DOE/EIA-M067(2000)

Model Documentation Report: Residential Sector Demand Module of the National Energy Modeling System

December 1999

Office of Integrated Analysis and Forecasting
Energy Information Administration
U.S. Department of Energy
Washington, DC

Update Information

This is the sixth edition of the *Model Documentation Report: Residential Sector Demand Module of the National Energy Modeling System (NEMS).* It reflects changes made to the module over the past year for the *Annual Energy Outlook 2000*.

Changes to the model over the past year include the following: specific technology data (cost, performance, year of availability) were updated to reflect current market status; shell efficiency indexes were updated to reflect the current status of building codes and standards; base year data for appliance stocks and end use intensities have been updated to 1997, the most current year for EIA's Residential Energy Consumption Survey (RECS); a new sub-module was created to include the effects of distributed generation technologies; a new sub-module was created to advance the availability of efficient technologies due to large increases in fuel prices.

Table of Contents

Tables

Figures

1. Introduction

Purpose of this Report

This report documents the objectives, analytical approach, and development of the National Energy Modeling System (NEMS) Residential Sector Demand Module. The report catalogues and describes the model assumptions, computational methodology, parameter estimation techniques, and FORTRAN source code.

This document serves three purposes. First, it is a reference document that provides a detailed description for energy analysts, other users, and the public. Second, this report meets the legal requirement of the Energy Information Administration (EIA) to provide adequate documentation in support of its statistical and forecast reports according to Public Law 93-275, section 57(b)(1). Third, it facilitates continuity in model development by providing documentation from which energy analysts can undertake model enhancements, data updates, and parameter refinements.

Model Summary

The NEMS Residential Sector Demand Module is currently used for mid-term forecasting purposes and energy policy analysis over the forecast horizon of 1997 through 2020. The model generates forecasts of energy demand, which is used interchangeably with the concept of energy consumption in this document, for the residential sector by service, fuel, and Census Division. The policy impacts that result from the introduction of new technologies, market incentives, and regulatory changes can be estimated using the module, by the user who defines alternative input and parameter assumptions.

The Residential Sector Demand Module uses inputs from the NEMS system to generate outputs needed in the NEMS integration process. The inputs required by the Residential

Sector Demand Module from the NEMS system include energy prices and macroeconomic indicators. These inputs are used by the module to generate energy consumption by fuel type and Census Division in the residential sector. The NEMS system uses these forecasts to compute equilibrium energy prices and quantities.

The Residential Sector Demand Module is an analysis tool to address current and proposed legislation, private sector initiatives, and technological developments that affect the residential sector. Examples of policy analyses include assessing the potential impacts of the following:

- New end-use technologies (such as natural gas heat pumps)
- Changes in fuel prices due to tax policies
- Changes in equipment energy efficiency standards
- Financial incentives for energy efficiency investments
- Financial incentives for renewable energy investments

Archival Media

The Residential Sector Demand Module has been archived as part of the NEMS production runs that generate the Annual Energy Outlook 2000 (AEO2000) on the EIA IBM RS-6000 workstation.

Model Contact

John H. Cymbalsky
Office of Integrated Analysis and Forecasting
Demand and Integration Division
Phone: (202) 586 - 4815

NEMS Residential Sector Demand Module Structure

The residential sector encompasses residential housing units classified as single-family, multifamily, and mobile homes. Energy consumed in residential buildings is the sum of energy required to provide specific energy services that use selected technologies according to energy efficiency levels of building structures. The Residential Sector Demand Module projects energy demand following a sequence of five steps. The first step is to forecast housing stock. The second step is to select specific technologies to meet the demand for each energy service. The third step is to forecast appliance stocks. The fourth step is to forecast changes in building shell integrity. The fifth step is to calculate the energy consumed by the equipment chosen to meet the demand for energy services.

Housing Stock Component

The Housing Stock Component forecasts numbers of occupied households by housing type and Census Division. Forecasted housing starts are input from the NEMS Macroeconomic Activity Module (MAM). The housing stock is assumed to retire based on set proportions consistent with available housing demolition data. The housing stock retirement assumptions are presented in the Fundamental Assumptions section of this report.

Technology Choice Component

The Technology Choice Component simulates the behavior of residential consumers based on the relative importance of life-cycle costs, capital costs, and operating costs of competing technologies within a service. New and replacement equipment decisions reflect additional factors beyond the traditional life-cycle cost methodology, including main space heating fuel choice and previous equipment choices. The Technology Choice Component allocates end-use services based upon a defined equipment menu of the various technologies and fuels that compete in the market. The Technology Choice Component also establishes the criteria upon which consumers base equipment choices. A new concept, *price induced technology change*, advances the year of availability of efficient technologies if fuel prices increase and remain high over a multi-year period.

Appliance Stock Component

The Appliance Stock Component forecasts the number of appliances required by each end-use service. A piecewise linear decay function retires equipment based on minimum and maximum life expectancies. The Appliance Stock Component tracks each type of equipment purchased for new households and replacement units.

Shell Integrity Component

The Residential Sector Demand Module monitors the changes in building shell integrity for the space conditioning services. The Shell Integrity Component computes an index that incorporates increases in existing building shell efficiency based upon responses to fuel price changes from the base year. Building shell efficiency in new and existing housing is assumed to improve over the forecast period because of stricter building codes and other efficiency programs.

Distributed Generation Component

The Distributed Generation Component allows fuel cells and solar photovoltaic systems compete for on-site electricity generation. Through the use of a cash-flow formulation, the penetration rates of these systems are computed. Electricity generated from these systems is deducted from total household use, or sold back to the grid, if feasible.

Consumption and Unit Energy Consumption Component

The Consumption and Unit Energy Consumption Component tracks the composition of residential energy use over time as technological advances in residential equipment are introduced to the market. The component includes price elasticities that allow the user to specify consumer responses to changes in real fuel prices. Unit Energy Consumption (UEC) values are adjusted according to heating and cooling degree-day factors and household size.

A new concept called the ``rebound effect'' accounts for the fact that increasing equipment efficiency for a particular equipment class causes a corresponding change (normally, a decrease) in the price elasticity for the class.

Report Organization

Chapter 2 of this report discusses the purpose of the Residential Sector Demand Module, with specific details on the objectives, primary inputs and outputs, and relationship of the module to other modules of the NEMS system. Chapter 3 describes the rationale behind the design, fundamental assumptions regarding consumer behavior, module structure, and alternative modeling approaches. Chapter 4 reviews the key computations and data flows.

Appendices to this report document the variables and equations contained in the FORTRAN source code. Appendix A catalogues the input data used to generate estimates and forecasts in list and cross-tabular formats. Appendix B provides support to the mathematical representation of the source code equations provided in Chapter 4 of the main text. Appendix C is a bibliography of reference materials used in the development process. Appendix D consists of a model abstract. Appendix E discusses the data quality issues. Appendix F details the model sensitivities for some of the more important variables affecting residential energy consumption.

2. Model Purpose

Module Objectives

The NEMS Residential Sector Demand Module holds three fundamental objectives. First, the module generates disaggregated forecasts of energy demand in the residential sector for the period of 1997 through 2020 by housing and fuel type, Census Division, and end-use service. Second, it is a policy analysis tool that can assess the impacts of changes in energy markets, building and equipment technologies, and regulatory initiatives that affect the residential sector. Third, as an integral component of the NEMS system, it provides inputs to the Electricity Market Module, Natural Gas Supply Module, and Petroleum Market Module of NEMS, contributing to the calculation of the overall energy supply and demand balance.

The Residential Sector Demand Module projects residential sector energy demands in five sequential steps. These steps produce information on housing stocks, technology choices, appliance stocks, building shell integrity, and energy consumption. The module uses a stock-vintaging approach that allows the user to monitor equipment stock and equipment efficiency over time.

The module design allows the user to conduct a variety of policy analyses. Technological advancement in equipment design and efficiency, as well as first-cost incentive programs, are representable at the equipment level. Housing stock attrition and equipment retirement assumptions can be modified to model the accelerated decay of less-efficient energy-using equipment. Building shell characteristics can be modified to model policy options including updates to building codes and market penetration of energy-efficient mortgages.

Forecasted residential fuel demands generated by the Residential Sector Demand Module are used by the NEMS system in the calculation of the demand and supply equilibrium state. In addition, the NEMS supply modules referenced previously use the residential sector outputs to determine the patterns of consumption and the resulting amounts of energy delivered to the residential sector.

Module Input and Output

Inputs

The primary module inputs include fuel prices, housing stock characteristics, housing starts, population, and technology characteristics. The technology characteristics used in the module include installed capital costs, equipment efficiency, and expected equipment lifetimes. The major inputs by module component are as follows:

Housing Stock Component

- Housing starts
- Existing housing stock for 1997
- Housing stock attrition rates
- Housing floor area trends (new and existing)

Technology Choice Component

- Equipment capital cost
- Equipment energy efficiency
- Market share of new appliances
- Efficiency of retiring equipment
- Appliance penetration factors

Appliance Stock Component

- Expected equipment minimum and maximum lifetimes
- Base year appliance market shares
- Equipment saturation level

Building Shell Component

Maximum level of shell integrity

Price elasticity of shell integrity

Rate of improvement in new and existing housing shell integrity

Distributed Generation Component

Equipment Cost

Equipment Efficiency

Solar Insolation Values

System Penetration Parameters

Energy Consumption Component

Unit energy consumption (UEC)

Heating and cooling degree days

Expected fuel savings based upon the 1992 Energy Policy Act (EPACT)

Population

Outputs

Forecasted residential sector energy consumption by fuel type, service, and Census Division is the primary module output. The module also forecasts housing stock, and energy consumption per household. In addition, the module can produce a disaggregated forecast of appliance stock and efficiency. The types of appliances included in this forecast are:

Heat pumps (electric air-source, natural gas, and ground-source)

Furnaces (electric, natural gas, LPG, and distillate)

Hydronic heating systems (natural gas, distillate, and kerosene)

Wood stoves

Air conditioners (central and room)

Dishwashers

Water heaters (electric, natural gas, distillate, LPG, and solar)

Ranges/Ovens (electric, natural gas, and LPG)

Clothes dryers (electric and natural gas)

Refrigerators

Freezers

Clothes Washers

Fuel Cells

Solar Photovoltaic Systems

Variable Classification

The NEMS modules are required to provide and use system data at the nine Census Division level of detail. The input data available from the Residential Energy Consumption Survey (RECS) performed by EIA (which forms the basis for the Residential Sector Demand Module) and other sources are designed to be statistically significant at various levels, some of which are above the nine Census Division level. Another factor that drives the level of aggregation of the module variables is the technical constraints of the computing system required in order to run the NEMS model within a reasonable turnaround time. The key variables in the NEMS Residential Sector Demand Module are dimensioned as follows:

Census Divisions

1 New England
2 Middle Atlantic
3 East North Central
4 West North Central
5 South Atlantic
6 East South Central
7 West South Central
8 Mountain
9 Pacific

Housing Types

1 Single-Family
2 Multifamily
3 Mobile Home

End-Use Services

1 Space Heating
2 Space Cooling
3 Clothes Washers
4 Dishwashers
5 Water Heating
6 Cooking
7 Clothes Drying
8 Refrigeration
9 Freezing
10 Lighting
11 Color TVs
12 Personal Computers
13 Furnace Fans
14 Other Appliances
15 Secondary Space Heating
16 Distributed Generation

Fuels

1 Distillate
2 LPG
3 Natural Gas
4 Electricity
5 Kerosene
6 Wood
7 Geothermal
8 Coal
9 Solar

Relationship to Other Models

The Residential Sector Demand Module uses data from the Macroeconomic Activity Module (MAM) of the NEMS system. MAM provides forecasted population and housing starts by Census Division and housing type. The Residential Sector Demand Module uses fuel price forecasts generated by the NEMS supply modules previously listed as key drivers to calculate operating costs for technology selections, building shell integrity improvements, and short-term behavioral responses. The NEMS supply modules use the residential sector outputs to determine the fuel mix and the resulting amount of energy delivered to the residential sector.

3. Model Rationale

Theoretical Approach

The NEMS Residential Sector Demand Module is an integrated dynamic modeling system that generates forecasts of residential sector energy demand, appliance stocks, and market shares. The modeling approach is based on accounting principles and addresses residential consumer behavior issues.

The Residential Sector Demand Module is a housing and equipment stock model. The stock of households and the corresponding energy consuming equipment are tracked for each year of the forecast. The housing stock changes each forecast year as houses are retired from the stock and new construction is added. The equipment stock changes each forecast year as appliances fail and are replaced, and new technologies enter the market. A log-linear function is used to estimate the market shares of competing technologies within each service category. Market shares are determined for new construction equipment decisions as well as for replacement decisions. The Technology Choice Component of the module weights the relative installed capital and operating costs of each equipment type to allocate the relative market share of the technology within the service, region, and housing type. This approach is implemented in new housing for the services of space heating, space cooling, clothes washers, dishwasers, water heating, cooking, clothes drying, food refrigeration, and food freezing. It is also implemented for replacement equipment in single family housing for space heating, heat pump air conditioning, water heating, cooking, and clothes drying. Lighting, color televisions, furnace fans, personal computers, distributed generation, and miscellaneous equipment choices are modeled based upon alternative technology assumptions discussed below.

