new home; and (2) decay and replacement, where an appliance or piece of HVAC equipment is purchased to replace one that is at the end of its useful life.[3] For dishwashers, clothes washers, and clothes dryers, a non-owner acquisition option is also possible; in this case, an appliance is purchased by someone who has not previously owned this type of appliance (Hwang et al. 1994).

For lighting and miscellaneous appliances, ownership is not modeled, because there are no data to support such models. For these end-uses, energy consumption is based on the reduced-form usage equation described below. Ownership of these end-uses grows at exactly the same rate as growth in numbers of households. As shown below, this assumption results in a key difference between LBNL REEPS forecast results and those of the Annual Energy Outlook 1995.

Efficiency-Choice Models

The Efficiency-Choice decision model further refines ownership projections by indicating the level of efficiency chosen by the consumer for a particular type of appliance or HVAC equipment. In Table 4.2, the functional forms of the Efficiency-Choice model are detailed by end-use. The number of efficiency options for each generic technology is also specified.

Most household appliance efficiencies are estimated using a discrete choice model (also known as a "specific technology" model). The specific technology approach uses a multinomial logit equation to choose among different efficiency options that are characterized by utility functions based on purchase price and operating cost. For example, when REEPS models purchase decisions regarding electric water heaters, the consumer may choose among seven discrete water heater efficiency levels – three that account for the majority of the current market and four more that will become more widely used in the future (Hwang et al. 1994). Specific technology models, because they are based on more detailed information and explicitly represent a relationship between purchase price and chosen efficiency, are more useful for predicting the impacts of changes in energy policy (e.g. standards) that pertain only to certain technologies within a generic technology group.

[3] It is also possible to characterize purchases in terms of pre-failure replacement and conversion (the appliance is purchased to replace another one that is not yet at the end of its useful life) but LBL did not characterize this option in the current version of our REEPS data sets.

Table 4.2: Functional Form of the Ownership and Efficiency-Choice Models

End-Use	Generic Technology	Ownership Model Source/Type (1)	Efficiency Model	Number of Efficiency Options
Heating	Electric Furnace	LBNL/logit	reduced-form	NA
	Gas Furnace		reduced-form	NA
	LPG Furnace		reduced-form	NA
	Oil Furnace		reduced-form	NA
	Electric Heat Pump		reduced-form	NA
	Gas Boiler		reduced-form	NA
	Oil Boiler		reduced-form	NA
	Electric Room		reduced-form	NA
	Gas Room		reduced-form	NA
	Other		reduced-form	NA
	Wood Stove	default/reduced-form	none	NA
Cooling	Central AC	default/logit	reduced-form	NA
	Electric Heat Pump	default/logit	reduced-form	NA
	Room AC	default/reduced-form	none	NA
Freezers	Electric	default/logit	specific technology	10
Refrigerators	Electric	default/logit	specific technology	10
Water Heaters	Electric	LBNL/logit	specific technology	7
	Gas		specific technology	7
	Oil		specific technology	8
Dishwashers	Electric	default/logit	specific technology	5
Clothes Washers	Electric	default/logit	specific technology	9
Clothes Dryers	Electric	default/logit	specific technology	6
	Gas	default/logit	specific technology	4
Cooking	Electric	default/logit	none	NA
	Gas		none	NA
	Oil		none	NA
Miscellaneous	Electric	none	none	NA
	Gas	none	none	NA
	Oil	none	none	NA
Lighting	Electric	none	none	NA

(1) The Default Model is intrinsic to REEPS. The LBNL Model refers to cases in which LBNL used different parameters or changed the functional form in order to better characterize an end-use.
(2) Generic technologies where reduced-form equations are used to choose efficiency levels have no specific technology options, hence these are denoted with NA (not applicable) in the last column.

HVAC equipment efficiencies are modeled using a reduced-form equation, because the REEPS framework does not currently allow a specific technology representation for HVAC equipment. We estimated parameters for a discrete choice (specific technology) heating and cooling efficiency model that we implemented outside REEPS (in a spreadsheet) to generate an exogenous time-series of heating and cooling equipment efficiencies (see Johnson et al. (1994), pp.34-36 for details). This time series is an input to the reduced-form equation, which is then modified by a fuel price elasticity multiplier, as further explained in Johnson et al. (1994).

See Appendix C, Table C.2 for a breakdown by end-use of the variables upon which the efficiency-choice calculation depends. As mentioned above, efficiency-choice is not modeled for cooking, miscellaneous, and lighting end-uses.

Usage Model

The Usage Model determines annual energy use for individual appliances and pieces of HVAC equipment. Unlike efficiency and capacity, which are constant over the lifetimes of appliances and HVAC equipment, usage is computed annually. The importance of the usage model is its contribution to the forecasting of UEC. See Appendix C, Table C.3 for a breakdown by end-use of the variables upon which the usage calculation depends.

Size/Capacity Model

The Size/Capacity Model is used to forecast the capacity of HVAC systems and the size of refrigerators and freezers; for all other technologies, the size/capacity is normalized to 1.0 and is not modeled explicitly. See Appendix C, Table C.4 for a breakdown by end-use of the variables upon which the size/capacity calculation depends.

Decision Models that are specific to the HVAC Module

In addition to the four decision models mentioned above, the HVAC module makes use of decision models that forecast both home size and thermal shell choice (see **Table 4.3**). The variables used in the home size equation are household income by house type and household size by house type. The thermal shell model forecasts the efficiency of thermal shells for new homes as a function of the physical properties of homes. Six components are used to describe the thermal shell: walls, roofs, window conduction, window solar, floors/foundations, and infiltration.

Table 4.3 Decision Models that are specific to the HVAC Module

Model	Description	Model Type (1)
Home Size Model for HVAC Equipment	Forecasts how home size changes over time.	Default
Thermal Shell Efficiency-Choice Model	Forecasts the efficiency of thermal shells for new homes; this model minimizes the life-cycle cost of thermal upgrades using a discount rate of 20% (it trades off the capital costs of thermal upgrade relative to increased fuel costs using this discount rate).	Default

(1) The Default Model is intrinsic to REEPS. The LBNL Model refers to cases in which we used different parameters or changed the functional form in order to better characterize an end-use.

Calibration

To insure forecasting accuracy, REEPS uses control-year data from the first forecast year (1991) to calibrate the four decision models (ownership, efficiency, usage, and size). A calibration constant is appended to each decision model equation so that results from the decision model match the calibration values in the control year. Depending on the functional form of the different decision model equations, the calibration constants are either multiplicative or additive. The ownership and efficiency decision models utilize multinomial logit equations while the size and usage decision models use elasticity-driven reduced-form equations. In the case of logit equations, calibration constants are determined through an iterative process. These constants are then used for each consecutive year in the forecast period.

REEPS users have some control over the calibration process through the input for "calibration tolerance". The tolerance can range from zero to one; the default value is 0.001. Relaxing calibration tolerance frees up the calibration iteration process and subsequently expedites REEPS forecast execution. It is important to note that relaxing the calibration tolerance does not diminish the effect of calibration on forecast results, it simply relaxes the 'fit' of the forecast results to control year shares.

The calibration tolerance determines how closely 1991 forecasts "match" control year values. Our experimentation indicates that REEPS forecasts can be very sensitive to the chosen calibration tolerance. This result highlights the importance of carefully choosing the control year values to which the model calibrates, as they are instrumental in the forecasting process and even minor imperfections in these data are amplified in future years. Any analysis of REEPS decision model results should distinguish between differences attributable to the functional form/parameters of the model equation and those that are attributable to the calibration constants applied to the equation.

5. RESULTS

The forecasts of the REEPS model offer a picture of how much energy will be used for what purposes in the residential sector over time. Specifically, for each generic technology, the model forecasts:

- Purchases (for existing homes and for new homes)
- Size/capacity (refrigerators, freezers, and HVAC equipment only)
- Efficiency
- Unit Energy Consumption
- Stock
- Ownership
- Energy Consumption[4]

Forecasting results can be disaggregated in terms of fuel type within end-uses; house type; and new homes versus the entire housing stock.[5]

The Tables in Appendix A give detailed forecasting results. In this section we compare these results to those of the EIA's Annual Energy Outlook 1995 (US DOE 1995a). We focus on two key indicators, the forecasted absolute and annual percentage changes in primary energy by end-use over the forecast period. Those end-uses that are growing more quickly than the average in either absolute or percentage terms are likely to be fruitful targets of energy programs and policies. Isolating the end-uses where there are large differences between the two forecasts in absolute magnitudes, percentage changes, or in sign will allow us to determine where input data and models need improvement.

Figure 5.1 shows the forecasted absolute growth in primary energy by end-use from 1995 to 2010, for both our forecast and the Annual Energy Outlook 1995. The end-uses are ranked based on the REEPS forecast estimate of absolute growth, with the end-uses with highest absolute growth at the top and the lowest at the bottom. Space heating with electricity and natural gas are projected in REEPS to contribute the largest absolute growth in primary energy use, while water heating, refrigerator, and freezer end-uses show absolute declines. These declines are driven by the efficiency standards in place for these end-uses (Hanford et al. 1994, Hwang et al. 1994, Koomey et al. 1995), and for gas water heaters also by the increasing penetration of electric water heating in new homes. Total projected growth over all end-uses for REEPS is 0.9 exajoules (10^18 joules), or about 5% over the forecast period, while total projected growth for AEO 95 is