Base year information developed from the 1997 RECS data base forms the foundation of modeling changes to the equipment and housing stock over the forecast period. Market share information from RECS is used to estimate the number and type of replacements and additions to the equipment stock. The choice between the capital cost and the first year's operating cost determines the market share within a given service. Market shares are also modeled as functions of the corresponding fuel prices, expected level of equipment usage, and equipment efficiency characteristics.

Building shell integrity is also considered in the forecast of end-use consumption. Building shell integrity in existing homes is sensitive to real price increases over base year price levels for space conditioning fuels. Final residential sector energy consumption is determined as a function of the equipment and housing stock, average unit energy consumption, weighted equipment characteristics, and building shell integrity improvements.

Fundamental Assumptions

The Residential Sector Demand Module assumes that the residential energy marketplace has the following characteristics:

- Equipment lifetime is limited by a minimum and maximum number of years. All equipment is assumed to survive a minimum number of years, and no equipment is assumed to survive beyond the maximum number of years. The equipment retirement rate is defined by a linear decay function.

- The equipment contained in a retiring housing structure is assumed to retire when the structure is removed from the housing stock. Zero salvage value for equipment is assumed.

- Space heaters, heat pump air conditioners, water heaters, stoves, and clothes dryers may be replaced (up to an input percentage) with competing technologies in single-family homes. Switching is based on a technology choice component, retail cost of new equipment, switching cost, and lifecycle cost.

- New housing stock building shell efficiency is assumed to improve throughout the forecast period at a specific rate defined by fuel, Census Division, and housing type.

- Life-cycle costs used in the technology cost calculations are computed over a 7-year time horizon and a discount rate of 20%.

- Two housing vintages are assumed: pre-1998 (old housing) and post-1997 (new housing).

- The type of fuel used for cooking and water heating in new housing units is assumed to be a function of the main space heating fuel in most cases. Exceptions to this assumption are included for specific cooking fuel decisions. It is assumed that roughly 65% of new housing units are equipped with natural gas cooking units, while natural gas is the main space heating fuel.

- The type of fuel used for cooking and water heating when replacing retiring equipment in single-family homes is based on an input percentage of those who may switch and a technology choice switching algorithm. Replacements are with the same technology in multifamily and mobile homes.

- Housing units are removed from the housing stock at a constant rate over time. The survival rates for housing stock types are assumed to be 99.7% for single-family homes, 99.6% for multifamily homes, and 96.6% for mobile homes.

- Projected new home heating fuel shares are based on the Census Bureau's new construction data and vary over time due to changes in life-cycle cost for each of the 11 heating system types.

Further Assumptions

Technology Choice

The efficiency choices made for residential equipment are based on a log-linear function. The functional form is flexible, to allow the user to specify parameters as either life-cycle costs, or as weighted of bias, capital and discounted operating costs. Currently, the module calculates choices based on the latter approach. A time dependant function calculates the installed capital cost of equipment in new construction based on logistic shape parameters. If fuel prices increase markedly and remain high over a multi-year period, efficient appliances will be available earlier in the forecast period than would have otherwise.

Climate Adjustment

Space conditioning usage is adjusted across Census Divisions by heating and cooling degree day factors to account for potential deviations from “normal" temperatures during the RECS 1997 survey performance period.

Technology Switching

Space heaters, heat pump air conditioners, water heaters, stoves, and clothes dryers may be replaced with competing technologies in single-family homes. The amount of equipment which may switch is based on a model input. The technology choice is based on a log-linear function. The functional form is flexible to allow the user to specify parameters, such as weighted bias, retail equipment cost, and technology switching cost. Replacements are with the same technology in multifamily and mobile homes. A time dependant function calculates the retail cost of replacement equipment based on logistic shape parameters.

Space Cooling: Room and Central Air Conditioning Units

Room and central air conditioning units are disaggregated based on existing housing data. The market penetration of room and central air systems by Census Division and housing type, along with new housing construction data, are used to determine the number of new units of each type. The penetration rate for central air-conditioning is estimated by means of time series analysis of RECS survey data.

Water Heating: Solar Water Heaters

Market shares for solar water heaters are tabulated from the 1997 RECS data base. The module currently assumes that solar energy provides 55% of the energy needed to satisfy hot water demand, and the remaining 45% is satisfied by an electric back-up unit.

Through-the-Door Refrigeration Units

A recent innovation in residential food refrigerators has been the advancement of through-the-door access panels for ice and water. This added convenience results in a greater energy use than conventional refrigerator models. The Residential Sector Demand Module assumes that 28% of all post-1997 refrigerators incorporate the through-the-door access feature, based upon recent appliance shipment data.[1]

Clothes Dryer Saturation

The module currently assumes that clothes dryer market penetration occurs over the forecast period, with a terminal saturation level that is consistent with the market penetration of clothes washers. This assumption is based upon analysis of the RECS data base.

Clothes Washers

The module links clothes washer choice to the water heating service. This is a vital link since many efficiency features for clothes washers act to cut the demand for hot water.

Color Televisions and Personal Computers

The module accounts for these fast growing electronic devices based on saturation data from RECS and assumptions about future growth in the respective categories.

Furnace Fans

Furnace fan energy consumption is determined by the number of households that have central forced-air heating. The relative size of heating and cooling degree-days also affects the amount of energy used for this service.

Other Appliances

The consumption of other appliances by Census Division is calculated by multiplying the sum of new and existing housing units by Unit Energy Consumption (UEC), housing type, and Census Division.

Secondary Heating

The consumption of secondary heating fuels is determined by the share of total housing that uses a secondary heating fuel multiplied by the UEC adjusted for the shell integrity.

---

[1] ***Association of Home Appliances Manufacturers, ``Refrigerators: Energy Efficiency and Consumption Trends," Chicago, IL, December, 1997.***

Distributed Generation

Fuel cells and solar photovoltaic systems compete in single-family housing to generate electricity on-site through a cash-flow formulation. The electricity generated from these systems is either used on-site or sold back to the grid.

Alternative Approaches

Residential models reviewed during the model development process are discussed in this section.[2] The discussion is presented in the order of the components of the NEMS Residential Sector Demand Module.

Housing Stock

The Residential End-use Energy Planning System (REEPS) model[3] developed by the Electric Power Research Institute (EPRI) and DRI/McGraw-Hill's (DRI) Macroeconomic model[4] also forecast domestic housing stock. The Bureau of the Census also predicts household formation based on a complex regression with numerous demographic variables.

Appliance Stock

It is necessary to track the appliance stocks in order to evaluate specific policies likely to affect residential sector energy use. For this reason, models developed recently[5] have focused on keeping track of the capital stock of major household appliances such as heating and cooling equipment, refrigerators, and clothes dryers.

---

[2] For a more complete description of these residential sector modeling systems see the ``Residential Sector Component Design Report," Energy Information Administration, January 19, 1993.

[3] Electric Power Research Institute, ``Residential End-Use Energy Planning System (REEPS) Draft Model Documentation," Palo Alto, CA, 1990.

[4] DRI/McGraw-Hill (DRI), ``Quarterly Model of the U.S. Economy: Version US89A Equation Listing," DRI/McGraw-Hill, Lexington, MA, 1990.

[5] REEPS version 2.0, for example, was officially released in 1991.

REEPS tracks the capital stock of energy-using technologies using a method similar to the method proposed here. The GRI energy model[6] also tracks the capital stock of major residential appliances in order to forecast residential energy consumption.

Technology Choice

The Technology Choice component of the NEMS Residential Sector Demand Module requires extensive data that describe end-use technologies. Equipment costs, efficiency levels, and other characteristics must be specified for all technologies modeled. These data are available from Department of Energy sources[7], Lawrence Berkeley Laboratory (LBL)[8] studies, engineering analyses performed by Arthur D. Little (ADL)[9], Gas Research Institute (GRI)[10] research, Electric Power Research Institute (EPRI)[11], Gas Appliance Manufacturing Association (GAMA)[12], Association of Home Appliance Manufacturers (AHAM), the Air Conditioning and Refrigeration Institute (ARI)[13], and numerous trade publications.

REEPS simulates consumer choice based on the consumer's evaluation of certain equipment attributes (such as capital cost and energy efficiency), with the choice of a particular unit expressed as a probability of the consumer choosing that unit. This probability is based on empirical estimation that reflects observed trends in the home appliance market described in home appliance trade publications.

---

[6] Gas Research Institute, ``1991 Edition for the GRI Baseline Projection Methodology and Assumptions Topical Report," Lexington, MA, December, 1990.

[7] U.S. Department of Energy, Technical Support Document: Energy Conservation Standards for Consumer Products: Dishwashers, Clothes Washers, and Clothes Dryers, DOE/CE-0267, Washington, D.C., July 1989. Also U.S. Department of Energy, Technical Support Document: Energy Conservation Standards for Consumer Products: Refrigerators and Furnaces, DOE/CE-0277, Washington D.C., November, 1989.

[8] Koomey, J.G., et al., ``The Potential for Electricity Efficiency Improvements in the U.S. Residential Sector," Lawrence Berkeley Laboratory, Berkeley, CA, July, 1991. Turiel, I., et. al., ``U.S. Residential Appliance Energy Efficiency: Present Status and Future Directions," Lawrence Berkeley Laboratory, Berkeley, CA, April, 1991. Lawrence Berkeley Laboratory, ``Baseline Data for the Residential Sector and Development of a Residential Forecasting Database," Berkeley, CA, May, 1994.

[9] Arthur D. Little, ``EIA- Technology Forecast Updates- Residential and Commercial Building Technologies," Washington DC, 1998.

[10] Gas Research Institute, ``Baseline Projection Data Book," Washington, DC, 1990.

[11] Electric Power Research Institute, ``Draft Model Documentation for REEPS," 1990.

[12] Gas Appliance Manufacturers Association, ``Consumers' Directory for Certified Efficiency Ratings," Arlington, VA, 1994.

[13] Air Conditioning and Refrigeration Institute, ``Directory of Certified Cooling Equipment," Arlington, VA, 1994.

Shell Integrity

The EPRI, LBL, and GRI models account for energy conservation through shell retrofit. EPRI's REEPS and LBL's REM models both use a sophisticated approach to account for shell retrofits. The REEPS model groups different retrofits into several levels, with each level assigned a different cost and energy savings. Over time, housing structures choose better combinations of shell attributes, which causes a savings in energy consumption. The decision process is simulated by a log-linear function that weighs parameters such as first cost, energy savings, and discount rate. The LBL model uses conservation supply curves to describe the trade-off between investment in different shell measures and the energy savings associated with them. The choice to retrofit depends on the cost of conserved energy. If the retrofit option saves more money than it costs, the option is selected. The GRI model assumes an exogenous rate of annual improvement.

Reasons for Selecting the NEMS Residential Sector Demand Module Approach

Execution time and memory requirements established in the design stage of the NEMS model development effort contribute to the ultimate design of the Residential Sector Demand Module. The component approaches for modeling housing stock, appliance stock, technology choice, and shell integrity are designed in a modular fashion to facilitate enhancements to each component design. The module design draws upon aspects of the REEPS, DRI, and GRI models discussed above, in an attempt to enhance previous modeling methodologies while retaining as much simplicity as possible in the modeling approach. The current module design is flexible enough to lend itself to further enhancement in all components.

Table 1 compares the previous EIA residential sector demand model with the NEMS approach. The Residential Energy End-Use Demand Model (REEM), developed in 1989, consisted of four modules—housing stock, service demand, service capacity, and new technology choice. REEM was used to produce long-term projections of residential energy consumption. Limitations of REEM as compared to the NEMS Residential Demand Module include:

1) Inability to track appliances through time,
2) Projections were generated for only four Census regions (Northeast, South, Midwest, and West),
3) Only six fuel types and six services were considered,

Table 1. Comparison of Previous EIA Model (REEM) With NEMS Residential Sector Demand Module

Conceptual Task	REEM Methodology	NEMS Methodology
Forecast housing stock additions	Increase additions (for each housing type) by proportion of national housing starts. Regional shares of each housing type are constant over time	Forecast by housing type and region, based on demographic variables exogenous to the Residential Module. Housing starts by type and region provided by the NEMS Macroeconomic Module
Compute and forecast appliance stock and appliance penetration for new and existing housing	No stock method employed; use service demand and capacity as proxies	Count appliance stock in base year; vintage and add equipment over time; forecast penetration based on assumptions
Choose equipment to meet appliance stock demand	Use logit function based on minimum life-cycle cost; assume initial equipment shares, fixed discount rate, and inertia factor (lagged penetration)	Segment market based on type of acquisition, house type, etc.; vary consumer preference parameters by service type.
Calculate energy consumption	Weight share of equipment chosen by average efficiency for each fuel and apply to service demand	Weight share of equipment chosen by average efficiency for each technology and apply to appliance (unit) demand

4) Did not incorporate consumer choice parameters in the technology choice module,

5) Technology choice methodology was limited to a life-cycle cost approach,

6) Did not produce energy consumption forecasts for each service by fuel type,

7) Did not explicitly include dispersed renewable technologies,

8) Did not account for weather effects,

9) Did not account for distributed generation, and

10) Did not account for price induced technology change.

4. Model Structure

Structural Overview

The NEMS Residential Sector Demand Module characterizes energy consumption using an algorithm that accounts for the stocks of housing and appliances, equipment market shares, and energy intensity. The module assesses the shifts of market shares between competing technologies based on assumptions about the behavior of residential consumers.