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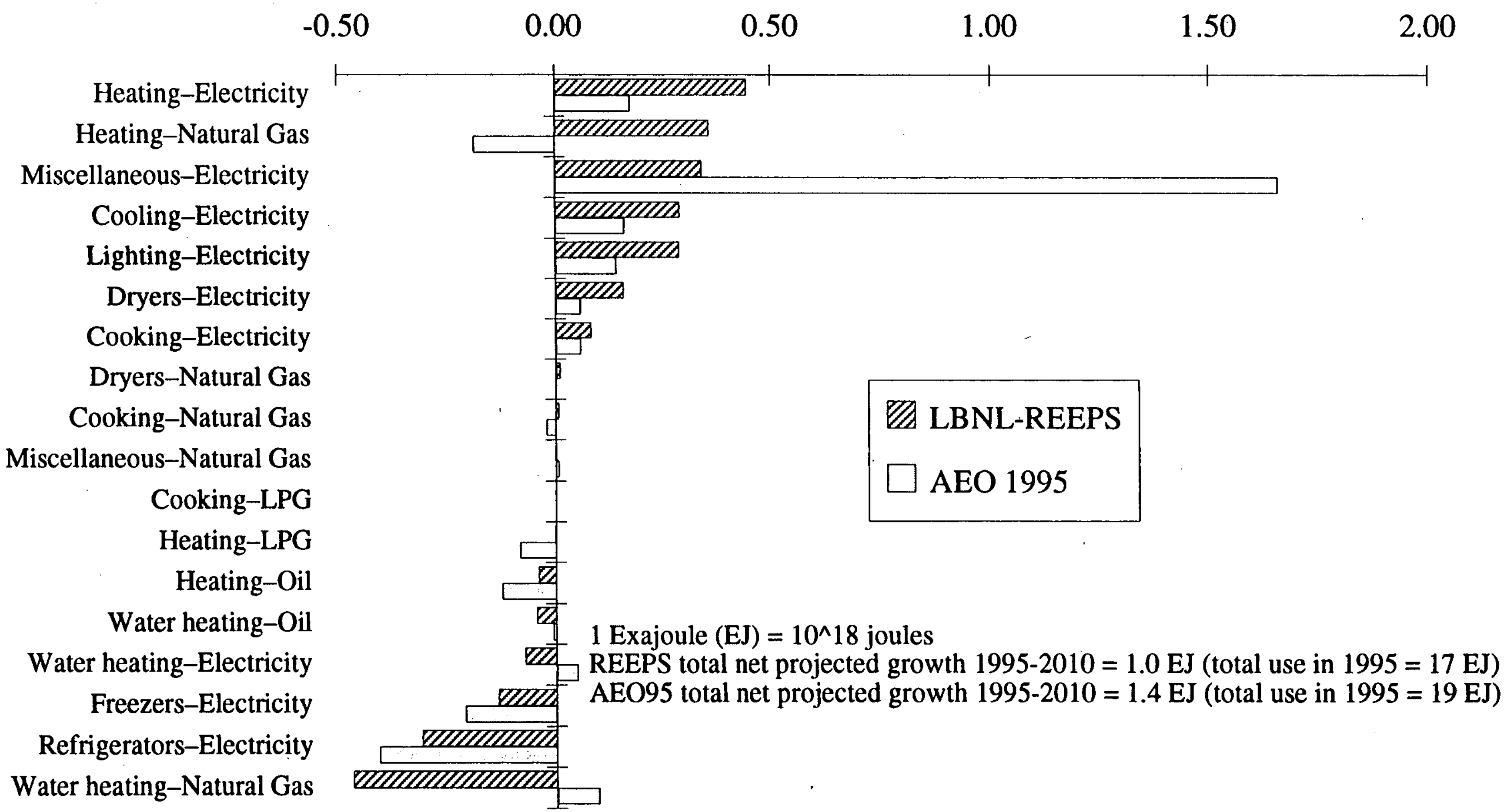
[4] We convert site electricity consumption to primary energy using a multiplier of 3.22 kWh primary/1 kWh site.

[5] The forecasting results of the REEPS model can also be disaggregated by household size and income. At this time, the LBNL version of the model is not set up to disaggregate data in terms of these variables.

Figure 5.1: Projected absolute changes in primary energy use by end-use 1995-2010 (exajoules)



1.4 exajoules (7% over the forecast period). The overall average percentage growth over this period is about 0.3% per year for REEPS and 0.5% for AEO 95.

This figure reveals substantial differences between the REEPS and AEO forecasts. Absolute growth in miscellaneous electricity use from AEO 95 is a factor of five higher than that projected by REEPS. Growth in electric cooling, electric heating, electric dryers, and lighting are projected by REEPS to be at least twice as large as the growth projected by AEO. Natural gas heating and gas and electric water heating show differences in sign, with REEPS showing significant growth for natural gas heating and significant declines for water heating, and AEO projecting declines in natural gas space heating and increasing consumption for water heating. REEPS seems generally to estimate higher growth in space conditioning consumption than does AEO. AEO 95 does not explicitly include the effect of the EPACT flow control standards on water use (Koomey et al. 1995), which in part explains why the AEO forecast shows higher growth in water heating use than does REEPS.

These differences are further highlighted in **Figure 5.2**, which shows the forecasted annual percentage growth in primary energy by end-use from 1995 to 2010, for both our forecast and the Annual Energy Outlook 1995. The end-uses are ranked based on the REEPS forecast estimate of annual percentage growth, with the end-uses with highest percentage growth at the top and the lowest at the bottom. REEPS projects percentage growth rates for electric dryers, electric heating, electric cooking, and cooling that are at least a factor of two higher than those projected by AEO, while AEO projects that miscellaneous electricity use will grow twice as fast as projected by REEPS. Refrigerator and freezer percentage changes are comparable for the two forecasts, indicating that the differences in absolute changes in primary energy use for these two end-uses (shown in Figure 5.1) are caused by differences in base year consumption estimates.

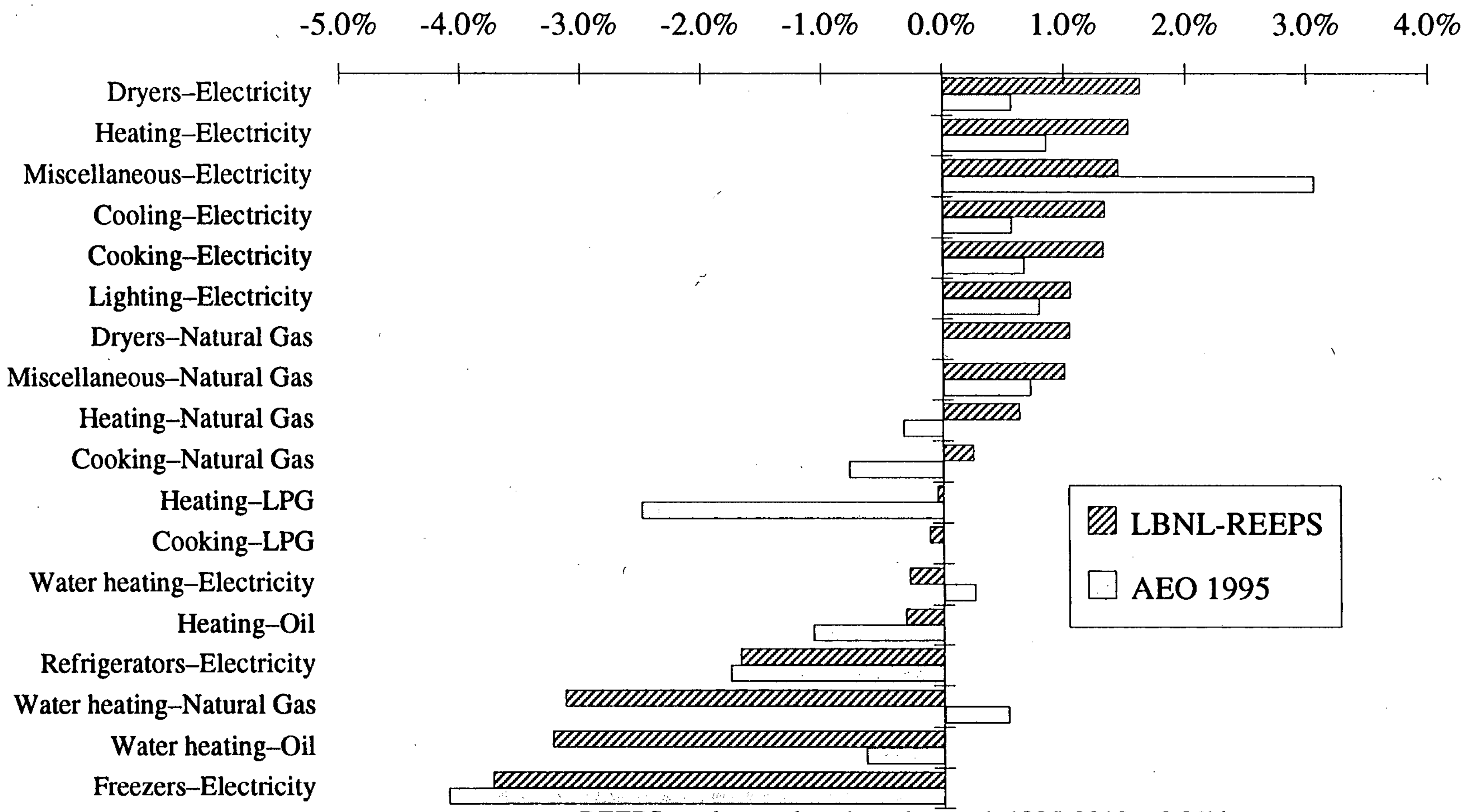
6. DISCUSSION

The Importance of Miscellaneous Electricity Use

While growth in many end-uses has been reduced or eliminated by efficiency standards, utility programs, and other government policies, growth in miscellaneous electricity use has traditionally been ignored. This end-use is often treated as an afterthought in even the most detailed bottom-up analyses, in large part because of its complexity. Because it is the category containing previously unknown uses for electricity, understanding it requires constant attention to market data and a deep appreciation for the subtleties of end-use analysis.

The LBNL REEPS forecast assumes that growth in miscellaneous will continue at the same rate as growth in the number of households. while the forecast for miscellaneous energy use in the Annual Energy Outlook is based on a simple extrapolation of recent trends embodied in the US DOE's market surveys (US DOE 1995b, US DOE 1995c, US DOE 1995d, US DOE 1994). Because of the compounding nature of exponential growth, such extrapolation is often problematic, particularly in a twenty year forecast. Without extensive data collection and detailed analysis of what is contributing to these recent trends, it is impossible to say whether they will continue or not.

Figure 5.2: Projected annual percentage changes in primary energy use by end-use 1995-2010 (%/year)



REEPS total annual projected growth 1995-2010 = 0.3%/year
AEO95 total annual projected growth 1995-2010 = 0.5%/year

One example of an end-use unexpectedly emerging on the scene is the recent rapid growth in use of standing halogen torchieres.[6] Other technologies falling into the miscellaneous category include home computers, game machines, bread makers, TVs, stereos, VCRs, well pumps, and a host of other devices (Meier et al. 1992). Detailed investigation of trends in each of these end-uses is required to determine likely changes in service demand for miscellaneous electricity.

Single-Region Vs. Two-Region National HVAC Models

In an effort to capture climatic differences existing in the US, the REEPS HVAC model was separated into two regional models, the North and the South[7]. The REEPS HVAC model previously treated the US as a single region. The North and South forecasts can be combined to describe HVAC energy use at a national level. A comparison of national energy consumption by fuel type between the two-region model and the single-region model appears in **Table 6.1.**

Table 6.1: Ratio of Two-Region HVAC Energy Consumption to Single-Region HVAC Energy Consumption

	1990	1991	1995	2000	2005	2010
Electric	1.00	1.00	0.99	0.98	0.98	0.98
GAS	1.03	1.03	1.04	1.04	1.04	1.04
OIL	1.07	1.07	1.07	1.08	1.08	1.09
LPG	0.99	0.99	1.00	1.00	1.00	1.01
WOOD	0.91	0.91	0.91	0.91	0.91	0.92

The models follow the same trend over time, demonstrating no significant difference between the single-region and two-region HVAC model forecasts, aside from initial calibration differences which are a result of inconsistencies in exogenous base year input sources. Even in the case of an exogenous fuel price shock, the models respond in the same manner, with the only noticeable difference stemming from base year calibration differences.

These results suggest that the national forecast of HVAC energy use is not significantly changed by disaggregating to two regions. However, there may be specific forecast results that are affected by more detailed geographic disaggregation that are masked when only examining the total energy consumption results (such as projected adoption rates for condensing gas furnaces).

Using forecasting models

The REEPS model as described here can be used to enhance national policy analyses in a variety of ways. At the core of any such analysis is an assessment of end-uses and the effect of existing government policies on those end-uses. REEPS can help systematize such efforts as well as indicate which end-uses are growing most rapidly and hence are the logical focus for future policy. The model, like all such end-use models, is especially good at assessing the impacts of future efficiency standards on appliances and building shells.

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[6] These lamps are not explicitly represented in the AEO 95 residential lighting category, and it is doubtful that the rapid growth in the use of such lamps is contained in the AEO forecast (except implicitly in miscellaneous). None of the standard sources of shipment data for lighting technologies even tracks sales of these torchieres. It is only recently that information on shipments of these lamps (15 million in 1994) has become available and the magnitude of the demand growth caused by them became manifest.

[7] The North consists of Federal regions 1,2,3,5,7,8 and 10 while the South consists of Federal regions 4, 6, and 9.

It is important also to recognize the limitations of any detailed forecasting framework. The resource and time requirements for updating the saturation and technology data in such a framework are large and beyond the resources of most users of forecasting models. Yet these data are key drivers in determining the results. Users of model results must understand that old or poor data will lead to unreliable results regardless of the experience of the modelers or the sophistication of the model. They should demand that compiling current data be the primary focus of policy analysis efforts.

The ability of forecasting models to predict technology penetration is always of primary concern to policy analysts, but our experience with such forecasts leaves us skeptical. Predicting the penetration of particular technologies, even using modeling frameworks as sophisticated as REEPS, is not for the faint-of-heart. The principal reason for difficulty in this area is that market response parameters estimated based on historical experience may be rendered obsolete by policy actions (such as appliance efficiency standards) that completely change the markets for particular appliances. In addition, some new technologies (such as geothermal heat pumps) have no historical data upon which to rely. Nearly all policy analysis efforts to date have fallen into this fatal trap, and more research is needed on this point.

The main value of REEPS (or any other forecasting model) is not so much in doing forecasts of technology penetration as it is in organizing the end-use data and allowing analysts to easily conduct "what-if" scenarios based on exogenous assumptions about the effectiveness of policies in the real world. This latter approach is the one that most analysts should adopt as they decide how to use the end-use forecasting framework described in this report. For an example of how to conduct such analyses, see Krause et al. (1995).

7. CONCLUSIONS

This paper described the structure and data requirements of the EPRI REEPS forecasting framework, and summarized the results of forecasts computed using that framework. Projected growth in residential sector primary energy use over the 1995 to 2010 period is 0.3% per year, which is modest relative to historical growth rates. Electricity demand is projected to grow at about 0.7% per year over this period, which is comparable to the projected growth rate in the number of households. These results are dependent upon assumptions related to growth in miscellaneous electricity, about which there is significant uncertainty.

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REFERENCES

Hanford, James W., Jonathan G. Koomey, Lisa E. Stewart, Matthew E. Lecar, Richard E. Brown, Francis X. Johnson, Roland J. Hwang, and Lynn Price. 1994. *Baseline Data for the Residential Sector and Development of a Residential Forecasting Database*. Lawrence Berkeley Laboratory. LBL-33717. May.

Hwang, Roland J., Francis X. Johnson, Richard E. Brown, James W. Hanford, Alan H. Sanstad, and Jonathan G. Koomey. 1994. *Residential Appliance Data, Assumptions and Methodology for End-Use Forecasting with EPRI-REEPS 2.1*. Lawrence Berkeley Laboratory. LBL-34046. June.

Johnson, Francis X., James W. Hanford, Richard E. Brown, Alan H. Sanstad, and Jonathan G. Koomey. 1994. *Residential HVAC Data, Assumptions and Methodology for End-Use Forecasting with EPRI-REEPS 2.1*. Lawrence Berkeley Laboratory. LBL-34045. June.

Koomey, Jonathan G., Camilla Dunham, and James D. Lutz. 1995. "The Effect of Efficiency Standards on Water Use and Water Heating Energy Use in the U.S.: A Detailed End-use Treatment". *Energy–The International Journal*. vol. 20, no. 7. July.

Krause, Florentin, David Olivier, and Jonathan Koomey. 1995.*Negawatt Power: The Cost and Potential of Low-Carbon Resource Options in Western Europe* in Energy Policy in the Greenhouse, Volume II, Part 3B . El Cerrito, CA: International Project for Sustainable Energy Paths.

McMenamin, Stuart, Ingrid Rohmund, John Pritchard, and Dave Fabiszak. 1992. *REEPS 2.1: Residential End-Use Energy Planning System User's Guide*. Prepared by Regional Economic Research, Inc. for the Electric Power Research Institute. EPRI Research Project 2863-01.

Meier, Alan K., Steve Greenberg, and Leo Rainer. 1992. *Emerging Miscellaneous Uses of Electricity in Homes*. Asilomar, CA: American Council for an Energy Efficient Economy, Washington DC.

US DOE. 1995a. *Annual Energy Outlook 1995, with Projections to 2010*. Energy Information Administration, U.S. Department of Energy. DOE/EIA-0383(95). January.

US DOE. 1995b. *Commercial Buildings Energy Consumption Survey: Consumption and Expenditures 1992*. Energy Information Administration, U.S. Department of Energy. DOE/EIA-0318(92). April.

US DOE. 1995c. *Residential Energy Consumption Survey (RECS): Household Energy Consumption and Expenditures 1993*. EIA, Energy Information Administration, U.S. Department of Energy, Washington, DC. DOE/EIA-0321(93). October.

US DOE. 1995d. *Residential Energy Consumption Survey (RECS): Housing Characteristics 1993*. EIA, Energy Information Administration, U.S. Department of Energy, Washington, DC. DOE/EIA-0314(93). June.

US DOE, U.S. Department of Energy. 1994. *Commercial Buildings Energy Consumption Survey: Commercial Buildings Characteristics 1992*. Energy Information Administration. DOE/EIA-0246(92). April.

APPENDIX A: FORECAST RESULTS

The following tables summarize the results of our REEPS forecast of residential sector energy use:

Table A.1: Exogenous Input Assumptions

Table A.2.a: Purchases of Equipment in New Homes (millions of units)

Table A.2.b: Purchases of Replacement Equipment in Existing Homes (millions of units)

Table A.2.c: New Acquisitions of Equipment in Existing Homes (millions of units)

Table A.2.d: Total Purchases of Equipment (millions of units)

Table A.3: Number of Appliances in Existing Homes (millions)

Table A.4.a: Market Shares of Equipment in Existing Homes

Table A.4.b: Market Shares of New Equipment

Table A.5.a: Efficiency of Equipment in Existing Homes

Table A.5.b: Efficiency of New Equipment

Table A.6.a: Capacity of Equipment in Existing Homes

Table A.6.b: Capacity of New Equipment

Table A.7.a: UEC of Equipment in Existing Homes

Table A.7.b: UEC of New Equipment

Table A.8: Energy Used by Stock Equipment (Primary Energy, Trillion Btu)

Table A.1: Exogenous Input Assumptions

Exogenous Drivers	*Units*	*1990*	*2000*	*2010*	*Index 1990 = 1.0 2010/1990*	*Average annual growth rate 1990-2010*
Households						
Single family	millions	64.36	71.78	78.56	1.22	1.0%
Multifamily	millions	24.42	24.69	26.62	1.09	0.4%
Mobile home	millions	5.21	5.42	5.51	1.06	0.3%
Total	millions	93.99	101.89	110.69	1.18	0.8%
Housing Starts						
Single family	millions	0.90	1.04	1.06	1.18	0.8%
Multifamily	millions	0.30	0.39	0.50	1.67	2.6%
Mobile home	millions	0.19	0.22	0.23	1.21	1.0%
Total	millions	1.39	1.65	1.79	1.29	1.3%
Household Members	people/household	2.68	2.70	2.70	1.01	0.0%
Median Household Disposable Income	10e3 1990$/household	43.05	49.36	53.42	1.24	1.1%
Site Energy Prices						
Electricity	1990¢/kWh	7.79	7.39	7.92	1.02	0.1%
Electricity	1990$/MMBtu	22.83	21.66	23.21	1.02	0.1%
Natural gas	1990$/MMBtu	5.58	5.32	6.26	1.12	0.6%
Distillate oil	1990$/MMBtu	7.59	6.96	7.88	1.04	0.2%
LPG	1990$/MMBtu	10.84	10.82	12.28	1.13	0.6%

(1) Median Household Disposable Income is Real Disposable Personal Income divided by Total Households, from AEO 95 (US DOE 1995a).
(2) AEO 95 published forecasts start with 1992, 1990 data was procured directly from EIA.
(3) Source of Households and Housing Starts: AEO 95 (US DOE 1995a).
(4) Number of Household Members is Total Population divided by Total Households (from AEO 93 for 1990-92, AEO 95 after 1992).
(5) Source of Site Energy Prices: AEO 95 (US DOE 1995a).

Table A.2.a: Purchases of Equipment in New Homes (millions of units)							
	Equipment	Annual New Home Purchases					*Index 1991 = 1.0*
End-Use	*Type*	*1991*	*1995*	*2000*	*2005*	*2010*	*2010/1991*
Heating	Elec Furnace	0.10	0.14	0.16	0.18	0.18	*1.75*
	Gas Furnace	0.61	0.84	0.84	0.86	0.89	*1.45*
	LPG Furnace	0.06	0.09	0.08	0.08	0.08	*1.23*
	Oil Furnace	0.02	0.03	0.02	0.03	0.03	*1.38*
	Elec Heat Pump	0.24	0.32	0.34	0.36	0.37	*1.53*
	Gas Boiler	0.02	0.03	0.03	0.04	0.04	*2.07*
	Oil Boiler	0.03	0.04	0.03	0.03	0.03	*1.01*
	Elec Room	0.05	0.06	0.07	0.08	0.08	*1.75*
	Gas Room	0.01	0.01	0.02	0.02	0.02	*2.63*
	Other (wood)	0.03	0.04	0.04	0.05	0.06	*1.80*
Cooling	Central AC	0.61	0.84	0.85	0.88	0.91	*1.48*
	Elec HeatPump	0.24	0.32	0.34	0.36	0.37	*1.53*
	None	0.33	0.45	0.46	0.48	0.50	*1.53*
Freezers	Electricity	0.34	0.47	0.46	0.48	0.49	*1.45*
Refrigerators	Electricity	1.30	1.78	1.82	1.91	1.97	*1.51*
Water heat	Electricity	0.71	0.97	1.08	1.18	1.23	*1.74*
	Natural gas	0.45	0.61	0.55	0.53	0.53	*1.17*
	Oil	0.02	0.03	0.02	0.01	0.01	*0.79*
Dishwasher	Electricity	0.91	1.26	1.30	1.37	1.43	*1.56*
Clothes washer	Electricity	1.00	1.40	1.43	1.53	1.61	*1.61*
Dryer	Electricity	0.91	1.24	1.22	1.27	1.30	*1.43*
	Natural gas	0.14	0.19	0.18	0.18	0.18	*1.35*
Cooking	Electricity	0.86	1.16	1.20	1.26	1.30	*1.52*
	Natural gas	0.27	0.37	0.38	0.39	0.41	*1.53*
	Oil	0.05	0.08	0.07	0.07	0.07	*1.27*

(1) Source: EPRI REEPS 2.1 Model with LBNL Data, using input assumptions from Table A.1.
(2) Miscellaneous and Lighting purchases are not modeled, but are assumed to grow at the same rate as numbers of households.
(3) New home purchases account for equipment purchased for new construction.