The NEMS Residential Sector Demand Module is a sequential structured system of algorithms, with succeeding computations using the results from previously-executed components as inputs. The module is composed of five logical components: housing stock forecast, technology choice, appliance stock forecast, building shell integrity, and energy consumption.

Housing Stock Forecast

The location and type of housing stock are the primary model drivers. The first component uses data from the NEMS Macroeconomic Activity Module to project new and existing housing for three dwelling types at the nine Census Division level. The three housing types are as follows:

- Single-Family Homes
- Multifamily Homes
- Mobile Homes

Technology (Equipment) Choice

The Technology Choice Component simulates the behavior of consumers by forecasting market shares for each available equipment type. New and replacement equipment decisions are modeled for each technology type. For new construction, home heating fuel is determined by relative life-cycle costs of all competing heating systems.

Table 2. Services and Equipment in the NEMS Residential Sector Demand Module

Space Heating Equipment	**Cookstoves**
Electric Furnace	**Natural Gas**
Electric Air-Source Heat Pump	**LPG**
Natural Gas Furnace	**Electric**
Natural Gas Other (Hydronic)	
Kerosene Furnace	**Clothes Dryers**
LPG Furnace	**Natural Gas**
Distillate Furnace	**Electric**
Distillate Other (Hydronic)	
Wood Stove	**Refrigerators**
Electric Ground-Source Heat Pump	**18 cubic-foot Top Mounted Freezer**
Natural Gas Heat Pump	**24 cubic-foot Side-by-Side with Through-the-Door Features**
Space Cooling Equipment	
Electric Room Air Conditioner	**Freezers**
Central Air Conditioner	**Chest Manual Defrost**
Electric Air-Source Heat Pump	**Upright Manual Defrost**
Electric Ground-Source Heat Pump	
Natural Gas Heat Pump	**Clothes Washers**
	Vertical Axis
Water Heaters	**Horizontal Axis**
Natural Gas	
Electric Resistance / Heat Pump	**Lighting**
Distillate	**Incandescent**
LPG	**Compact Fluorescent**
Solar Thermal	**Halogen Tochiere**
	Distributed Generation
	Fuel Cells
	Solar Photovoltaic

Relative weights are determined for each equipment type based on the existing market share, the installed capital cost, and the operating cost. These relative weights are then used to compute the market shares and composite average efficiencies for each service. The technologies are distinguished by the service demand that they satisfy, by the fuel that they consume, and by their efficiency.

Appliance Stock Forecast

The Appliance Stock Component forecasts the number of end-use appliances within all occupied households. This component tracks equipment additions and replacements. Equipment is required to meet the following services:

- Space Heating
- Water Heating
- Clothes Drying
- Food Freezing
- Space Cooling
- Cooking
- Food Refrigerating
- Clothes Washers
- Dishwashers

Building Shell Integrity

Building shell integrity is modeled for existing and new housing. The existing housing stock responds to rising prices of space conditioning fuels by improving shell integrity. Shell integrity improvements might range from relatively inexpensive measures (such as caulking and weatherstripping) to projects with substantial costs (such as window replacement).

New housing stock also incorporates shell integrity improvements. The shell integrity of new and existing housing is assumed to improve throughout the forecast horizon, as building codes and other efficiency programs become more widespread.

Distributed Generation Component

The Distributed Generation Component allows fuel cells and solar photovoltaic systems compete for on-site electricity generation. Through the use of a cash-flow formulation, the penetration rates of these systems are computed. Electricity generated from these systems is deducted from total household use, or sold back to the grid, if feasible.

Energy Consumption

The Energy Consumption Component calculates end-use consumption for each service and fuel type. The consumption forecasts are constructed as the product of the number of units in the equipment stock and the average technology UEC. The average UEC changes over time as the composition of the equipment stock changes over time.

In each year of the forecast, the following steps are performed to develop the energy consumption forecast:

1. A forecast of housing stock is generated based on the retirement of existing housing stock and the addition of new construction as determined in the MAM.

2. Pre-1998 vintage equipment stock is estimated, accounting for housing demolitions and additions.

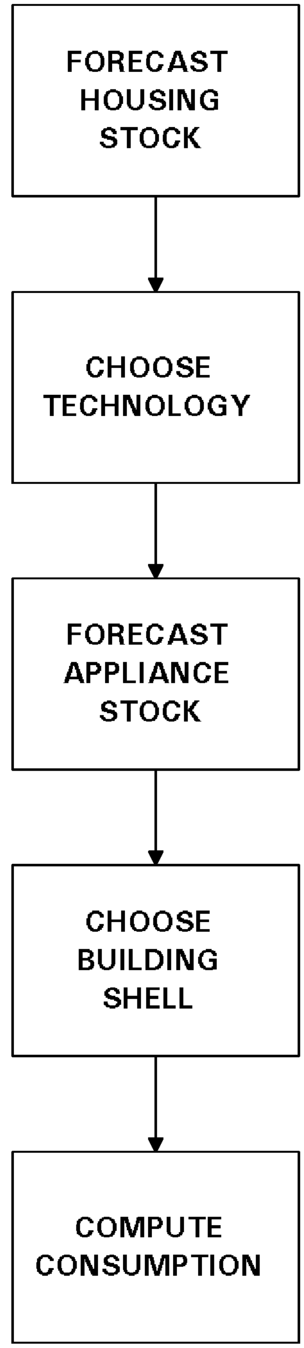
3. Market shares are determined for equipment types by service.

4. The previous year's equipment additions and replacements for both pre-1998 and post-1997 vintage are determined based on the current year market share.

5. Efficiencies weighted by market share are calculated.

6. Fuel consumption is calculated using UEC and the weighted efficiencies (shell integrities and household size, if applicable).

Figure 1. NEMS Residential Sector Demand Module Basic Structure



Flow Diagrams

This section includes flow diagrams that represent the structure of the NEMS Residential Sector Demand Module. Figure 1 presents the overall sequential structure. Figure 2 illustrates the Housing Stock Component flow. The Technology Choice Component flow is represented in Figure 3. Figure 4 provides the flow of the Appliance Stock Additions and Replacements Component, the calculation of building shell efficiencies is found in Figure 5, and the Consumption and UEC Component flow is provided in Figure 6.

The overall sequential structure as illustrated in Figure 1 details the five primary steps that calculate the final residential sector energy consumption. These five steps are discussed in the first chapter of this report.

Figure 2 illustrates the Housing Stock Component of the module. This component draws upon existing housing characteristics from the RECS data base and new housing characteristics from the MAM forecast. The Housing Stock calculates housing stock additions, survival, and retirements in order to produce the total housing stock by vintage, type, and Census Division.

Figure 3 illustrates the Appliance Stock Component of the module. The base year existing stock of major household appliances is derived from analysis of the RECS 1997 data. Appliance retirements are determined based upon the minimum and maximum equipment lifetime assumptions discussed in the Fundamental Assumptions section of this report. Additions to the appliance stock are calculated in this component, as is the surviving stock of equipment.

Figure 4 illustrates the Technology Choice Component of the module. The existing, replacement, and new appliance stock characteristics are used by this component to determine the stock requirements. Technology characterization information input to this component determines the set of equipment from which the required choices are made. The consumer choice functions by decision type determine the type, number, and equipment efficiency by end-use service.

Figure 5 illustrates the Building Shell Integrity Component, which calculates indices that reflect increasing building shell efficiencies over time, in response to increasing energy prices, EPACT window labeling standards, and technology improvement.

Figure 6 illustrates the Consumption and UEC Component of the module. This component uses the base year UEC information developed from the RECS data, the technology selection information developed previously, building shell integrity, household size, and heating- and cooling-degree day effects to determine end-use consumption.

Figure 2. Housing Stock Component Flow.

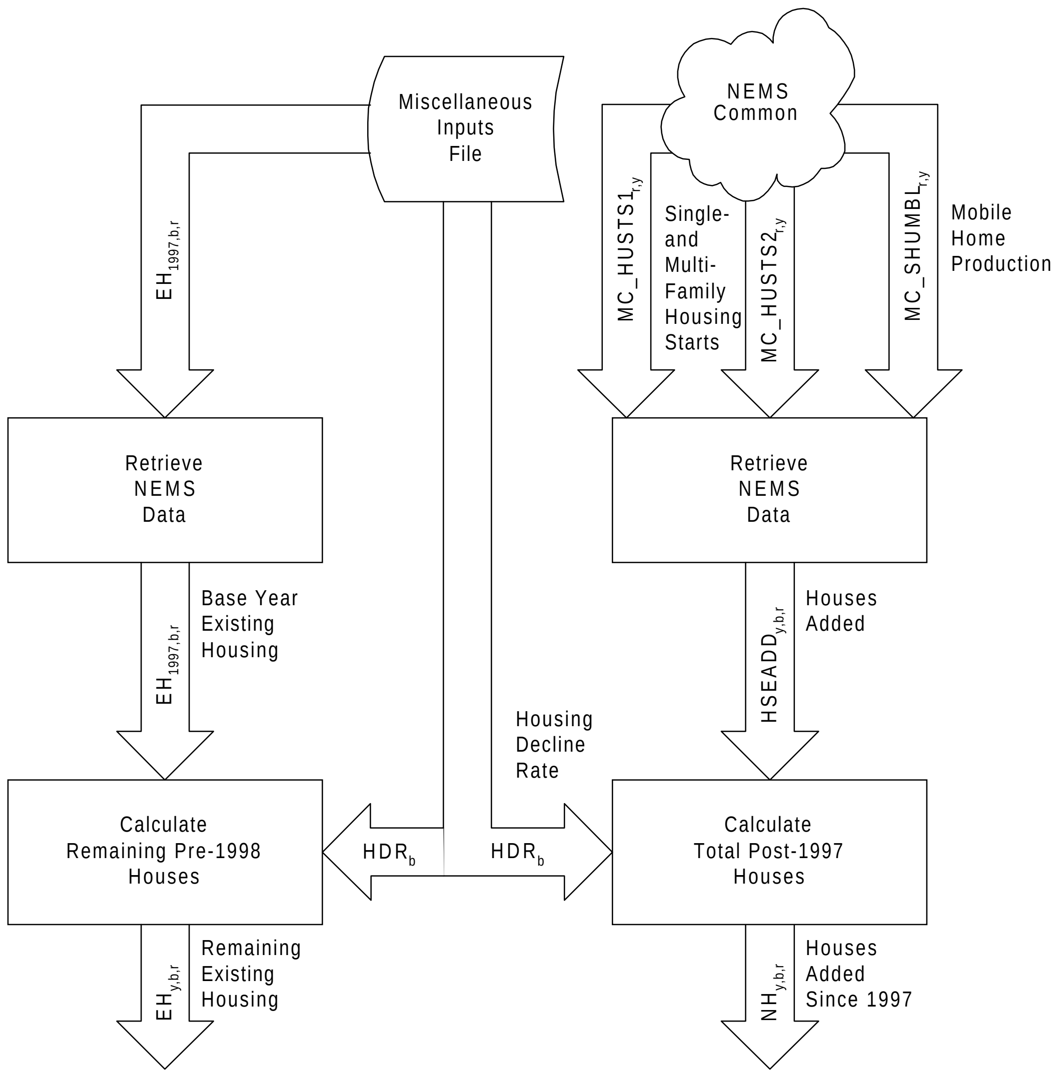


Figure 3. Technology Choice Component Flow

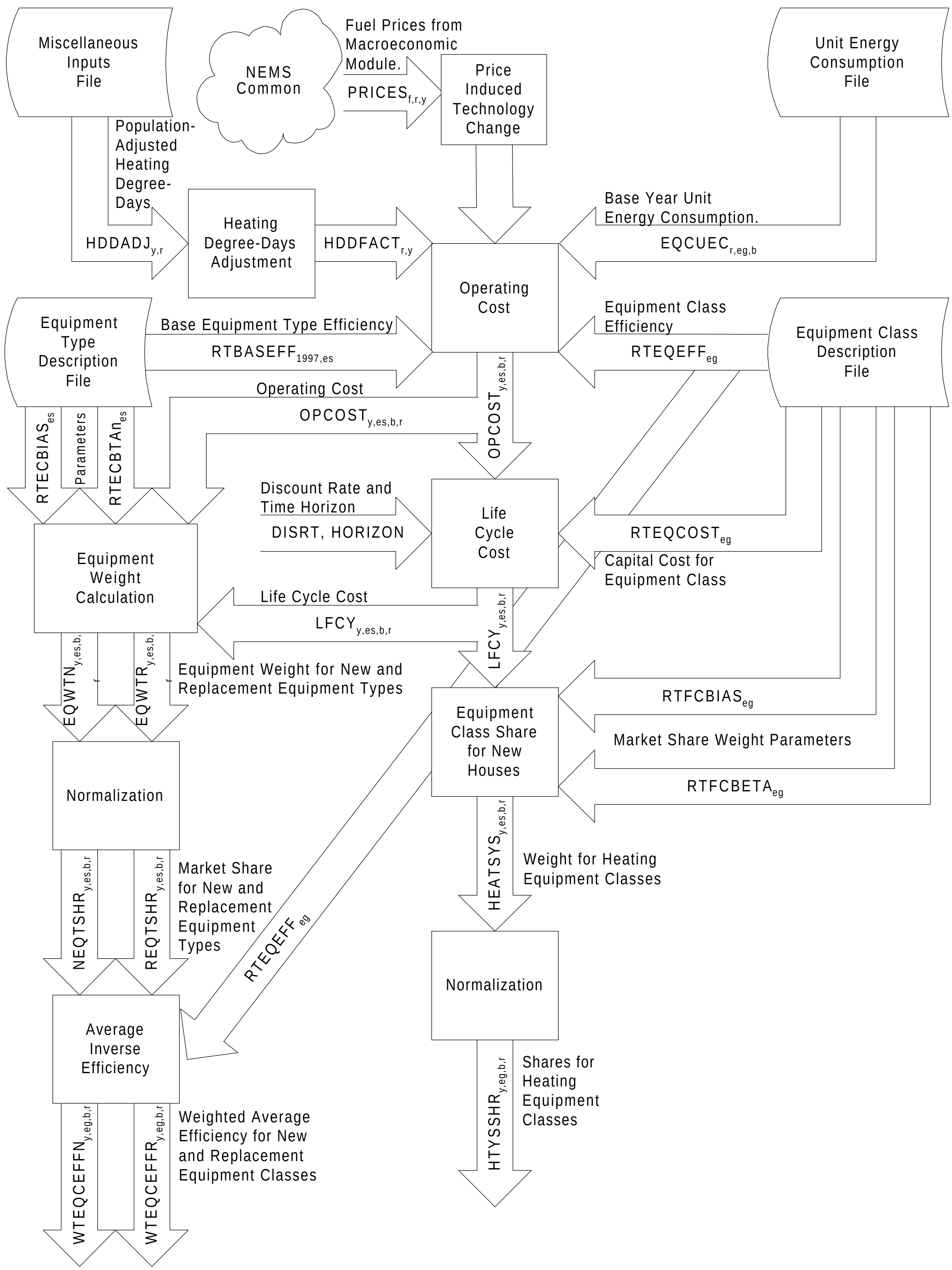


Figure 4. Appliance Stock Component Flow.