Table A.2.b: Purchases of Replacement Equipment for Existing Homes (millions of units)							
							Index
	Equipment	Annual Replacement Purchases					*1991 = 1.0*
End-Use	*Type*	*1991*	*1995*	*2000*	*2005*	*2010*	*2010/1991*
Heating	Elec Furnace	0.13	0.22	0.34	0.34	0.26	*2.09*
	Gas Furnace	1.64	1.38	1.07	1.09	1.26	*0.77*
	LPG Furnace	0.10	0.10	0.10	0.12	0.18	*1.77*
	Oil Furnace	0.29	0.21	0.12	0.12	0.17	*0.57*
	Elec Heat Pump	0.47	0.40	0.43	0.50	0.68	*1.43*
	Gas Boiler	0.60	0.44	0.24	0.19	0.21	*0.35*
	Oil Boiler	0.44	0.31	0.14	0.12	0.17	*0.38*
	Elec Room	0.41	0.34	0.26	0.24	0.25	*0.61*
	Gas Room	0.69	0.49	0.24	0.20	0.21	*0.30*
	Other (wood)	0.10	0.12	0.14	0.21	0.30	*2.96*
Cooling	Central AC	1.94	1.02	1.06	1.41	1.75	*0.90*
	Elec Heat Pump	0.47	0.40	0.43	0.50	0.68	*1.43*
Freezers	Electricity	1.06	1.07	1.05	0.99	0.90	*0.85*
Refrigerators	Electricity	5.31	5.33	5.48	5.65	5.93	*1.12*
Water heat	Electricity	1.74	1.92	2.19	2.51	2.76	*1.59*
	Natural gas	2.43	2.48	2.44	2.39	2.39	*0.98*
	Oil	0.24	0.25	0.26	0.26	0.27	*1.13*
Dishwasher	Electricity	3.01	3.30	3.70	4.13	4.72	*1.57*
Clothes washer	Electricity	4.70	4.86	5.07	5.39	5.82	*1.24*
Dryer	Electricity	2.33	2.47	2.71	2.97	3.24	*1.39*
	Natural gas	0.79	0.80	0.82	0.85	0.91	*1.14*
Cooking	Electricity	2.80	2.74	2.38	2.44	2.59	*0.93*
	Natural gas	2.38	2.16	1.71	1.59	1.63	*0.69*
	Oil	0.35	0.31	0.23	0.21	0.22	*0.63*

(1) Source: EPRI REEPS 2.1 Model with LBNL Data, using input assumptions from Table A.1.
(2) Miscellaneous and Lighting purchases are not modeled, but are assumed to grow at the same rate as numbers of households.
(3) Replacement purchases account for new equipment purchased to replace retired equipment in existing homes.

Table A.2.c: New Acquisitions of Equipment for Existing Homes (millions of units)							
							Index
	Equipment	Annual Acquisitions					*1991 = 1.0*
End-Use	*Type*	*1991*	*1995*	*2000*	*2005*	*2010*	*2010/1991*
Dishwasher	Electricity	0.49	0.50	0.53	0.52	0.51	*1.06*
Clothes washer	Electricity	0.07	0.07	0.08	0.08	0.08	*1.21*
Dryer	Electricity	0.34	0.35	0.35	0.33	0.31	*0.90*
	Natural gas	0.11	0.11	0.11	0.10	0.09	*0.83*

(1) Source: EPRI REEPS 2.1 Model with LBNL Data, using input assumptions from Table A.1.

(2) Appliance Acquisitions account for purchases in existing homes that do not own a particular appliance at the beginning of the forecast period.

(3) Appliance Acquisitions are modeled explicitly only for Dishwashers, Clothes Washers, and Dryers. Acquisition of new refrigerators, freezers, cooling, and other end-uses can be approximated by altering saturations of these end-uses.

Table A.2.d: Total Purchases of Equipment (millions of units)

End-Use	Equipment Type	Total Annual Purchases 1991	1995	2000	2005	2010	Index 1991 = 1.0 2010/1991
Heating	Elec Furnace	0.23	0.37	0.50	0.51	0.45	*1.94*
	Gas Furnace	2.25	2.22	1.91	1.95	2.15	*0.96*
	LPG Furnace	0.17	0.19	0.18	0.20	0.26	*1.56*
	Oil Furnace	0.31	0.24	0.14	0.14	0.19	*0.62*
	Elec Heat Pump	0.72	0.72	0.77	0.86	1.05	*1.46*
	Gas Boiler	0.62	0.46	0.27	0.22	0.25	*0.40*
	Oil Boiler	0.47	0.35	0.18	0.16	0.20	*0.42*
	Elec Room	0.46	0.40	0.33	0.32	0.33	*0.72*
	Gas Room	0.70	0.50	0.26	0.22	0.23	*0.33*
	Other (wood)	0.13	0.16	0.19	0.26	0.36	*2.69*
Cooling	Central AC	2.55	1.86	1.92	2.29	2.66	*1.04*
	Elec Heat Pump	0.72	0.72	0.77	0.86	1.05	*1.46*
	None	0.33	0.45	0.46	0.48	0.50	*1.53*
Freezers	Electricity	1.40	1.54	1.51	1.47	1.39	*0.99*
Refrigerators	Electricity	6.61	7.12	7.30	7.55	7.90	*1.19*
Water heat	Electricity	2.45	2.89	3.26	3.68	3.99	*1.63*
	Natural gas	2.89	3.09	2.99	2.92	2.92	*1.01*
	Oil	0.26	0.28	0.28	0.28	0.28	*1.10*
Dishwasher	Electricity	4.40	5.06	5.53	6.03	6.66	*1.51*
Clothes washer	Electricity	5.77	6.33	6.58	7.00	7.51	*1.30*
Dryer	Electricity	3.58	4.06	4.28	4.57	4.85	*1.35*
	Natural gas	1.04	1.10	1.10	1.13	1.18	*1.14*
Cooking	Electricity	3.66	3.91	3.58	3.70	3.89	*1.06*
	Natural gas	2.65	2.53	2.09	1.98	2.04	*0.77*
	Oil	0.40	0.38	0.30	0.28	0.29	*0.72*

(1) Source: EPRI REEPS 2.1 Model with LBNL Data, using input assumptions from Table A.1.

(2) Miscellaneous and Lighting purchases are not modeled, but are assumed to grow at the same rate as numbers of households.

(3) Total purchases represent the sum of replacement, new home, and acquisition purchases.

Table A.3: Number of Appliances in Existing Homes (millions)

End-Use	*Equipment Type*	Appliance stock in millions of units *1990*	*1995*	*2000*	*2005*	*2010*	*Index 1990 = 1.0 2010/1990*
Heating	Elec Furnace	7.6	7.9	8.3	8.8	9.3	*1.23*
	Gas Furnace	35.1	37.6	40.5	43.2	45.9	*1.31*
	LPG Furnace	4.5	4.6	4.6	4.7	4.7	*1.07*
	Oil Furnace	4.7	4.7	4.7	4.6	4.6	*0.97*
	Elec Heat Pump	5.9	7.2	8.6	10.1	11.6	*1.95*
	Gas Boiler	8.2	8.0	7.9	7.7	7.6	*0.93*
	Oil Boiler	5.7	5.7	5.7	5.7	5.7	*0.99*
	Elec Room	8.0	7.9	7.9	7.9	8.0	*1.00*
	Gas Room	8.3	8.1	7.9	7.8	7.6	*0.91*
	Other (wood)	5.9	5.8	5.8	5.8	5.8	*0.98*
Cooling	Central AC	30.6	33.2	36.3	39.2	42.1	*1.37*
	Elec Heat Pump	5.9	7.2	8.6	10.1	11.6	*1.95*
Freezers	Electricity	32.4	31.1	30.2	29.5	29.1	*0.90*
Refrigerators	Electricity	108.1	112.1	116.9	121.8	126.7	*1.17*
Water heat	Electricity	35.3	39.0	43.8	49.3	55.0	*1.56*
	Natural gas	53.6	53.5	53.1	52.1	50.9	*0.95*
	Oil	5.1	5.1	5.0	4.9	4.8	*0.94*
Dishwasher	Electricity	42.7	49.3	56.7	64.0	71.3	*1.67*
Clothes washer	Electricity	71.7	75.7	80.5	85.3	90.4	*1.26*
Dryer	Electricity	49.5	55.0	60.8	66.4	71.7	*1.45*
	Natural gas	15.3	16.2	17.1	17.9	18.7	*1.22*
Cooking	Electricity	51.3	54.8	58.8	62.8	66.8	*1.30*
	Natural gas	37.2	37.4	37.8	38.2	38.6	*1.04*
	Oil	5.4	5.4	5.4	5.3	5.3	*0.98*

(1) Source: EPRI REEPS 2.1 Model with LBNL Data, using input assumptions from Table A.1.
(2) Miscellaneous and Lighting stocks and purchases are not modeled, but are assumed to grow at the same rate as numbers of households.
(4) Refrigerator stock accounts for homes with 2 refrigerators.

Table A.4.a: Market Shares of Equipment in Existing Homes

End-Use	*Equipment Type*	*1990*	*1995*	*2000*	*2005*	*2010*	*Index 1990 = 1.0 2010/1990*
		Equipment Market Shares					
Heating	Elec Furnace	8%	8%	8%	8%	8%	*1.04*
	Gas Furnace	37%	39%	40%	41%	41%	*1.11*
	LPG Furnace	5%	5%	5%	4%	4%	*0.90*
	Oil Furnace	5%	5%	5%	4%	4%	*0.82*
	Elec Heat Pump	6%	7%	8%	9%	10%	*1.66*
	Gas Boiler	9%	8%	8%	7%	7%	*0.79*
	Oil Boiler	6%	6%	6%	5%	5%	*0.84*
	Elec Room	9%	8%	8%	7%	7%	*0.85*
	Gas Room	9%	8%	8%	7%	7%	*0.77*
	Other (wood)	6%	6%	6%	5%	5%	*0.83*
Cooling	Central AC	33%	34%	36%	37%	38%	*1.17*
	Elec Heat Pump	6%	7%	8%	9%	10%	*1.66*
	None	61%	59%	56%	54%	52%	*0.84*
Freezers	Electricity	34%	32%	30%	28%	26%	*0.76*
	None	66%	68%	70%	72%	74%	*1.12*
Refrigerators	Electricity	115%	115%	115%	115%	114%	*1.00*
Water heat	Electricity	38%	40%	43%	46%	50%	*1.32*
	Natural gas	57%	55%	52%	49%	46%	*0.81*
	Oil	5%	5%	5%	5%	4%	*0.79*
Dishwasher	Electricity	45%	51%	56%	60%	64%	*1.42*
	None	55%	49%	44%	40%	36%	*0.65*
Clothes washer	Electricity	76%	78%	79%	80%	82%	*1.07*
	None	24%	22%	21%	20%	18%	*0.77*
Dryer	Electricity	53%	56%	60%	62%	65%	*1.23*
	Natural gas	16%	17%	17%	17%	17%	*1.04*
	None	31%	27%	24%	21%	18%	*0.59*
Cooking	Electricity	55%	56%	58%	59%	60%	*1.10*
	Natural gas	40%	38%	37%	36%	35%	*0.88*
	Oil	6%	6%	5%	5%	5%	*0.83*
Miscellaneous	Electricity	96%	96%	96%	97%	97%	*1.00*
	Natural gas	3%	3%	3%	3%	3%	*0.94*
	Oil	1%	1%	1%	1%	1%	*0.74*
Lighting	0-1 hrs	40%	40%	40%	40%	40%	*1.00*
	1-2 hrs	20%	20%	20%	20%	20%	*1.00*
Usage level	2-3 hrs	10%	10%	10%	10%	10%	*1.00*
	3-4 hrs	10%	10%	10%	10%	10%	*1.00*
	4+ hrs	20%	20%	20%	20%	20%	*1.00*
	Flourescent	100%	100%	100%	100%	100%	*1.00*
Secondary Heating	Wood Stove	4%	4%	4%	4%	4%	*0.98*
Secondary Cooling	Room AC	30%	29%	28%	27%	26%	*0.88*

(1) Source: EPRI REEPS 2.1 Model with LBNL Data, using input assumptions from Table A.1.

(2) For Lighting end-use, saturation is based on the fraction of light bulbs having designated usage level in the average house.

(3) Refrigerator market share includes a second refrigerator in some homes.

Table A.4.b: Market Shares of New Equipment

End-Use	*Equipment Type*	*1991*	*1995*	*2000*	*2005*	*2010*	*Index 1991 = 1.0 2010/1991*
		Equipment Market Shares					
Heating	Elec Furnace	9%	9%	10%	10%	10%	*1.16*
	Gas Furnace	52%	52%	51%	50%	50%	*0.96*
	LPG Furnace	5%	5%	5%	5%	4%	*0.82*
	Oil Furnace	2%	2%	2%	1%	1%	*0.92*
	Elec Heat Pump	21%	20%	20%	21%	21%	*1.02*
	Gas Boiler	2%	2%	2%	2%	2%	*1.37*
	Oil Boiler	3%	3%	2%.	2%	2%	*0.67*
	Elec Room	4%	4%	4%	5%	5%	*1.16*
	Gas Room	1%	1%	1%	1%	1%	*1.74*
	Other (wood)	3%	3%	3%	3%	3%	*1.20*
Cooling	Central AC	52%	52%	52%	51%	51%	*0.98*
	Elec Heat Pump	21%	20%	20%	21%	21%	*1.02*
Freezers	Electricity	28%	29%	28%	28%	27%	*0.96*
Refrigerators	Electricity	110%	111%	111%	111%	111%	*1.00*
Water heat	Electricity	60%	60%	66%	68%	69%	*1.16*
	Natural gas	39%	38%	33%	31%	30%	*0.78*
	Oil	1%	2%	1%	1%	1%	*0.53*
Dishwasher	Electricity	77%	78%	79%	80%	80%	*1.04*
Clothes washer	Electricity	85%	87%	87%	89%	90%	*1.07*
Dryer	Electricity	77%	77%	74%	74%	73%	*0.95*
	Natural gas	12%	12%	11%	10%	10%	*0.90*
Cooking	Electricity	73%	73%	73%	73%	73%	*1.01*
	Natural gas	23%	23%	23%	23%	23%	*1.02*
	Oil	5%	5%	4%	4%	4%	*0.84*
Miscellaneous	Electricity	98%	98%	98%	98%	98%	*1.00*
	Natural Gas	2%	2%	2%	2%	2%	*0.84*
	Oil	0%	0%	0%	0%	0%	-
Lighting	0-1 hrs	40%	40%	40%	40%	40%	*1.00*
	1-2 hrs	20%	20%	20%	20%	20%	*1.00*
Usage level	2-3 hrs	10%	10%	10%	10%	10%	*1.00*
	3-4 hrs	10%	10%	10%	10%	10%	*1.00*
	4+ hrs	20%	20%	20%	20%	20%	*1.00*
	Flourescent	100%	100%	100%	100%	100%	*1.00*

(1) Source: EPRI REEPS 2.1 Model with LBNL Data, using input assumptions from Table A.1.
(2) For Lighting end-use, saturation is based on the fraction of light bulbs having designated usage level in the average house.
(3) Refrigerator market share includes a second refrigerator in some homes.
(4) For HVAC, "New" represents new equipment in new homes; for appliances, "New" represents new equipment in new and existing homes.

Table A.5.a: Efficiency of Equipment in Existing Homes

End-Use	*Equipment Type*	*Units*	*1990*	*1995*	*2000*	*2005*	*2010*	*Index 1990 = 1.0 2010/1990*
			Efficiency for Stock Equipment					
Heating	Elec Furnace	Btu.out/Wh.in	3.41	3.41	3.41	3.41	3.41	*1.00*
	Gas Furnace	AFUE	0.71	0.74	0.75	0.76	0.76	*1.07*
	LPG Furnace	AFUE	0.73	0.74	0.75	0.76	0.76	*1.05*
	Oil Furnace	AFUE	0.72	0.76	0.78	0.79	0.80	*1.10*
	Elec Heat Pump	HSPF	6.35	6.75	6.97	7.03	7.03	*1.11*
	Gas Boiler	AFUE	0.70	0.75	0.77	0.79	0.79	*1.14*
	Oil Boiler	AFUE	0.77	0.80	0.82	0.83	0.84	*1.10*
	Elec Room	Btu.out/Wh.in	3.41	3.41	3.41	3.41	3.41	*1.00*
	Gas Room	AFUE	0.59	0.63	0.65	0.66	0.67	*1.13*
	Other (wood)	AFUE	0.70	0.70	0.70	0.70	0.70	*1.00*
Cooling	Central AC	SEER	8.00	8.74	9.27	9.65	9.89	*1.24*
	Elec Heat Pump	SEER	8.69	9.38	9.79	9.96	9.99	*1.15*
Freezers	Electricity	cf/kWh/day	9.48	10.99	13.05	15.32	16.79	*1.77*
Refrigerators	Electricity	cf/kWh/day	5.61	6.96	8.49	9.75	10.55	*1.88*
Water Heat	Electricity	kWh.th/kWh.e	0.83	0.85	0.87	0.88	0.88	*1.06*
	Natural gas	Btu.th/Btu.f	0.50	0.52	0.53	0.54	0.55	*1.10*
	Oil	Btu.th/Btu.f	0.49	0.51	0.52	0.54	0.55	*1.12*
Dishwasher	Electricity	cycle/kWh	1.29	1.31	1.32	1.33	1.34	*1.04*
Clothes Washer	Electricity	cycle/kWh	3.72	3.72	3.72	3.72	3.72	*1.00*
Dryer	Electricity	lb/kWh	2.56	2.63	2.68	2.72	2.74	*1.07*
	Natural gas	lb/kBtu	0.70	0.72	0.72	0.72	0.72	*1.02*
Cooking	Electricity	Btu.out/Wh.in	3.41	3.41	3.41	3.41	3.41	*1.00*
	Natural gas	Index 1990 = 1	1.00	1.00	1.00	1.00	1.00	*1.00*
	Oil	Index 1990 = 1	1.00	1.00	1.00	1.00	1.00	*1.00*
Miscellaneous	Electricity	Btu.out/Wh.in	3.41	3.41	3.41	3.41	3.41	*1.00*
	Natural gas	Index 1990 = 1	1.00	1.00	1.00	1.00	1.00	*1.00*
	Oil	Index 1990 = 1	1.00	1.00	1.00	1.00	1.00	*1.00*
Lighting	0-1 hrs	Index 1990 = 1	1.00	1.00	1.00	1.00	1.00	*1.00*
	1-2 hrs	Index 1990 = 1	1.00	1.00	1.00	1.00	1.00	*1.00*
Usage level	2-3 hrs	Index 1990 = 1	1.00	1.00	1.00	1.00	1.00	*1.00*
	3-4 hrs	Index 1990 = 1	1.00	1.00	1.00	1.00	1.00	*1.00*
	4+ hrs	Index 1990 = 1	1.00	1.00	1.00	1.00	1.00	*1.00*
	Flourescent	Index 1990 = 1	1.00	1.00	1.00	1.00	1.00	*1.00*

(1) Source: EPRI REEPS 2.1 Model with LBNL Data, using input assumptions from Table A.1.
(2) Efficiencies are based on U.S. government test procedures.
(3) kWh.th = thermal kWh; kWh.e = electric kWh; Btu.th = thermal Btu; Btu.f = fuel Btu
(4) SEER = Seasonal Energy Efficiency Ratio, AFUE = Annual Fuel Utilization Efficiency, HSPF = Heating Seasonal Performance Factor.
(5) Freezer, refrigerator, water heat, dishwasher, clothes washer, dryer end-uses are modeled using a specific technology efficiency model.
(6) For Lighting, Cooking, and Miscellaneous end-uses, efficiencies are normalized, effectively removing efficiency analysis from modeling.