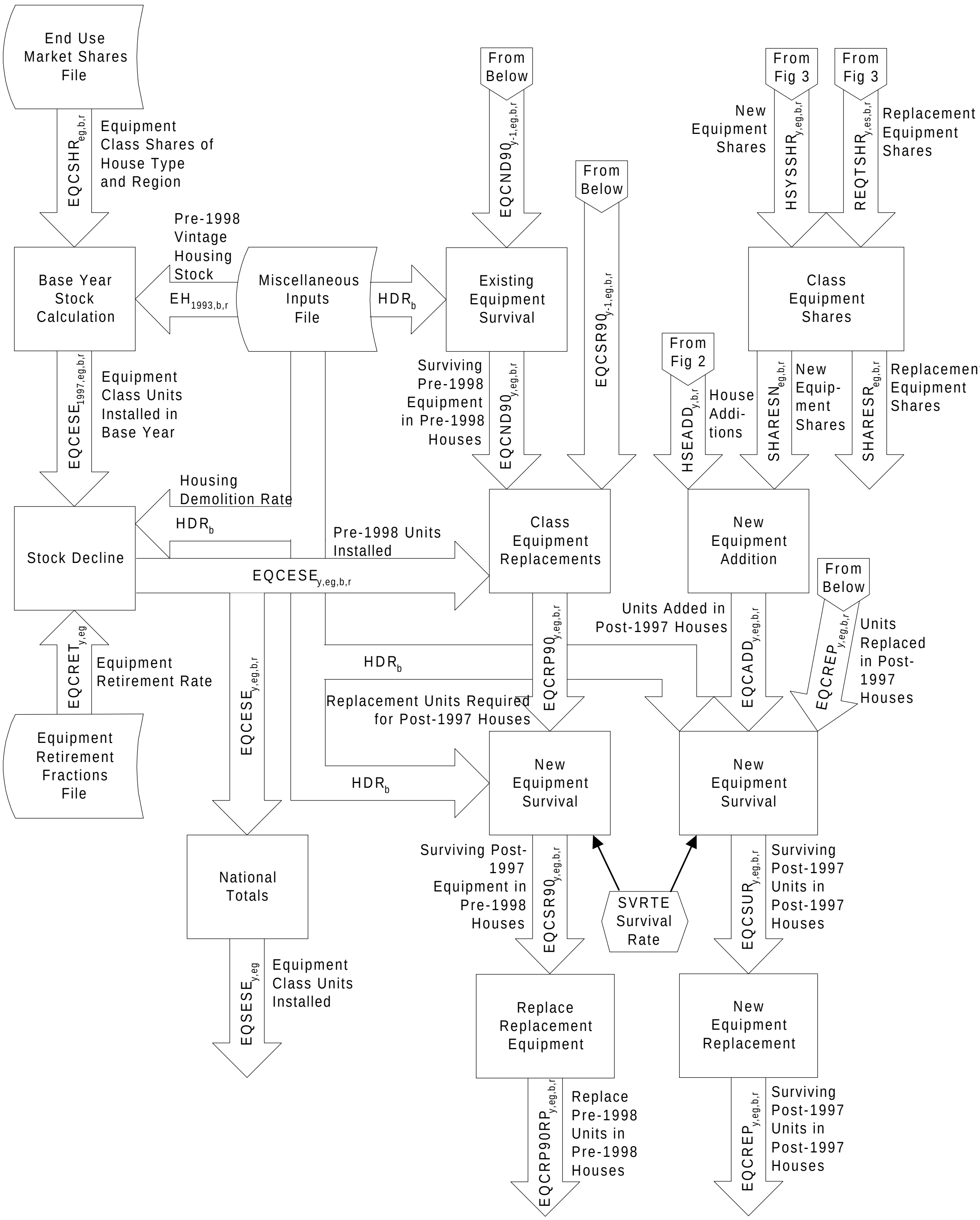


Figure 5. Building Shell Integrity Component Flow.

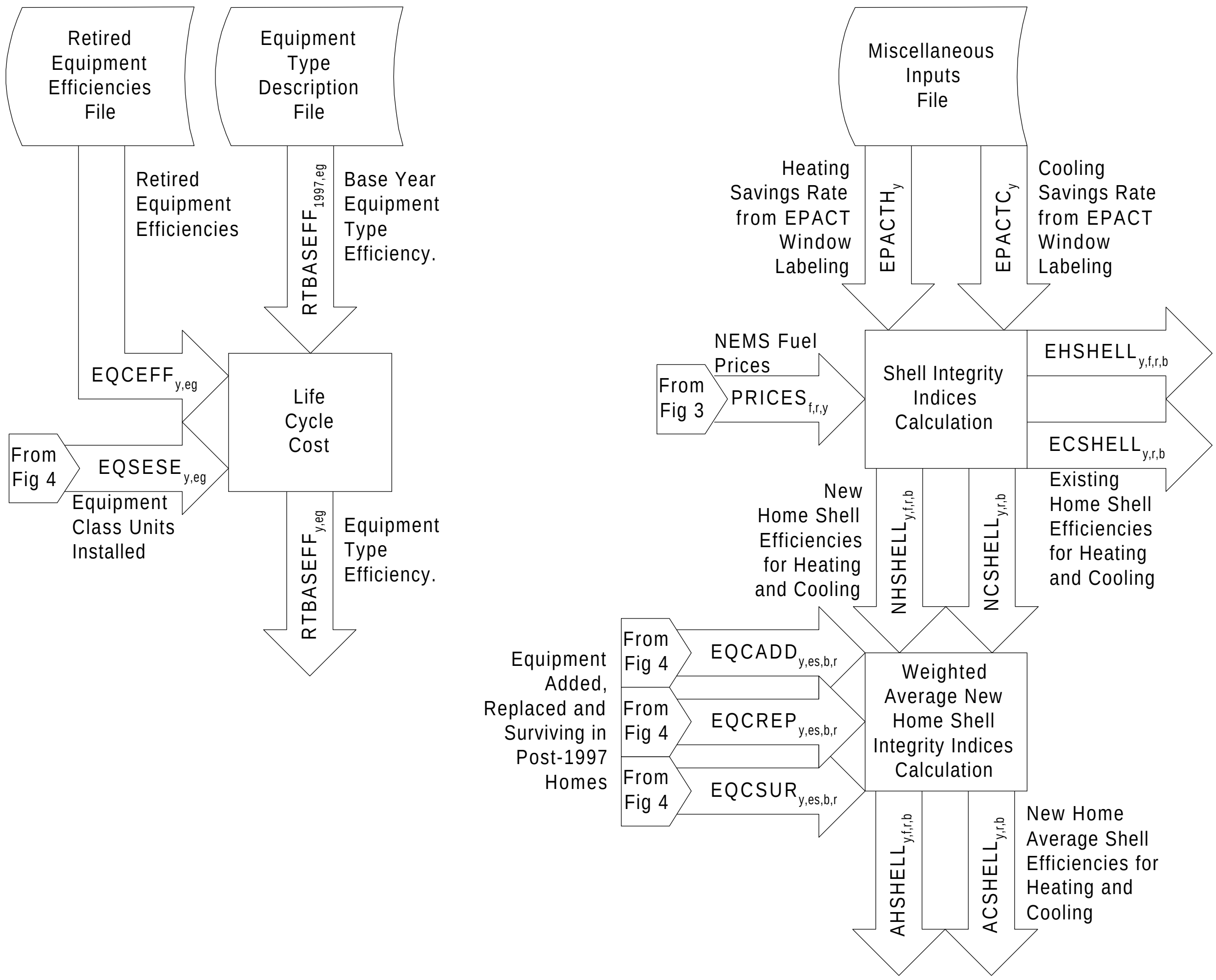
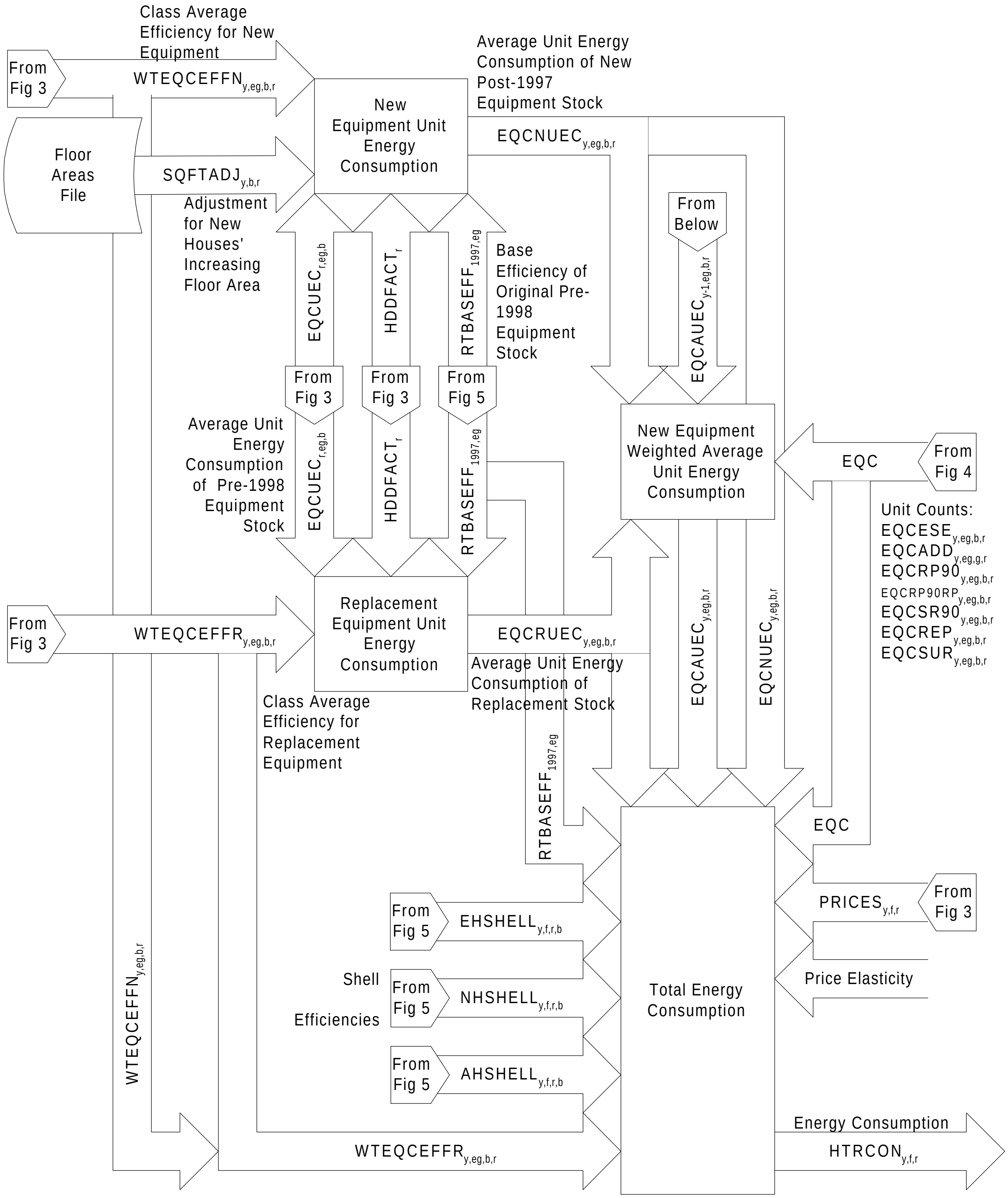


Figure 6. Consumption and UEC Component Flow.