Table A.5.b: Efficiency of New Equipment

End-Use	*Equipment Type*	*Units*	*1991*	*1995*	*2000*	*2005*	*2010*	*Index 1991 = 1.0 2010/1991*
			Efficiency for New Equipment					
Heating	Elec Furnace	Btu.out/Wh.in	3.41	3.41	3.41	3.41	3.41	*1.00*
	Gas Furnace	AFUE	0.76	0.77	0.77	0.77	0.77	*1.01*
	LPG Furnace	AFUE	0.76	0.77	0.77	0.77	0.77	*1.01*
	Oil Furnace	AFUE	0.80	0.80	0.80	0.80	0.80	*1.00*
	Elec Heat Pump	HSPF	7.03	7.03	7.03	7.03	7.03	*1.00*
	Gas Boiler	AFUE	0.80	0.80	0.80	0.80	0.80	*1.00*
	Oil Boiler	AFUE	0.84	0.85	0.85	0.85	0.85	*1.01*
	Elec Room	Btu.out/Wh.in	3.41	3.41	3.41	3.41	3.41	*1.00*
	Gas Room	AFUE	0.67	0.67	0.67	0.67	0.67	*1.00*
	Other (wood)	AFUE	0.70	0.70	0.70	0.70	0.70	*1.00*
Cooling	Central AC	SEER	9.24	9.97	9.97	9.97	9.97	*1.08*
	Elec Heat Pump	SEER	9.41	9.99	9.99	9.99	9.99	*1.06*
Freezers	Electricity	cf/kWh/day	14.24	17.93	17.92	17.92	17.93	*1.26*
Refrigerators	Electricity	cf/kWh/day	8.88	11.12	11.12	11.12	11.12	*1.25*
Water heat	Electricity	kWh.th/kWh.e	0.88	0.89	0.89	0.89	0.89	*1.01*
	Natural gas	Btu.th/Btu.f	0.55	0.55	0.55	0.55	0.55	*1.00*
	Oil	Btu.th/Btu.f	0.55	0.56	0.56	0.56	0.56	*1.02*
Dishwasher	Electricity	cycle/kWh	1.34	1.34	1.34	1.34	1.34	*1.00*
Clothes washer	Electricity	cycle/kWh	3.72	3.72	3.72	3.72	3.72	*1.00*
Dryer	Electricity	lb/kWh	2.75	2.75	2.75	2.75	2.76	*1.00*
	Natural gas	lb/kBtu	0.72	0.72	0.72	0.72	0.72	*1.00*
Cooking	Electricity	Btu.out/Wh.in	3.41	3.41	3.41	3.41	3.41	*1.00*
	Natural gas	Index 1990 = 1	1.00	1.00	1.00	1.00	1.00	*1.00*
	Oil	Index 1990 = 1	1.00	1.00	1.00	1.00	1.00	*1.00*
Miscellaneous	Electricity	Btu.out/Wh.in	3.41	3.41	3.41	3.41	3.41	*1.00*
	Natural gas	Index 1990 = 1	1.00	1.00	1.00	1.00	1.00	*1.00*
	Oil	Index 1990 = 1	1.00	1.00	1.00	1.00	1.00	*1.00*
Lighting	0-1 hrs	Index 1990 = 1	1.00	1.00	1.00	1.00	1.00	*1.00*
	1-2 hrs	Index 1990 = 1	1.00	1.00	1.00	1.00	1.00	*1.00*
Usage level	2-3 hrs	Index 1990 = 1	1.00	1.00	1.00	1.00	1.00	*1.00*
	3-4 hrs	Index 1990 = 1	1.00	1.00	1.00	1.00	1.00	*1.00*
	4+ hrs	Index 1990 = 1	1.00	1.00	1.00	1.00	1.00	*1.00*
	Flourescent	Index 1990 = 1	1.00	1.00	1.00	1.00	1.00	*1.00*

(1) Source: EPRI REEPS 2.1 Model with LBNL Data, using input assumptions from Table A.1.
(2) Efficiencies are based on U.S. government test procedures.
(3) kWh.th = thermal kWh; kWh.e = electric kWh; Btu.th = thermal Btu; Btu.f = fuel Btu
(4) SEER = Seasonal Energy Efficiency Ratio, AFUE = Annual Fuel Utilization Efficiency, HSPF = Heating Seasonal Performance Factor.
(5) Freezer, refrigerator, water heat, dishwasher, clothes washer, dryer end-uses are modeled using a specific technology efficiency model.
(6) For Lighting, Cooking, and Miscellaneous end-uses, efficiencies are normalized, effectively removing efficiency analysis from modeling.
(7) For HVAC, "New" represents new equipment in new homes; for appliances, "New" represents new equipment in new and existing homes.

Table A.6.a: Capacity of Equipment in Existing Homes

End-Use	*Equipment Type*	*Units*	*1990*	*1995*	*2000*	*2005*	*2010*	*Index 1990 = 1.0 2010/1990*
			Equipment Capacity					
Heating	Elec Furnace	kBtu/h	43	43	43	43	44	*1.01*
	Gas Furnace	kBtu/h	82	80	78	77	75	*0.91*
	LPG Furnace	kBtu/h	77	75	73	71	70	*0.91*
	Oil Furnace	kBtu/h	96	95	94	94	93	*0.97*
	Elec Heat Pump	kBtu/h	32	32	31	31	31	*0.98*
	Gas Boiler	kBtu/h	74	74	75	75	75	*1.00*
	Oil Boiler	kBtu/h	91	91	90	90	90	*0.99*
	Elec Room	kBtu/h	39	39	39	39	39	*1.00*
	Gas Room	kBtu/h	39	39	39	39	39	*1.01*
	Other (wood)	kBtu/h	34	34	34	34	33	*0.99*
Cooling	Central AC	kBtu/h	24	23	23	23	23	*0.97*
	Elec Heat Pump	kBtu/h	24	23	24	24	24	*1.02*
Freezers	Electricity	cubic ft	27	25	24	24	23	*0.88*
Refrigerators	Electricity	cubic ft	20	20	21	21	21	*1.07*
Water Heat	Electricity	normalized	1	1	1	1	1	*1.00*
	Natural gas	normalized	1	1	1	1	1	*1.00*
	Oil	normalized	1	1	1	1	1	*1.00*
Dishwasher	Electricity	normalized	1	1	1	1	1	*1.00*
Clothes Washer	Electricity	normalized	1	1	1	1	1	*1.00*
Dryer	Electricity	normalized	1	1	1	1	1	*1.00*
	Natural gas	normalized	1	1	1	1	1	*1.00*
Cooking	Electricity	normalized	1	1	1	1	1	*1.00*
	Natural gas	normalized	1	1	1	1	1	*1.00*
	Oil	normalized	1	1	1	1	1	*1.00*
Miscellaneous	Electricity	normalized	1	1	1	1	1	*1.00*
	Natural gas	normalized	1	1	1	1	1	*1.00*
	Oil	normalized	1	1	1	1	1	*1.00*
Lighting	0-1 hrs	normalized	1	1	1	1	1	*1.00*
	1-2 hrs	normalized	1	1	1	1	1	*1.00*
Usage level	2-3 hrs	normalized	1	1	1	1	1	*1.00*
	3-4 hrs	normalized	1	1	1	1	1	*1.00*
	4+ hrs	normalized	1	1	1	1	1	*1.00*
	Flourescent	normalized	1	1	1	1	1	*1.00*

(1) Source: EPRI REEPS 2.1 Model with LBNL Data, using input assumptions from Table A.1.
(2) Water heat, dishwasher, clothes washer, dryer, cooking, miscellaneous, and lighting end-use capacities are treated using an indexed approach, effectively removing capacity from modeling consideration.

Table A.6.b: Capacity of New Equipment								
End-Use	*Equipment Type*	*Units*	Equipment Capacity *1991*	*1995*	*2000*	*2005*	*2010*	*Index 1991 = 1.0 2010/1991*
Heating	Elec Furnace	kBtu/h	43	44	44	44	43	*1.00*
	Gas Furnace	kBtu/h	77	75	73	73	73	*0.95*
	LPG Furnace	kBtu/h	68	66	66	67	69	*1.02*
	Oil Furnace	kBtu/h	94	93	92	92	94	*0.99*
	Elec Heat Pump	kBtu/h	31	32	31	31	31	*0.99*
	Gas Boiler	kBtu/h	74	75	75	75	75	*1.02*
	Oil Boiler	kBtu/h	90	90	90	90	92	*1.02*
	Elec Room	kBtu/h	39	39	39	39	39	*1.00*
	Gas Room	kBtu/h	39	39	39	40	40	*1.03*
	Other (wood)	kBtu/h	33	33	33	33	33	*1.00*
Cooling	Central AC	kBtu/h	23	23	23	23	23	*1.01*
	Elec Heat Pump	kBtu/h	23	23	24	24	24	*1.03*
Freezers	Electricity	cubic ft	23	23	23	23	23	*1.00*
Refrigerators	Electricity	cubic ft	21	21	21	21	21	*1.00*
Water heat	Electricity	normalized	1	1	1	1	1	*1.00*
	Natural gas	normalized	1	1	1	1	1	*1.00*
	Oil	normalized	1	1	1	1	1	*1.00*
Dishwasher	Electricity	normalized	1	1	1	1	1	*1.00*
Clothes washer	Electricity	normalized	1	1	1	1	1	*1.00*
Dryer	Electricity	normalized	1	1	1	1	1	*1.00*
	Natural gas	normalized	1	1	1	1	1	*1.00*
Cooking	Electricity	normalized	1	1	1	1	1	*1.00*
	Natural gas	normalized	1	1	1	1	1	*1.00*
	Oil	normalized	1	1	1	1	1	*1.00*
Miscellaneous	Electricity	normalized	1	1	1	1	1	*1.00*
	Natural gas	normalized	1	1	1	1	1	*1.00*
	Oil	normalized	1	1	1	1	1	*1.00*
Lighting	0-1 hrs	normalized	1	1	1	1	1	*1.00*
	1-2 hrs	normalized	1	1	1	1	1	*1.00*
Usage level	2-3 hrs	normalized	1	1	1	1	1	*1.00*
	3-4 hrs	normalized	1	1	1	1	1	*1.00*
	4+ hrs	normalized	1	1	1	1	1	*1.00*
	Flourescent	normalized	1	1	1	1	1	*1.00*

(1) Source: EPRI REEPS 2.1 Model with LBNL Data, using input assumptions from Table A.1.
(2) Water heat, dishwasher, clothes washer, dryer, cooking, miscellaneous, and lighting end-use capacities are treated using an indexed approach, effectively removing capacity from modeling consideration.
(3) For HVAC, "New" represents new equipment in new homes; for appliances, "New" represents new equipment in new and existing homes.