FORTRAN Subroutine Descriptions

The NEMS Residential Sector Demand Module FORTRAN source code consists of more than 50 subroutines sequentially called during the execution of the module. Table 3 lists the major subroutines and their corresponding descriptions. The subroutines can be grouped into the following categories according to their functions:

Fuel Price Subroutine

The code includes the following subroutine that reads fuel prices:

RDPR reads in fuel prices from the NEMS system.

Initialization Subroutines

The code includes the following subroutine for initialization purposes:

INTEQT initializes heating equipment market shares and applies the decay rate to the existing equipment.

Housing Subroutines

The code includes the following subroutine to assess housing stocks:

NEWHSE Reads housing starts from NEMS Macroeconomic Activity Module and computes new housing stock

Existing Equipment - RDHTRTEC Subroutine

This subroutine projects pre-1998 (existing) vintage equipment by service. In this subroutine, the following operations are performed:

1. The equipment market share is read from an exogenous data file by equipment type, housing type, and Census Division.

Table 3. Primary NEMS Residential Sector Demand Module Subroutines

Subroutine Name	Description of the Subroutine
RTEKREAD	Reads technological characterizations for all equipment
RDSQFT	Reads annual average housing floor areas
RMISCREAD	Reads miscellaneous data for the module
RDPR	Reads prices
PITC	Computes price induced technology change
INTEQT	Initialize heating equipment market share
RDHTREQC	Project 1993 vintage for all services
RDUECS	Initialize equipment UECs (service aggregates)
RCONSFL	Rationalize fuel numbering among equipment types
EXCONS	Calculate 1993 consumption
RDISTGEN	Project Distributed Generation Penetration
NEWHSE	Calculate new housing.
EPACTWD	Calculate the impact of EPACT window labeling
SQFTCALC	Calculate average floor area of housing
RDEFF	Read in efficiency of retiring equipment from 1993 stock
RDRET	Read in proportion of retiring equipment from 1993 stock
REPLACE	Shares out replacement equipment switching among competing technologies for single-family homes up to an input limit
RCWTEC	Choose clothes washer equipment
RCWADD	Calculate new and replacement clothes washers
RCWCON	Calculate consumption for clothes washers
RDWTEC	Choose dishwasher equipment
RDWADD	Calculate new and replacement dishwashers
RDWCON	Calculate consumption for dishwashers
PCCNS	Calculate personal computer consumption
TVCNS	Calculate color television consumption
RWHTEC	Choose water heating equipment
REUADD	Calculate new and replacement water heaters and stoves
RWHCON	Calculate consumption for hot water heating
RSTVTEC	Choose cooking equipment
RSTVCON	Calculate consumption for cooking
RDRYTEC	Choose dryer equipment
RDRYADD	Calculate new and replacement dryers
RDRYCON	Calculate consumption for dryers
RHTRTEC	Choose heating equipment and compute average efficiencies
RHTRADD	Calculate new and replacement heating equipment
RHTRCON	Calculate heating consumption
RCLTEC	Choose air-conditioning equipment
RCLAD	Calculate new and replacement cooling equipment
RCLCON	Calculate cooling consumption
RREFTEC	Choose refrigeration equipment
RREFADD	Calculate new and replacement refrigerators
RREFCON	Calculate energy consumption for refrigerators
RFRZTEC	Choose freezer equipment
RFRZADD	Calculate new and replacement freezer equipment
RFRZCON	Calculate consumption by freezers
LTCNS	Calculate lighting consumption
APCNS	Calculate consumption for electric appliances
SHTCNS	Calculate consumption for secondary heating
APPCNS	Calculate appliance consumption
FUELCN	Calculate fuel consumption
RSBENCH	Calibrate consumption to benchmark values
NEMSCN	Calculate and report NEMS output variables
RESDRP	Prepare data for reporting
RESDRP2	Report module results

2. The base year equipment stock or the pre-1998 vintage stock is the product of the share and the amount of existing housing.

3. Surviving equipment of the pre-1998 vintage is forecasted using the equipment survival rate and the housing decay rate for every year in the forecast.

Other Input Subroutines

These subroutines read other information from files:

RDEFF	reads efficiencies of retiring equipment
RDRET	reads equipment retirement rates
RTEKREAD	reads the detailed technology data
RMISCREAD	reads miscellaneous variables
RDSQFT	reads home floor areas
RDUECS	reads unit energy consumption data

Calculation Subroutines (3)

The model includes a subroutine identified as **EPACTWD** to estimate the EPACT window labeling impact, **SQFTCALC** to calculate average home floor areas, and **PITC** to calculate the amount of price induced technology change based on fuel prices.

Technology Choice - TEC Subroutines (9)

The code includes nine technology choice subroutines that follow these general steps:

1. Initialize capital costs and equipment efficiencies.
2. Set discount rate, adjustment factors and present value horizon.
3. Compute operating costs of each equipment type.
4. Compute life cycle costs of each equipment type.
5. Compute technology share for new housing.
6. Calculate new and replacement equipment weights based on the bias, capital cost, and operating costs using a log-linear function.
7. Compute new market shares, ratio between equipment weights and total equipment weight.
8. Efficiencies for equipment types are calculated for new and replacement equipment weighted by their respective market shares.

These subroutines are as follows:

RHTRTEC	**RSTVTEC**	**RFRZTEC**
RCLTEC	**RDRYTEC**	**RCWTEC**
RWHTEC	**RREFTEC**	**RDWTEC**

In addition to the TEC subroutines, the LTCNS, TVCNS, and PCCNS subroutines assign market shares to respective technologies within each class.

Replacements and Additions - ADD Subroutines (8)

The code contains six equipment replacement and additions subroutines. (Water heaters and stoves use the same ``ADD'' subroutine.) ``TEC'' subroutines for each service are followed by ``ADD'' subroutines that calculate new and replacement equipment for the previous year based on the current year's market share. The following steps are implemented in these subroutines:

1. The post-1997 vintage equipment additions are determined by the share of new (post-1997) houses from the MAM that demand that service.

2. Compute the surviving post-1997 vintage equipment in pre-1998 vintage houses.

3. Compute total equipment required for pre-1998 vintage houses.

4. Compute the equipment replacements in pre-1998 vintage houses by subtracting the sum of surviving pre-1998 vintage equipment and surviving post-1997 vintage equipment in pre-1998 vintage houses from the total equipment demanded for pre-1998 vintage houses. Technology switching is allowed at replacement for space heaters, heat pump air conditioners, water heaters, stoves, and clothes dryers in single-family homes.

5. Compute the surviving post-1997 vintage equipment that was purchased as either additions or replacements for post-1997 houses.

6. Calculate the current year's replacements of post-1997 vintage equipment in post-1997 houses as by subtracting the surviving replacements and equipment additions in post-1997 houses from the stock of surviving post-1997 houses. Technology switching is allowed at

replacement for space heaters, heat pump air conditioners, water heaters, stoves, and clothes dryers in single-family homes. These subroutines are as follows:

RHTADD	**RDRYADD**	**RCWADD**
RCLADD	**RREFADD**	**RDWADD**
REUADD	**RFRZADD**	

End-use Consumption - CON/CNS Subroutines (13)

The code contains 11 end-use consumption subroutines defined by service. The ADD subroutines are followed by consumption subroutines. Within each of these subroutines the new, replacement and average unit energy consumption values are calculated. These UECs are then multiplied by the equipment stock (and climate adjustment factor and shell integrity for space conditioning) to yield final fuel consumption. These subroutines, which follow, also include a price sensitivity expression that adjusts short-term demand for fuels:

RHTRCON	**RREFCON**	**APPCNS**
RCLCON	**RFRZCON**	**RCWCON**
RWHCON	**LTCNS**	**RDWCON**
RSTVCON	**APCNS**	**TVCNS**
RDRYCON	**SHTCNS**	**PCCNS**

Distributed Generation - RDISTGEN

Projects the number of households with distributed generation technologies and amount of electricity generated.

Overall Consumption - CN Subroutines (2)

The model includes the following two subroutines that calculate overall fuel consumption and list output NEMS consumption:

FUELCN	calculates fuel consumption
NEMSCN	Output NEMS consumption

Historical Consumption/Calibration Subroutines (2)

The code includes the following two subroutines to determine historical energy consumption:

EXCONS calculate 1997 consumption

RSBENCH calibrate consumption to 1997-2000 STEO consumption.

Report Subroutines (2)

The following subroutines produce the output reports:

RESDRP

RESDRP2

Key Computations and Equations

This section presents the detailed calculations used in each of the module components, couched in terms of the space heating end use, because it provides the best examples for generalization. Calculations for other end uses follow the space heating pattern, with different variable names. For more detail refer to Appendix B, where calculations are provided at the subroutine level. Table 4 shows the correspondence between the subscripts in the documentation and the subscripts in the FORTRAN source code.

Table 4. Definitions of Subscripts

Subscript in Documentation	Subscript in the FORTRAN Code
r	R or D, refers to Census Division
t	Y, when Y is a year increment
f	F, fuel types
b	B, housing type
y	CURIYR, the annual index
y-1	PREVYR, CURIYR-1
eg	EQC, equipment class # within an end use (e.g., 1 - 11 for heat) RECCL, equipment class # from all end uses (currently 1 - 27)
egsw	EQCSW, equipment class # within an end use to switch to RECCLSW, equipment class # from all end uses to switch to
es	EQT, equipment type # within an end use (e.g., 1 - 26 for heat) RECTY, equipment type # from all end uses (currently 1 - 164)
v	Vintage of equipment (pre-1994, post-1993)

Please note the following conventions:

- The table of subscripts includes all of the major usages. In some minor instances, additional subscripts are defined as needed.

- The equations follow the logic of the FORTRAN code very closely to facilitate an understanding of the code and its structure. In several instances, a variable appears on both sides of an equation. This is a FORTRAN programming device that allows a previous calculation to be updated (for example, multiplied by a factor) and re-stored under the same variable name (i.e., in the same memory location).

- The subscript, y, in the documentation refers to the year represented as 1990 through 2020. In the FORTRAN code, the subscripts for CURIYR represent array dimensions starting with an index of 1 to represent 1990.

- Some variables are documented as having a “y'' dimension when in fact they do not. The most common instances are for the variables, LFCY, OPCOST, SA, SHARESN, and SHARESR. These variables are calculated on an annual basis, but are retained only for the current year. The “y'' dimension is used in the documentation to highlight 1) that the calculations do vary by year, and 2) to indicate the current year in formulas to avoid confusion.

- Summations over all relevant variables are usually written without upper and lower range limits on the summation signs.

- Unless otherwise stated, the range of y for an equation is 1990 through 2020.

Housing Stock Component

To calculate the number of existing dwellings, the Housing Stock Component adds newly-built homes to the inventory and subtracts demolitions. Housing construction starts are obtained from regional outputs of the MAM. Existing base year housing stock is designated as the “pre-1998'' vintage, and new additions to the housing stock are referred to as the “post-1997'' vintage. Additions and replacements for both housing vintages are tracked through the forecast period.

Houses are removed from the stock at a constant rate over time. The survival rates for the household types (HDR_b) are as follows:

Single-Family Homes: $HDR_1 = 0.996$
Multifamily Homes: $HDR_2 = 0.996$
Mobile Homes: $HDR_3 = 0.965$

The surviving 1997 housing stock is defined by

$$EH_{y,b,r} = RECS\ data \quad , if\ y = 1997$$
$$EH_{y,b,r} = EH_{y-1,b,r} \times HDR_b \ , if\ y > 1997 \tag{1}$$

where,

$EH_{y,b,r}$ is 1997 housing stock surviving by year, housing type and Census Division.

New houses are added to the stock each year, as defined by the NEMS Macroeconomic Module. The total number of new additions in a given year is defined as:

$$NH_{y,r} = HUSTS1_{y,r} + HUSTS2_{y,r} + SHUMBL_{y,r} \tag{2}$$

where,

$NH_{y,r}$ is total new housing added by year and Census Division,

$HUSTS1_{y,r}$ is single-family housing added by year and Census Division,

$HUSTS2_{y,r}$ is multifamily housing added by year and Census Division,

$SHUMBL_{y,r}$ is mobile home shipments added by year and Census Division,

Technology Choice Component

The Technology Choice Component uses a log-linear function to estimate technology market shares. The module is able to calculate market shares based on consumer behavior as a function of bias, capital costs, and operating costs or as a function of life-cycle costs.

The seven major services modeled are:

Space Heating
Space Cooling
Water Heating
Cooking
Clothes Drying
Food Refrigeration
Food Freezing
Clothes Washers
Dishwashers

Lighting, color televisions, personal computers, and other appliance decisions are modeled differently from the major services listed above.

New equipment operating costs are computed by the expression,

$$OPCOST_{y,es,b,r,v} = PRICES_{f,r,y} \times EQCUEC_{r,eg,b} \times HDDFACT_{r,y} \times RTEFFAC_{eg,v} \tag{3}$$

where,

$OPCOST_{y,es,b,r,v}$	is the operating cost for the specific equipment type by year, housing type, and Census Division, and vintage,
$PRICES_{f,r,y}$	is the fuel prices for the equipment by fuel, by region and forecast year,
$EQCUEC_{r,eg,b}$	is the unit energy consumption by Census Division, equipment class and housing type,
$HDDFACT_{r,y}$	is a factor, the ratio between heating degree days in the current year and in the base year, for adjusting for abnormal weather in either the base year or in the current year, and
$RTEFFAC_{eg,v}$	is the efficiency adjustment for the general equipment class and vintage.

The consumer is allowed to choose among the various levels of cost and efficiency for a given class of equipment. Electric heat pumps are an example of an equipment class (denoted by eg). Equipment type (denoted by es) refers to the same class of equipment with different efficiency ratings (e.g., high vs low efficiency electric heat pumps).

EQCOST is a time-dependant function for computing the installed capital cost of equipment in new construction and the retail replacement cost of equipment in existing housing. It is called if the cost trend switch COSTTRSW = 1 in COMMON RTEK (which is the default). Its mathematical description is as follows:

$$\begin{aligned} EQCOST_{es,y,CAP} &= RTEQCOST_{es} \;, \; if \; RTMATURE_{es} = MATURE \\ EQCOST_{es,y,RET} &= RTRECOST_{es} \;, \; if \; RTMATURE_{es} = MATURE \end{aligned} \tag{4}$$

$$EQCOST_{es,y,CAP}=\frac{RTEQCOST_{es}\times 2\times d}{1+\left(\frac{y-y_1}{y_0-y_1}\right)^{\gamma}}+(1-d)\times RTEQCOST_{es}\quad ,\ if\ RTMATURE_{es}=ADOLESCENT$$

$$EQCOST_{es,y,RET}=\frac{RTRECOST_{es}\times 2\times d}{1+\left(\frac{y-y_1}{y_0-y_1}\right)^{\gamma}}+(1-d)\times RTRECOST_{es}\quad ,\ if\ RTMATURE_{es}=ADOLESCENT \tag{5}$$

$$EQCOST_{es,y,CAP}=\frac{RTEQCOST_{es}\times d}{1.0+\left(\frac{y-y_1}{y_0-y_1}\right)^{\gamma}}+(1.0-d)\times RTEQCOST_{es}\quad ,\ if\ RTMATURE_{es}=INFANT$$

$$EQCOST_{es,y,RET}=\frac{RTRECOST_{es}\times d}{1.0+\left(\frac{y-y_1}{y_0-y_1}\right)^{\gamma}}+(1.0-d)\times RTRECOST_{es}\quad ,\ if\ RTMATURE_{es}=INFANT \tag{6}$$

where,

$EQCOST_{es,y,ctype}$ is time-dependant installed capital cost of equipment in new construction or the retail replacement cost of equipment in existing housing,

ctype tells function type of equipment cost to return,

CAP = Return installed capital cost in new construction,

RET = Return retail replacement cost in existing housing,

$RTMATURE_{es}$ Technology maturity description,

MATURE = No further equipment cost reductions expected,

ADOLESCENT = Major cost reductions occurred before base year,

INFANT = All cost reductions expected after first year available,

$RTEQCOST_{es}$ Installed wholesale capital cost in \$1998 per unit for new homes, remains constant for MATURE technologies only (used when ctype = CAP),

$RTRECOST_{es}$ Retail capital cost in \$1998 per unit for replacements, remains constant for MATURE technologies only (used when ctype = RET),

y_0 is the year of inflection of cost trend,

$RTINITYR_{es}$ if ADOLESCENT,

$RTCOSTP1_{es}$ if INFANT,

y_1 is the year cost decline began,

$RTCOSTP1_{es}$ if ADOLESCENT,

$RTINITYR_{es}$ if INFANT,

d	is the total possible proportional decline in equipment cost, $RTCOSTP3_{es}$, from y_0 onward if ADOLESCENT, from y_1 onward if INFANT,
γ	is the logistic curve shape parameter, $RTCOSTP2_{es}$.

The module includes the option to use life-cycle costing to calculate market share weights. The life cycle cost calculation is,

$$LFCY_{y,es,b,r,v} = CAPITAL_{es} + OPCOST_{y,es,b,r,v} \times \left[\frac{1 - (1 + DISRT)^{-HORIZON}}{DISRT} \right] \quad \textbf{(7)}$$

where,

$LFCY_{y,es,b,r,v}$	is the life cycle cost of an equipment type by forecast year, housing type, and Census Division, and vintage,
$CAPITAL_{es}$	is the installed capital cost of an equipment type based on calling EQCOST with $RTEQCOST_{es}$[1],
HORIZON	is the number of years into the future that is used to compute the present value of future operating cost expenditures presently set to seven years, and
DISRT	is the discount rate applied to compute the present value of future operating costs presently at 20 percent.

A weight for each equipment class is calculated to estimate the market share for each of the 11 heating systems for new construction based on the cost factors computed above. The functional form is expressed as,

$$HEATSYS_{y,eg,b,r} = e^{[\,RFTCBIAS_{eg} + RFTCBETA_{eg} \times LFCY_{y,eg,b,r,v}\,]} \quad \textbf{(8)}$$

where,

$HEATSYS_{y,eg,b,r}$	is the equipment weight for a heating equipment class for new housing by year, housing type, and Census Division,
$RTFCBIAS_{eg}$	is a consumer preference parameter that fits the current market share to historical shipment data,
$LFCY_{y,eg,b,r,v}$	is the life cycle cost for the equipment class by year, housing type, and Census Division, and vintage, and

$RTFCBETA_{eg}$ is a parameter value of the log-linear function.

The sum over the heating equipment classes gives the total weight for all of the heating equipment:

$$SYSTOT_{y,b,r} = \sum_{eg=1}^{eg=11} HEATSYS_{y,eg,b,r} \quad \textbf{(9)}$$

where,

$SYSTOT_{y,b,r}$ is the sum of equipment class weights for the all equipment classes.

The equipment class fuel share is computed by

$$HTYSSHR_{y,eg,b,r} = \frac{HEATSYS_{y,eg,b,r}}{SYSTOT_{y,b,r}}, \text{ if } SYSTOT_{y,b,r} > 0$$
$$HTYSSHR_{y,eg,b,r} = 0, \text{ otherwise} \quad \textbf{(10)}$$

where,

$HTYSSHR_{y,eg,b,r}$ is the equipment class fuel share by year, building type, and Census Division.

For each equipment type within each class, a weight is calculated based on the cost factors computed above. The functional form is expressed as,

$$EQWTN_{y,es,b,r} = e^{[RTECBIAS_{es} + RTECBTA2_{es} \times OPCOST_{y,es,b,r} + RTECBTA3_{3} \times LFCY_{y,es,b,r}]} \quad \textbf{(11)}$$

$$EQWTR_{y,es,b,r} = e^{[RTECBIAS_{es} + RTECBTA2_{es} \times OPCOST_{y,es,b,r} + RTECBTA3_{3} \times LFCY_{y,es,b,r}]} \quad \textbf{(12)}$$

where,

$EQWTN_{y,es,b,r}$ is the equipment weight for new equipment type by year, housing type, and Census Division,

$EQWTR_{y,es,b,r}$ is the equipment weight for replacement equipment type by year, housing type, and Census Division,

$OPCOST_{y,es,b,r,v}$ is the operating cost for the equipment type by year, housing type, Census Division, and vintage

$LFCY_{y,es,b,r,v}$ is the life cycle cost for the equipment type by year, housing type, Census Division, and vintage,

$RTECBIAS_{es}$	is a consumer preference parameter that fits the current market share to shipment data, and
$RTECBTA2_{es}$, $RTECBTA3_{es}$	are parameter values of the same fit.

Sums over the equipment types within each class give total weights for the equipment classes:

$$TOTEWTN_{y,eg,b,r} = \sum_{es=low\ eff}^{hi\ eff} EQWTN_{y,es,b,r} \quad \textbf{(13)}$$

$$TOTEWTR_{y,eg,b,r} = \sum_{es=low\ eff}^{hi\ eff} EQWTR_{y,es,b,r} \quad \textbf{(14)}$$

where,

$TOTEWTN_{y,eg,b,r}$	is the sum of weights for the new equipment types within equipment classes,
$TOTEWTR_{y,eg,b,r}$	is the sum of weights for the replacement equipment types within equipment classes.

The equipment type fuel share is computed by

$$\begin{aligned} EQFSHRN_{y,es,b,r} &= \frac{EQWTN_{y,es,b,r}}{TOTEWTN_{y,eg,b,r}}, \ if\ TOTEWTN_{y,eg,b,r} > 0 \\ EQFSHRN_{y,es,b,r} &= 0 \qquad , \ otherwise \end{aligned} \quad \textbf{(15)}$$

$$\begin{aligned} EQFSHRR_{y,es,b,r} &= \frac{EQWTR_{y,es,b,r}}{TOTEWTR_{y,eg,b,r}}, \ if\ TOTEWTR_{y,eg,b,r} > 0 \\ EQFSHRR_{y,es,b,r} &= 0 \qquad , \ otherwise \end{aligned} \quad \textbf{(16)}$$

where,

$EQFSHRN_{y,es,b,r}$	is the new equipment type fuel share by year, building type, and Census Division.
$EQFSHRR_{y,es,b,r}$	is the replacement equipment type fuel share by year, building type, and Census Division.

This value is multiplied by the market share of the equipment type to yield the new market share for the equipment type. The relationship is expressed as,

$$NEQTSHR_{y,es,b,r} = EQFSHRN_{y,es,b,r} \quad (17)$$

$$REQTSHR_{y,es,b,r} = EQFSHRR_{y,es,b,r} \quad (18)$$

where,

$NEQTSHR_{y,es,b,r}$ is the new market share for the new equipment type by year, housing type, and Census Division.

$REQTSHR_{y,es,b,r}$ is the new market share for the replacement equipment type by year, housing type, and Census Division.

The weighted average equipment efficiencies for the equipment types within each equipment class are then computed as,

$$\begin{aligned} WTEQCEFFN_{y,eg,b,r} &= \frac{\sum_{es}\left[\frac{NEQTSHR_{y,es,b,r}}{RTEQEFF_{y,es}}\right]}{\sum_{es} NEQTSHR_{y,es,b,r}} &&, \ if \sum_{es} NEQTSHR_{y,es,b,r} > 0 \\ WTEQCEFFN_{y,eg,b,r} &= \frac{1}{RTBASEFF_{eg}} &&, \ otherwise \end{aligned} \quad (19)$$

$$\begin{aligned} WTEQCEFFR_{y,eg,b,r} &= \frac{\sum_{es}\left[\frac{REQTSHR_{y,es,b,r}}{RTEQEFF_{y,es}}\right]}{\sum_{es} REQTSHR_{y,es,b,r}} &&, \ if \sum_{es} REQTSHR_{y,es,b,r} > 0 \\ WTEQCEFFR_{y,eg,b,r} &= \frac{1}{RTBASEFF_{eg}} &&, \ otherwise \end{aligned} \quad (20)$$

where,

$WTEQCEFFN_{y,eg,b,r}$ is the weighted average efficiency of new equipment type within each equipment class by year, housing type, and Census Division.

$WTEQCEFFR_{y,eg,b,r}$ is the weighted average efficiency of replacement equipment types within each equipment class by year, housing type, and Census Division.

Appliance Stock Component

The appliance stock component tracks the major energy-consuming equipment by housing vintage and equipment vintage for additions, replacements, and surviving equipment.

Table 5 depicts the equipment accounting methodology. For simplicity, this discussion omits the details of the variable subscripts, which is explained later. The equipment accounting system partitions equipment into two major categories, depending on the vintage of the housing unit: equipment installed in housing units built before 1998 (at the beginning of a model run) and equipment added to new housing units (those added during the model run). Equipment is further partitioned into three additional survival/replacement categories: equipment that survives, equipment purchased to replace other equipment, and equipment purchased for new construction. The categorization of equipment by housing vintage and surviving/replacement type results in six categories of equipment that are tracked.

Table 5. Heating Equipment, UEC and Housing Shell Accounting Scheme

Housing Units that Existed in 1997

Equipment	UEC	Shell
EQCRP90RP	EQCNUEC	EHSHELL
EQCRP90	EQCRUEC	EHSHELL
EQCSR90	EQCAUEC	EHSHELL
EQCESE	EQCSUEC	EHSHELL

Housing Units Added From 1997 through 2015

Equipment	UEC	Shell
EQCADD	EQCNUEC	NHSHELL
EQCREP	EQCNUEC	AHSHELL
EQCSUR	EQCAUEC	AHSHELL

The equipment categories for pre-1998 housing units are:

EQCESE denotes the surviving pre-1998 equipment stock in pre-1998 homes,

EQCSR90 represents equipment stock in pre-1998 homes that has been replaced after 1997 and that still survives, and

EQCRP90 is current-year replacement equipment for pre-1998 housing.

EQCRP90RP is current-year replacements for the EQCRP90 equipment.

Note: EQCND90 is the sum of EQCESE, EQCSR90, EQCRP90RP, and EQCRP90.

The equipment categories for post-1997 housing units are:

EQCSUR denotes equipment that has been modeled as added and still survives,

EQCREP is equipment that has been modeled as added and is in need of replacement in the current year, and

EQCADD is equipment for housing units added in the current year.