Table A.7.a: Unit Energy Consumption of Equipment in Existing Homes								
End-Use	*Equipment Type*	*Units*	Equipment UECs (Site Energy) *1990*	*1995*	*2000*	*2005*	*2010*	*Index 1990 = 1.0 2010/1990*
Heating	Elec Furnace	kWh/Year	6159	6423	6637	6721	6762	*1.10*
	Gas Furnace	MMBtu/Year	67	66	66	64	63	*0.94*
	LPG Furnace	MMBtu/Year	41	42	41	40	40	*0.97*
	Oil Furnace	MMBtu/Year	67	68	67	66	66	*0.98*
	Elec Heat Pump	kWh/Year	4968	4886	4851	4831	4821	*0.97*
	Gas Boiler	MMBtu/Year	81	79	79	77	78	*0.96*
	Oil Boiler	MMBtu/Year	90	92	91	90	90	*1.00*
	Elec Room	kWh/Year	7768	8191	8540	8702	8795	*1.13*
	Gas Room	MMBtu/Year	38	38	38	37	37	*0.97*
	Other (wood)	MMBtu/Year	17	17	18	18	18	*1.07*
Cooling	Central AC	kWh/Year	2338	2234	2176	2111	2067	*0.88*
	Elec Heat Pump	kWh/Year	2472	2417	2394	2368	2362	*0.96*
Freezers	Electricity	kWh/Year	1027	847	685	566	510	*0.50*
Refrigerators	Electricity	kWh/Year	1273	1056	884	779	724	*0.57*
Water heat	Electricity	kWh/Year	4292	3902	3253	2879	2654	*0.62*
	Natural gas	MMBtu/Year	24	22	18	16	14	*0.58*
	Oil	MMBtu/Year	24	22	18	16	14	*0.58*
Dishwasher	Electricity	kWh/Year	178	178	178	179	179	*1.01*
Clothes washer	Electricity	kWh/Year	102	103	104	104	105	*1.03*
Dryer	Electricity	kWh/Year	920	905	894	887	883	*0.96*
	Natural gas	MMBtu/Year	4	4	4	4	4	*1.00*
Cooking	Electricity	kWh/Year	600	602	602	601	601	*1.00*
	Natural gas	MMBtu/Year	5	5	5	5	5	*1.01*
	Oil	MMBtu/Year	5	5	5	5	5	*1.00*
Miscellaneous	Electricity	kWh/Year	1092	1129	1165	1191	1213	*1.11*
	Natural gas	MMBtu/Year	5	5	5	6	6	*1.10*
	Oil	MMBtu/Year	5	5	5	5	5	*1.10*
Lighting	0-1 hrs	kWh/Year	126	128	129	130	132	*1.05*
	1-2 hrs	kWh/Year	189	192	194	196	198	*1.05*
Usage level	2-3 hrs	kWh/Year	157	160	162	163	165	*1.05*
	3-4 hrs	kWh/Year	220	223	226	228	230	*1.05*
	4+ hrs	kWh/Year	628	638	646	653	658	*1.05*
	Flourescent	kWh/Year	156	157	158	160	161	*1.03*
	Total	kWh/Year	1475	1498	1515	1530	1543	*1.05*
Secondary Heating	Wood Stove	MMBtu/Year	19	20	20	20	20	*1.03*
Secondary Cooling	Room AC	kWh/Year	759	788	818	835	848	*1.12*

(1) Source: EPRI REEPS 2.1 Model with LBNL Data, using input assumptions from Table A.1.
(2) Dishwasher UEC pertains to motor, dryer, and heater only.
(3) Clothes washer UEC pertains to motor only.
(4) Incandescent lighting UECs are weighted by bulb fraction (market share) to obtain true operating UEC.
(5) Flourescent UEC not differentiated by housetype and influenced by floor area.
(6) Incandescent UEC differentiated by housetype and influenced by floor area.
(7) For fuel fired heating equipment with ducted or hydronic distribution systems, fan or pump electricity is assumed to be contained in miscellaneous. Electric furnaces, HP, and CAC have fan energy included in the UEC.

Table A.7.b: Unit Energy Consumption of New Equipment

End-Use	*Equipment Type*	*Units*	Equipment UECs (Site Energy) *1991*	*1995*	*2000*	*2005*	*2010*	*Index 1991 = 1.0 2010/1991*
Heating	Elec Furnace	kWh/Year	5680	5895	6052	6144	6187	*1.09*
	Gas Furnace	MMBtu/Year	47	48	50	49	50	*1.06*
	LPG Furnace	MMBtu/Year	24	25	26	26	26	*1.07*
	Oil Furnace	MMBtu/Year	38	40	40	40	41	*1.08*
	Elec Heat Pump	kWh/Year	4337	4506	4371	4376	4315	*0.99*
	Gas Boiler	MMBtu/Year	57	59	60	59	60	*1.06*
	Oil Boiler	MMBtu/Year	64	67	67	68	68	*1.06*
	Elec Room	kWh/Year	7268	7528	7466	7513	7489	*1.03*
	Gas Room	MMBtu/Year	25	25	26	26	27	*1.09*
	Other (wood)	MMBtu/Year	19	19	19	20	20	*1.04*
Cooling	Central AC	kWh/Year	1855	1792	1780	1799	1797	*0.97*
	Elec Heat Pump	kWh/Year	2291	2249	2156	2156	2119	*0.93*
Freezers	Electricity	kWh/Year	598	475	475	475	475	*0.79*
Refrigerators	Electricity	kWh/Year	864	689	689	689	689	*0.80*
Water heat	Electricity	kWh/Year	3825	3583	3086	2813	2639	*0.69*
	Natural gas	MMBtu/Year	20	20	17	15	14	*0.68*
	Oil	MMBtu/Year	21	19	16	15	13	*0.65*
Dishwasher	Electricity	kWh/Year	172	174	176	178	178	*1.04*
Clothes washer	Electricity	kWh/Year	102	103	104	104	105	*1.02*
Dryer	Electricity	kWh/Year	859	867	873	876	877	*1.02*
	Natural gas	MMBtu/Year	4	4	4	4	4	*1.02*
Cooking	Electricity	kWh/Year	599	600	593	592	590	*0.98*
	Natural gas	MMBtu/Year	5	5	5	5	5	*0.99*
	Oil	MMBtu/Year	5	5	5	5	5	*1.00*
Miscellaneous	Electricity	kWh/Year	1181	1209	1178	1191	1195	*1.01*
	Natural gas	MMBtu/Year	5	5	5	5	6	*1.09*
	Oil	MMBtu/Year	0	0	0	0	0	-
Lighting	0-1 hrs	kWh/Year	128	129	124	123	122	*0.95*
	1-2 hrs	kWh/Year	192	194	185	185	183	*0.95*
Usage level	2-3 hrs	kWh/Year	160	162	154	154	153	*0.95*
	3-4 hrs	kWh/Year	224	226	216	216	214	*0.95*
	4+ hrs	kWh/Year	641	647	618	616	611	*0.95*
	Flourescent	kWh/Year	156	157	158	160	161	*1.03*
	Total	kWh/Year	1502	1515	1456	1453	1444	*0.96*

(1) Source: EPRI REEPS 2.1 Model with LBNL Data, using input assumptions from Table A.1.
(2) Dishwasher UEC pertains to motor, dryer, and heater only.
(3) Clothes washer UEC pertains to motor only.
(4) Incandescent lighting UECs are weighted by bulb fraction (market share) to obtain true operating UEC.
(5) Flourescent UEC not differentiated by housetype and influenced by floor area.
(6) Incandescent UEC differentiated by housetype and influenced by floor area.
(7) For HVAC, "New" represents new equipment in new homes; for appliances, "New" represents new equipment in new and existing homes.
(8) For fuel fired heating equipment with ducted or hydronic distribution systems, fan or pump electricity is assumed to be contained in miscellaneous. Electric furnaces, HP, and CAC have fan energy included in the UEC.

Table A.8: Energy Used by Stock Equipment (Primary Energy, Trillion Btu)							
							Index
	Equipment			Primary Energy Consumption			*1990 = 1.0*
End-Use	*Type*	*1990*	*1995*	*2000*	*2005*	*2010*	*2010/1990*
Heating	Elec Furnace	514	558	609	652	692	*1.35*
	Gas Furnace	2358	2491	2667	2754	2892	*1.23*
	LPG Furnace	183	190	190	190	189	*1.03*
	Oil Furnace	316	320	310	305	300	*0.95*
	Elec Heat Pump	323	386	460	535	612	*1.89*
	Gas Boiler	663	631	619	597	590	*0.89*
	Oil Boiler	512	528	518	514	508	*0.99*
	Elec Room	683	710	740	758	771	*1.13*
	Gas Room	320	306	301	289	284	*0.89*
	Other (wood)	99	100	102	102	103	*1.05*
Cooling	Central AC	787	816	867	908	955	*1.21*
	Elec Heat Pump	161	191	227	262	300	*1.86*
Freezers	Electricity	366	289	228	184	163	*0.45*
Refrigerators	Electricity	1512	1301	1136	1042	1008	*0.67*
Water heat	Electricity	1662	1671	1566	1558	1602	*0.96*
	Natural gas	1309	1167	952	814	723	*0.55*
	Oil	124	111	90	76	68	*0.54*
Dishwasher motor/dryer/heater	Electricity	83	96	111	126	140	*1.68*
Clothes washer motor	Electricity	80	86	92	98	104	*1.29*
Dryer	Electricity	500	547	597	647	696	*1.39*
	Natural gas	59	62	66	69	73	*1.23*
Cooking	Electricity	338	362	388	414	441	*1.30*
	Natural gas	182	184	186	188	191	*1.05*
	Oil	27	27	26	26	26	*0.98*
Miscellaneous	Electricity	1085	1166	1258	1342	1426	*1.31*
	Natural gas	14	15	16	17	17	*1.23*
	Oil	3	3	3	3	3	*0.96*
Lighting	0-1 hrs	130	137	145	152	160	*1.23*
	1-2 hrs	195	205	217	229	240	*1.23*
Usage level	2-3 hrs	162	171	181	190	200	*1.23*
	3-4 hrs	227	239	253	267	280	*1.23*
	4+ hrs	649	684	723	762	801	*1.23*
	Flourescent	161	168	177	186	195	*1.21*
	Total	1524	1605	1696	1786	1877	*1.23*
Secondary Heating	Wood Stove	73	80	83	85	87	*1.19*
Secondary Cooling	Room AC	231	242	254	262	268	*1.16*
Total	Electricity	9850	10025	10229	10573	11054	*1.12*
	Natural Gas	4905	4856	4806	4728	4770	*0.97*
	Oil	983	989	948	926	906	*0.92*
	LPG	183	190	190	190	189	*1.03*
	Wood	172	179	185	187	190	*1.11*
	Total Primary Energy	16093	16240	16359	16604	17109	*1.06*

(1) Source: EPRI REEPS 2.1 Model with LBNL Data, using input assumptions from Table A.1.
(2) Primary Energy conversion (electricity) is calculated using a factor of 3.22 kWh primary energy to 1 kWh site electricity.
(3) Wood total includes Heating OTHER in addition to secondary heating (wood stove).

APPENDIX B: MODIFICATIONS TO THE HVAC MODULE OF THE REEPS 2.1 MODEL

This appendix summarizes LBNL's changes to the HVAC module of the REEPS 2.1 model since the detailed report on the HVAC component of REEPS (Johnson et al, 1994) was published.