Unit energy consumption (UEC) is tracked for equipment added by category of housing unit:

EQCUEC is the average UEC for the original 1997 equipment in housing units that existed in 1997,

EQCSUEC is the average UEC for surviving equipment in pre-1998 housing units,

EQCAUEC is the average UEC for surviving equipment in post-1998 housing units,

EQCRUEC is the UEC for all equipment added in the current year to replace pre-1998 equipment, and

EQCNUEC is the UEC for all equipment added in the current year, other than EQCRP90.

Shell indices are modeled for three categories of housing units:

EHSHELL is the shell index applicable to pre-1998 housing units,

AHSHELL is the shell index applicable to housing units added in all but the current year, and

NHSHELL is the shell index for housing units added in the current year.

For example, in accounting for the heating energy consumption of surviving equipment installed in pre-1998 housing units, the equipment stock, HTESE, would be multiplied by the unit energy consumption, HTUEC, and by the shell index EHSHELL. This explanation was designed to account for heating equipment, but the accounting principle is used throughout the residential module. For the pre-1998 housing example above, the appropriate space cooling variables would be CLESE, CLUEC and ECSHELL. The shell indices apply only to heating and cooling, thus, for example, for refrigeration the accounting requires only RFESE and RFUEC.

The housing decay rate is used in conjunction with the equipment survival rate to determine the number of equipment units that survive/retire each year in the forecast. A linear function is used to model the retirement of equipment after a minimum age is reached up to its maximum age. The linear function is expressed by,

$$SVRTE_{y-t,L_{min},L_{max}} = 1.0 \qquad , \text{ if } y-t \le L_{min}$$

$$SVRTE_{y-t,L_{min},L_{max}} = \frac{L_{max} - (y-t)}{L_{max} - L_{min}} \quad , \text{ if } L_{min} < y-t < L_{max} \qquad \textbf{(21)}$$

$$SVRTE_{y-t,L_{min},L_{max}} = 0.0 \qquad , \text{ if } y-t \ge L_{max}$$

where,

$SVRTE_{y-t,L_{min},L_{max}}$	is the equipment survival function,
y-t	is the age of the equipment,
L_{min}	is the minimum equipment lifetime in years, and
L_{max}	is the maximum equipment lifetime in years.

Equipment in post-1997 (new) houses is the product of the number of new houses and the market share of each equipment class. This is expressed as,

$$EQCADD_{y,t,eg,b,r} = HSEADD_{y,b,r} \times SHARESN_{y,eg,b,r} \qquad \textbf{(23)}$$

where,

$EQCADD_{y,t,eg,b,r}$	is the number of post-1997 vintage equipment units added to new houses in year *y*, vintaged to year *t*, by housing type and Census Division,
$HSEADD_{y,b,r}$	is the number of new housing units constructed in the forecast year by housing type and Census Division,
$SHARESN_{y,eg,b,r}$	is the current year market share for each equipment class by housing type and Census Division.

The number of replacements for the post-1997 equipment units in post-1997 houses is calculated as:

$$EQCREP_{y,t,eg,b,r} = \sum_{t=1998}^{y-1} \left(EQCADD_{t,eg,b,r} \times HDR_b^{y-t} \times (1 - SVRTE_{eg}) \right) \quad \textbf{(24)}$$

where,

$EQCREP_{y,t,eg,b,r}$	is the number of equipment replacements of post-1997 equipment in post-1997 houses,
HDR_b	is the housing survival rate by housing type, and
y-t	represents the age of the equipment.

Post-1997 replacement units required for pre-1998 houses in the current year are calculated as,

$$EQCRP90_{y,t,eg,b,r} = EQCESE_{1997,eg,b,r} \times EQCRET_{y,eg} \times HDR_b \quad \textbf{(25)}$$

where,

$EQCRP90_{y,t,eg,b,r}$	is the number of replacement units required for pre-1998 homes in year *y*, vintaged to year *t* by housing type and Census Division,
$EQCRET_{y,eg}$	is the equipment retirement rate for pre-1998 houses by forecast year,
$EQCESE_{1997,eg,b,r}$	is the pre-1998 vintage stock of equipment in pre-1998 vintage houses in 1997 by housing type and Census Division.

Within the forecast period, some of the EQCRP90 will also need to be replaced. This is represented as,

$$EQCRP90RP_{y,t,eg,b,r} = \sum_{y=1998}^{t-1} \left(EQCRP90_{y,t,eg,b,r} + EQCRP90RP_{y,t,eg,b,r} \right) * (1 - SVRTE_{eg}) \quad \textbf{(26)}$$

where,

$EQCRP90RP_{y,t,eg,b,r}$	is the number of replacement units required to replace post-1997 equipment in pre-1998 houses by forecast year, housing type and Census Division.

Next, a series of calculations is made to determine the number of replacement units that switch to a different technology type. For each type of replacement (EQCRP90, EQCRP90RP, EQCREP), first calculate the number of eligible switches (single-family houses only).

$$ELIGIBLE_{y,eg,b,r} = \sum_{eg} \left(EQCRP90_{y,t,eg,b,r} + EQCRP90RP_{y,t,eg,b,r} + EQCREP_{y,t,eg,b,r} \right) * SWFACT_{eg} \quad \textbf{(27)}$$

where,

$ELIGIBLE_{y,eg,b,r}$	is the nubmer of replacements eligible to switch technology types by housing type and Census Division, and
$RTSWFACT_{eg}$	is the fraction who may switch from equipment class eg.

The “switching” weight for each equipment type is calculated as,

$$RPWEIGHT_{y,egsw,b,r} = e^{[\ RTSWBIAS_{egsw} + RTSWBETA_{egsw} \times (\ LFCY_{y,essw,b,r,v} + RPINSCOST_{eg,egsw}\ )\ ]} \tag{28}$$

Summing over all equipment types,

$$TOTSH_{y,b,r} = \sum_{egsw=1}^{egsw=11} RPWEIGHT_{y,egsw,b,r} \tag{29}$$

allows for shares summing to 100 percent.

$$\begin{aligned} RPSHARE_{y,egsw,b,r} &= \frac{RPWEIGHT_{y,egsw,b,r}}{TOTSH_{y,b,r}} \quad , \ if\ TOTSH_{y,b,r} > 0 \\ RPSHARE_{y,egsw,b,r} &= 0 \quad , \ otherwise \end{aligned} \tag{30}$$

where,

$RPSHARE_{y,egsw,b,r}$	is the share that will switch to equipment class *egsw* on replacement by year, housing type, and Census Division,
$RPWEIGHT_{y,egsw,b,r}$	is the weight assigned to each equipment class *egsw* by year, housing type, and Census Division,
$RTSWBIAS_{egsw}$	is the consumer preference parameter for switching to this equipment class,
$RTSWBETA_{egsw}$	is the parameter value for the same fit,
$LFCY_{y,essw,b,r,v}$	is the lifecycle cost of the equipment type switching to (essw) by year, building type, region , and vintage,
$RPINSCOST_{eg,egsw}$	is the cost of switching from equipment class eg to egsw on switching, and
$TOTSH_{y,b,r}$	is the sum of the switch weigts.

The equipment classes are then reconciled by “from” and “to” switching categories and redistributed to the correct equipment class.

The surviving post-1997 vintage equipment in pre-1998 houses is computed as,

$$EQCSR90_{y,eg,b,r} = \sum_{t=1998}^{y-1} \left(\left(EQCRP90_{t,y,eg,b,r} + EQCRP90RP_{t,y,eg,b,r} \right) \times SVRTE_{y-t,Lmin,Lmax} \times HDR_b^{y-t} \right) \quad \textbf{(31)}$$

where,

$EQCSR90_{y,eg,b,r}$	is the equipment stock in pre-1998 homes that has been replaced after 1997 and still survives by housing type and Census Division,
$EQCRP90_{t,y,eg,b,r}$	is the number of replacement (post-1997 vintage) equipment units demanded each year in pre-1998 houses by housing type and Census Division,
$EQCRP90RP_{t,y,eg,b,r}$	is the number of replacements of the EQCRP90 equipment units demanded each year by housing type and Census Division,
$SVRTE_{y-t,L_{min},L_{max}}$	is the equipment survival function,
HDR_b	is the housing survival rate by housing type, and
y-t	represents the age of the equipment.

Surviving post-1997 equipment, originally purchased as additions or replacements in post-1997 houses, is calculated as,

$$EQCSUR_{y,eg,b,r} = \sum_{t=1998}^{y-1} \left[\left(EQCADD_{t,eg,b,r} + EQCREP_{t,eg,b,r} \right) \times SVRTE_{y-t,Lmin,Lmax} \times HDR_b^{y-t} \right] \quad \textbf{(33)}$$

where,

$EQCSUR_{y,eg,b,r}$	is the surviving post-1997 equipment purchased as additions or replacements in post-1997 houses by housing type and Census Division,
$EQCADD_{t,eg,b,r}$	is the quantity of post-1997 vintage equipment added to post-1997 houses by forecast year, housing type and Census Division,
$SVRTE_{y-t,Lmin,Lmax}$	is the equipment survival function,
HDR_b	is the housing survival rate by housing type,
$EQCREP_{t,eg,b,r}$	is the number of equipment replacements of post-1997 equipment in post-1997 houses, and

y-t represents the age of the equipment.

Shell Integrity Component

The shell integrity component uses three indices to capture the increases in the energy efficiency of building shells over time. One index corresponds to the pre-1998 housing stock, and two indices correspond to the post-1997 stock, one for housing constructed in the current year and the other for the average post-1997 stock. The shell indices are adjusted each year to account for fuel price increases (decreases have no effect on shell integrity, i.e., shell efficiency increases as price increases) and technology improvements.

An important part of shell integrity is the quality of windows. In the Energy Policy Act, there are regulations that require that all new windows be labeled with an index that describes their insulation properties. These regulations will be phased in over a period of years, beginning in 1995. The residential module evaluates the impacts of these regulations by means of an annual input variable, $EPWINPCT_y$, that gives the proportion of existing houses expected to be subject to window labeling. This quantity, when multiplied by the fraction of heat savings expected to be afforded by labeled windows, currently set at .08, gives the expected savings rate due to window labeling, $EPACTH_y$.

The first step in the algorithm calculates the percentage price change for all heating fuels as,

$$PRIDELTA_{f,r} = \frac{PRICES_{f,r,y} - PRICES_{f,r,1997}}{PRICES_{f,r,1997}} \times \frac{1}{PSTEP} \qquad \textbf{(34)}$$

where,

$PRIDELTA_{f,r}$ is the percentage change in price from the base year by fuel and Census Division converted to 5 percentage point increments,

PSTEP is a constant that is set to 0.05 to convert the percentage change in fuel price to the number of 5 percentage point increments of price change,

$PRICES_{f,r,y}$ is the fuel price by fuel, Census Division and year, and

$PRICES_{f,r,1997}$ is the 1997 (base year) fuel price by fuel and Census Division.

The PRIDELTA variable is spread out over a five year period to allow for a lagged response to price increases for shell improvements.

The existing housing heating shell index is calculated as,

$$
\begin{aligned}
EHSHELL_{y,f,r,b} &= EHSHELL_{y-1,f,r,b} &&, \text{ if } EHSHELL_{y,f,r,b} > EHSHELL_{y-1,f,r,b}\\
EHSHELL_{y,f,r,b} &= LIMIT &&, \text{ if } EHSHELL_{y,f,r,b} \geq LIMIT\\
EHSHELL_{y,f,r,b} &= (1. - PRIDELTA_{f,r} \times SSTEP) \times TECHG_{e,r,b} \times (1. - EPACTH_{y}) &&, \text{ otherwise}
\end{aligned} \quad \textbf{(35)}
$$

where,

- $EHSHELL_{y,f,r,b}$ is the shell integrity index for existing housing by year, fuel, Census Division, and building type,
- LIMIT limits the maximum shell index efficiency to 0.3 (i.e., maximum shell efficiency is limited to a 70-percent improvement on the base year value), and
- SSTEP is set to 0.01 and is a component of the shell elasticity with respect to heating fuel price,
- $TECHG_{1,d,b}$ is a parameter that represents the annual increase in existing shell integrity due to technology improvements, and
- $EPACTH_{y}$ is the projected national fractional savings in heating energy consumption from the EPACT window labeling program in year y, from the RMISC file.

PSTEP converts the percentage change in price to the number of 5 percentage point increments of price change in Equation Figure 1. In equation Figure 1, PRIDELTA is multiplied by SSTEP and converted to the shell efficiency index. Every 5 percentage point increase in fuel price relative to the base year results in a shell efficiency index decrease of 1 percentage point of the base year shell efficiency up to the limit of 0.3.

The new housing heating shell index is calculated as,

$$
\begin{aligned}
NHSHELL_{y,f,r,b} &= NHSHELL_{y-1,f,r,b} &&, \text{ if } NHSHELL_{y,f,r,b} > NHSHELL_{y-1,f,r,b}\\
NHSHELL_{y,f,r,b} &= LIMIT &&, \text{ if } NHSHELL_{y,f,r,b} < LIMIT\\
NHSHELL_{y,f,r,b} &= NHSHELL_{1998,f,r,b} \times TECHG_{e,r,b} + PRIDELTA_{f,r} \times SSTEP &&, \text{ otherwise}
\end{aligned} \quad \textbf{(36)}
$$

where,

- $NHSHELL_{y,f,r,b}$ is the new housing units shell integrity index by year, fuel, Census Division, and building type,
- $TECHG_{2,d,b}$ is a parameter that represents the annual increase in new shell integrity due to technology improvements,
- $PRIDELTA_{f,r}$ is the percent change in price of the fuel by Census Division in 5 percentage point increments,

SSTEP is set to 0.01 and is a component of the shell elasticity with respect to heating fuel price.