1) REEPS input screen HV4a: Changed zero values on new home HVAC system shares to the smallest possible input value (0.01). This screen represents control-year data for new home choice (see Table H.11 in REEPS HVAC report.) If a zero is entered for control-year data, and if components of this system are available in the first year, then a large negative constant adjustment is assigned in the calibration process. This large negative calibration constant was avoided by changing the zero values to the smallest possible input values.

2) REEPS input screens HV-3c.3 and HV-3c.6: Added "HOMESIZE" to stove and room AC (secondary heating and cooling) usage equations. Heat Loss Multipliers and Heat Gain Multipliers were previously included in the equations and are intended to be accompanied by a home size variable, which was added.

3) REEPS input screens HV-6c.1 and HV-6c.2: Added "max" function to efficiency change equations for HVAC equipment (see Table 6.1 in REEPS HVAC report). Max function was used to ensure that the chosen efficiency level was in compliance with Federal efficiency standards.

4) Equipment Lifetimes and Vintage Blocks:

During forecasting runs, a discontinuity was discovered between assumed HVAC equipment lifetimes and vintage block shares, which required the re-estimation of HVAC equipment lifetimes. Previous HVAC equipment lifetimes (from Table 4.2 of REEPS HVAC report (Johnson et al. 1994)) could not account for the pre-1971 vintage shares for most heating and cooling end-uses. With 1990 as the base year, a non-zero pre-1971 vintage share presumes an equipment lifetime of at least 21 years. With an equipment lifetime of less than 21 years, the pre-1971 vintage is replaced en masse in the first forecast year, resulting in a replacement spike. The severity of the replacement spike is dependent upon the magnitude of the pre-1971 vintage shares.

The approach taken with appliance end-uses (Hwang et al. 1994) was to modify equipment lifetimes so that equipment shipments in the first forecast year were consistent with historical data from Hanford et al. (1994). This benchmarking approach was emulated for heating and cooling end-uses to resolve the inconsistency between lifetimes and vintages. and the resulting lifetimes are shown in **Table B.1**.

The effect of revising equipment lifetimes is seen most clearly through changes in equipment shipments. The wholesale replacement of pre-1971 vintages in the forecast year resulted in large increases in shipments as old, less-efficient equipment was replaced. **Table 6.3** shows historical shipments, and projected shipments using the lifetimes from Johnson et al. and using the revised lifetimes in Table B.1. It is evident that the previous replacement spike in the first forecast year, brought about by premature equipment lifetimes, is now significantly reduced, though it was not possible to exactly match historical shipments in all cases.

Table B.1: Lifetimes for HVAC equipment, old and modified

HVAC Equipment Type	Johnson et al. Minimum Lifetime	Johnson et al. Maximum Lifetime	New Minimum Lifetime	New Maximum Lifetime
Elec Furnace	20	30	20	30
Gas Furnace	15	20	20	30
LPG Furnace	15	20	20	30
Oil Furnace	15	20	20	30
Elec Heat Pump	10	15	10	17
Gas Boiler	20	30	20	30
Oil Boiler	20	30	20	30
Elec Room	15	20	20	30
Gas Room	15	20	20	30
Other	15	20	20	30
Central AC	11	16	18	23

Table B.2: Historical and forecasted shipments

Year Source Units	1990 Historical shipments millions	1991 Old REEPS total purchases millions	1991 New REEPS total purchases millions
Elec Furn	0.3	0.23	0.23
Gas Furn	2	10.98	2.25
LPG Furn	-	0.76	0.17
Oil Furn	0.15	1.77	0.31
Elec Heat Pump	0.7	0.83	0.72
Gas Boil	0.2	0.62	0.62
Oil Boil	0.1	0.47	0.47
Elec Room	-	2.64	0.46
Gas Room	0.4	4.10	0.70
Other	-	0.79	0.13
CAC	2.5	4.97	2.55
Elec Heat Pump	0.7	0.71	0.72

(1) Old REEPS purchases are based on a forecast using the lifetimes from Johnson et al. (1994), while New REEPS purchases are based on a forecast using the lifetimes in Table B.1

APPENDIX C: DECISION MODEL TABLES

The following four tables describe the various components of the decision models in REEPS.

Table C.1: New Home Choice Decision Model Variables, by End-Use

Table C.2: Efficiency Choice Decision Model Variables, by End-Use

Table C.3: Equipment Capacity Choice Decision Model Variables, by End-Use

Table C.4: Equipment Usage Decision Model Variables, by End-Use

Table C.1: New Home Choice Decision Model Variables, by End-Use[8]

End-Uses	Variables	Definition
Heating (specific system)	HCAPCOST DISTCOST HOPCOST	Installed heating equipment cost Distribution system cost Heating equipment operating cost
Cooling (system type)	CCAPCOST COPCOST CDD DISCOUNT INCOME LOGSUM	Installed cooling equipment cost Cooling equipment operating cost Cooling degree days Discount rate Average household disposable income, by housing type Inclusive term which implements nested logit structure
Secondary Heating	CONST	multiplier of one, equivalent to constant market share
Secondary Cooling	AVGEL INCOME HHSIZE	Average price of electricity Average household disposable income, by housing type Average number of household members, by house type
Thermal Shell Choice	HEATPVOC COOLPVOC SHELCOST	Present value of heating equipment operating cost Present value of cooling equipment operating cost Thermal shell cost
Freezers	AVINC HHSIZE RURAL AVGEL	Average household disposable income Average number of household members, by housing type Share of rural households in the total population (average) Average electricity price
Refrigerators[9]	INCOME HHSIZE PVOC	Average household disposable income, by housing type Average number of household members, by housing type Present Value of Operating Cost
Water Heat	CAPCOST OPCOST	Installed appliance cost Operating cost
Dishwasher	INCOME HHSIZE NHRRL AVGEL	Average household disposable income, by housing type Average number of household members, by housing type Share of rural new homes Average electricity price
Clothes Washer	INCOME HHSIZE YEAR-1987	Average household disposable income, by housing type Average number of household members, by housing type Year index
Dryer	LCC INCOME HHSIZE	Life-Cycle Cost Average household disposable income, by housing type Average number of household members, by housing type
Cooking	LCC	Life-Cycle Cost
Misc.	-	
Lighting	-	

[8] Replacement decisions for all end-uses are assumed to be 100% replacement with the same generic technology, except for freezers and water heaters, which have separate replacement equations.

[9] This decision model applies to a 2nd refrigerator purchase, all new homes are assumed to contain a refrigerator.

Table C.2: Efficiency Choice Decision Model Variables, by End-Use

End-Uses	Variables	Definition
Heating (specific system)	PRICE Exog. Efficiency	Price of fuel used by heating equipment type Result of off-line efficiency choice modeling
Cooling (system type)	PRICE Exog. Efficiency	Price of fuel used by cooling equipment type Result of off-line efficiency choice modeling
Freezers	LCC PVOC OPCOST	Life-Cycle Cost Present value of operating cost Operating cost
Refrigerators	LCC PVOC OPCOST	Life-Cycle Cost Present value of operating cost Operating cost
Water Heat	LCC PVOC OPCOST	Life-Cycle Cost Present value of operating cost Operating cost
Dishwasher	LCC PVOC OPCOST WHEFFE SEWH AVGEL WHEFFG PGAS	Life-Cycle Cost Present value of operating cost Operating cost Electric water heat efficiency Electric water heater saturation Price of electricity Gas water heater efficiency Price of natural gas
Clothes Washer	LCC PVOC OPCOST WHEFFE SEWH AVGEL WHEFFG PGAS	Life-Cycle Cost Present value of operating cost Operating cost Electric water heat efficiency Electric water heater saturation Price of electricity Gas water heater efficiency Price of natural gas
Dryer	LCC PVOC OPCOST	Life-Cycle Cost Present value of operating cost Operating cost
Cooking	-	efficiency choice not modeled
Misc.	-	efficiency choice not modeled
Lighting	-	efficiency choice not modeled

Table C.3: Equipment Capacity Choice Decision Model Variables, by End-Use

End-Uses	Variables	Definition
Heating (specific system)	HOUSETYPE HOMESIZE HLM	Housing type Floor area, by housing type Heat Load Multiplier
Cooling (system type)	HOUSETYPE HOMESIZE HGM	House Type Floor Area, by housing type Heat Gain Multiplier
Freezers	-	Determined by specific efficiency choice
Refrigerators	-	Determined by specific efficiency choice
Water Heat	normalized	
Dishwasher	normalized	
Clothes Washer	normalized	
Dryer	normalized	
Cooking	normalized	
Misc.	normalized	
Lighting	normalized	

Table C.4: Equipment Usage Decision Model Variables, by End-Use

End-Uses	Variables	Definition
Heating (specific system)	HOMESIZE	Floor area, by housing type
	HLM	Heat Load Multiplier
	EFFIC	Efficiency of heating equipment type
	PRICE	Price of fuel used by heating equipment type
	INCOME	Average household disposable income, by housing type
	HHSIZE	Average number of household members, by housing type
Cooling (system type)	HOMESIZE	Floor area, by housing type
	HGM	Heat Gain Multiplier
	EFFIC	Efficiency of cooling equipment type
	PRICE	Price of fuel used by cooling equipment type
	INCOME	Average household disposable income, by housing type
	HHSIZE	Average number of household members, by housing type
Secondary Heating	HLM	Heat Load Multiplier
	HOMESIZE	Floor area, by housing type
	PRICE	Price of fuel used by heating equipment type
	INCOME	Average household disposable income, by housing type
	HHSIZE	Average number of household members, by housing type
Secondary Cooling	HGM	Heat Gain Multiplier
	HOMESIZE	Floor area, by housing type
	PRICE	Price of fuel used by cooling equipment type
	INCOME	Average household disposable income, by housing type
	HHSIZE	Average number of household members, by housing type
Freezers	-	Usage is constant
Refrigerators	-	Usage is constant
Water Heat	SFLOW	Stock average showerhead flow rate
	FFLOW	Stock average faucet flow rate
	INCOME	Average household disposable income, by housing type
	HHSIZE	Average number of household members, by housing type
	HWCW	Average clothes washer hot water load
	SHARE	Average saturation of electric or gas water heater
	CLTHWASH,OWN	Variable for clothes washer ownership
	HWDW	Average dish washer hot water load
	DISHWASH,OWN	Variable for dishwasher ownership
	EFFIC	Efficiency of electric or gas water heater
Dishwasher	INCOME	Average household disposable income, by housing type
	HHSIZE	Average number of household members, by housing type
Clothes Washer	INCOME	Average household disposable income, by housing type
	HHSIZE	Average number of household members, by housing type
Dryer	INCOME	Average household disposable income, by housing type
	HHSIZE	Average number of household members, by housing type
Cooking	HHSIZE	Average number of household members, by housing type
Misc.	INCOME	Average household disposable income, by housing type
	FLAREA	Floor area of residential housing stock
Lighting	FLAREA	Floor area of residential housing stock

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