The average post-1997 housing heating shell index is calculated as,

$$AHSHELL_{y,f,r,b} = \frac{\sum_{eg} [NHSHELL_{y,f,r,b} \times EQCADD_{y,eg,b,r} + AHSHELL_{y-1,f,r,b} \times (EQCREP_{y,eg,b,r} + EQCSUR_{y,eg,b,r})]}{\sum_{eg} [EQCADD_{y,eg,b,r} + EQCREP_{y,eg,b,r} + EQCSUR_{y,eg,b,r}]} \quad \textbf{(37)}$$

where,

$AHSHELL_{y,f,r,b}$ is the average post-1997 heating shell index by year, fuel, Census Division, and building type, equal to NHSHELL in 1998,

$NHSHELL_{y,f,r,b}$ is the new housing units shell integrity index by year, fuel, Census Division, and building type,

$EQCADD_{y,eg,b,r}$ is the number of equipment units installed in new construction by forecast year, housing type and Census Division,

$EQCREP_{y,eg,b,r}$ is the number of equipment replacements of post-1997 equipment in post-1997 houses, and

$EQCSUR_{y,eg,b,r}$ is the surviving post-1997 equipment purchased as additions or replacement in post-1997 houses by forecast year, housing type and Census Division.

In addition to the calculation shown above, the module places two additional restrictions upon $AHSHELL_y$: it may never increase, and it must not fall below LIMIT. If ever $AHSHELL_y$ is calculated to increase, its value is set to the prior year's value; if it falls below LIMIT, it is set equal to LIMIT.

Consumption and UEC Component

Final end-use fuel consumption is determined by the fuels demanded by the equipment to provide households with the demanded services. For each equipment class, the UEC for new equipment, replacement equipment, and the average of all equipment is computed. New equipment UEC values are calculated as:

$$EQCNUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \times WTEQCEFFN_{y,eg,b,r} \times RTBASEFF_{1997,eg} \times HDDFACT_r \times SQFTADJ_{y,b,r} \quad , \text{ if } WTEQCEFFN_{y,eg,b,r} > 0$$

$$EQCNUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \times HDDFACT_r \times SQFTADJ_{y,b,r} \quad , \text{ otherwise} \qquad \textbf{(38)}$$

where,

$EQCNUEC_{y,eg,b,r}$ is the unit energy consumption for new equipment by forecast year, housing type and Census Division,

$WTEQCEFFN_{y,eg,b,r}$ is the equipment class efficiency weighted by the market share of the specific equipment as computed in the logistic function in the technology choice component by housing type and Census Division,

$RTBASEFF_{1997,eg}$ is the 1997 stock-average efficiency of the equipment class,

$EQCUEC_{r,eg,b}$ is unit energy consumption for original 1997 stock of the equipment class by Census Division and housing type,

$HDDFACT_r$ is the heating degree day adjustment factor by Census Division to correct for the unusually warm weather during the RECS survey year, and

$SQFTADJ_{y,b,r}$ is the adjustment for increasing floor area of new houses.

Replacement equipment UEC values are calculated as:

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \times WTEQCEFFR_{y,eg,b,r} \times RTBASEFF_{1997,eg} \times HDDFACT_r \quad , \text{ if } WTEQCEFFR_{y,eg,b,r} > 0 \qquad \textbf{(39)}$$

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \times HDDFACT_r \quad , \text{ otherwise}$$

where,

$EQCRUEC_{y,eg,b,r}$ is the unit energy consumption for replacement equipment by housing type and Census Division,

$RTBASEFF_{1997,eg}$ is the efficiency of the weighted average of retiring units from the 1997 existing stock, and

$WTEQCEFFR_{y,eg,b,r}$ is the replacement equipment efficiency weighted by the market share of the specific equipment as computed in the logistic function in the technology choice component by housing type and Census Division.

And the UEC for the surviving stock must be adjusted, according to:

$$EQCSUEC_{y-1,eg,b,r} = EQCUEC_{r,eg,b} \times HDDFACT_r \times \frac{RTBASEFF_{1997,eg}}{RTBASEFF_{y,eg}} \quad (40)$$

where,

$EQCSUEC_{y,eg,b,r}$ is the average unit energy consumption of the original 1997 equipment stock that remains after the replacements have taken place.

The average UEC for all equipment is calculated as:

$$EQCAUEC_{y,eg,b,r} = EQCNUEC_{y,eg,b,r} \times HDDFACT_r \quad , \text{ if } y = 1997$$

$$EQCAUEC_{y,eg,b,r} = EQCNUEC_{y,eg,b,r} \quad , \text{ if the equipment stock } \leq 0$$

$$EQCAUEC_{y,eg,b,r} = \frac{\begin{array}{c} EQCRP90_{y,eg,b,r} \times EQCRUEC_{y,eg,b,r} \\ + (EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP90RP_{y,eg,b,r}) \times EQCNUEC_{y,eg,b,r} \\ + (EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r}) \times EQCAUEC_{y-1,eg,b,r} \end{array}}{\begin{array}{c} EQCRP90_{y,eg,b,r} + EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r} \end{array}} \quad , \text{ otherwise} \quad (41)$$

The final step of this algorithm is to calculate consumption for the service category. This is accomplished in two steps. The first year of the forecast is computed initially as,

$$HTRCON_{y=1998,f,r} = \sum_b \sum_{eg} \left[\left(\begin{array}{c} EQCESE_{y,eg,b,r} \times EQCUEC_{eg,b,r} \times EHSHELL_{y,f,r} \\ + EQCADD_{y,eg,b,r} \times EQCNUEC_{y,eg,b,r} \times NHSHELL_{y,f,r} \\ + EQCRP90RP_{y,eg,b,r} \times EQCNUEC_{y,eg,b,r} \times EHSHELL_{y,f,r} \\ + EQCRP90_{y,eg,b,r} \times EQCNUEC_{y,eg,b,r} \times EHSHELL_{y,f,r} \end{array} \right) \times \left(\frac{PRICES_{y,f,r}}{PRICES_{y-1,f,r}} \right)^{\alpha} \right] \quad (42)$$

and subsequent consumption as,

$$HTRCON_{y,f,r} = \sum_b \sum_{eg} \left[\left(\begin{array}{c} EQCESE_{y,eg,b,r} \times EQCUEC_{eg,b,r} \times EHSHELL_{y,f,r} \\ + EQCADD_{y,eg,b,r} \times EQCNUEC_{y,eg,b,r} \times NHSHELL_{y,f,r} \times RBN_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} \times EQCRUEC_{y,eg,b,r} \times EHSHELL_{y,f,r} \times RBR_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} \times EQCNUEC_{y,eg,b,r} \times EHSHELL_{y,f,r} \times RBN_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} \times EQCAUEC_{y,eg,b,r} \times EHSHELL_{y,f,r} \times RBA_{y,eg,b,r} \\ + EQCREP_{y,eg,b,r} \times EQCNUEC_{y,eg,b,r} \times AHSHELL_{y,f,r} \times RBN_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} \times EQCAUEC_{y,eg,b,r} \times AHSHELL_{y,f,r} \times RBA_{y,eg,b,r} \end{array} \right) \times \left(\frac{PRICES_{y,f,r}}{PRICES_{1997,f,r}} \right)^{\alpha} \right] \quad (43)$$

where,

α is the short-term price elasticity, presently valued at -0.25 and

Here, there is a new concept called the ``rebound effect'' that accounts for the fact that increasing equipment efficiency for a particular equipment class causes a corresponding change in the price elasticity for the class. Three variables represent this effect:

$$RBA_{y,eg,b,r} = WTEQCEFFA_{y,eg,b,r} \times RTBASEFF_{1997,eg}^{\alpha_1} \quad \textbf{(44)}$$

$$RBR_{y,eg,b,r} = WTEQCEFFR_{y,eg,b,r} \times RTBASEFF_{1997,eg}^{\alpha_1} \quad \textbf{(45)}$$

$$RBN_{y,eg,b,r} = WTEQCEFFN_{y,eg,b,r} \times RTBASEFF_{1997,eg}^{\alpha_1} \quad \textbf{(46)}$$

where,

$RBA_{y,eg,b,r}$ is the rebound effect factor for surviving equipment,

$RBR_{y,eg,b,r}$ is the rebound effect factor for replacement equipment, and

$RBN_{y,eg,b,r}$ is the rebound effect factor for new equipment.

α_1 is the rebound effect elasticity, presently valued at -0.15

Appendix A: Data Sources and Input Parameters

The Technology Choice Component requires extensive data describing end-use technologies. Equipment costs, efficiency levels, and other characteristics are specified for all the technologies included in the menu of choices. These data are drawn from numerous sources including Lawrence Berkeley Laboratory (LBL)[1], Arthur D. Little (ADL)[2], Gas Research Institute (GRI)[3], Electric Power Research Institute (EPRI)[4], Gas Appliance Manufacturing Association (GAMA)[5], Association of Home Appliance Manufacturers (AHAM), and the Air Conditioning and Refrigeration Institute (ARI)[6].

The remaining text of Appendix A describes the input data sources for the variables presented in Tables A-1 and A-2 where applicable information is available.

---

[1] Lawrence Berkeley Laboratory, "Energy Data Sourcebook for the U.S. Residential Sector," Berkeley, CA, May, 1997.

[2] Arthur D. Little, "EIA - Technology Forecast Updates," Reference Number 37125-00, 1998.

[3] Gas Research Institute, "Baseline Projection Data Book," Lexington, MA, 1990.

[4] Electric Power Research Institute, "Draft Model Documentation for Residential End-use Energy Planning System (REEPS), Version 2.0," Palo Alto, CA, 1990.

[5] Gas Appliance Manufacturers Association, "Consumers' Directory for Certified Efficiency Ratings," Arlington, VA, 1994.

[6] Air Conditioning and Refrigeration Institute, "Directory of Certified Cooling Equipment," Arlington, VA, 1994.

Residential Demand Module Input Data Files

Residential Equipment Retirement Fractions for 1997 Equipment

Definition: Retirement fractions for each of the 29 residential Equipment classes in for all forecast years.

Units: Dimensionless (units retired to date/units extant in 1997).

Source: Results from vintaging models developed based on shipment data. Shipment data from various sources including: AHAM, GAMA, ARI, LBL.

File: RSRET01.

Comments: Values in this table give the fraction of 1997 stocks of equipment expected to be retired as of each year. They are calculated in an external FORTRAN program that vintages efficiencies from the shipment data. Program reads all years.

Sequence of Equipment Classes:

Electric Furnace	Nat Gas Heat Pump	Water Heat Dist
Electric Heat Pump	Room Air Cond	Water Heat LPG
Gas Furnace	Central Air Cond	Cooking Nat Gas
Gas Boil/Radiator	Electric Heat Pump	Cooking LPG
Kerosene Furnace	Geothermal Heat Pump	Cooking Electric
LPG Furnace	Nat Gas Heat Pump	Dryers Nat Gas
Distill Furnace	Clothes Washers	Dryers Electric
Distill Other	Dishwashers	Refrigerators
Wood Stoves	Water Heat Nat Gas	Freezers
Geothermal Heat Pump	Water Heat Electric	

Variables: $EQCRET_{y,eg}$

Residential Floor Areas by Building Type, Year and Division.

Definition: Average of floor space in residential buildings in each of 3 house types, for each division, from 1990-2020.

Units: Square feet.

Source: RECS and Census C25 data series.

File: RSSQRFT.

Comments: Values after the last data year are held constant at that value. Data are used to adjust heating, cooling, and lighting loads.

Variables: $SQRFOOT_{y,b,d}$

Residential Existing Equipment

Definition: Stock of all equipment types for all end-uses in the base year within each building type in each Census Division.

Units: Number of units.

Source: EIA, Aggregation from the Residential Energy Consumption Survey 1997, DOE-EIA-0321(97).

File: RSEQP93.

Comments: Each value in the body of the table represents aggregated values from the Residential Energy Consumption Survey 1997. First, the census data were aggregated to determine the number of households in each Census Division of each building type that use the designated equipment class.

Equipment Classes Included:

Electric Furnace	Nat Gas Heat Pump	Water Heaters Distill
Electric Heat Pump	Room Air Conditioner	Water Heaters LPG
Gas Furnace	Central Air Conditioner	Cooking Nat Gas
Gas Boil/Radiator	Electric Heat Pump	Cooking LPG
Kerosene Furnace	Geothermal Heat Pump	Cooking Electric
LPG Furnace	Nat Gas Heat Pump	Dryers Nat Gas
Distill Furnace	Clothes Washers	Dryers Electric
Distill Other	Dishwashers	Refrigerators
Wood Stoves	Water Heaters Nat Gas	Freezers
Geothermal Heat Pump	Water Heaters Electric	

Variables: $EQCESE_{1997,eg,b,r}$

Residential Retired Equipment Efficiencies of 1997 stock

Definition: Retiring efficiencies for each of the 29 residential equipment classes in forecasted years.

Units: Dimensionless (energy out/energy in) except ref, frz, stoves.

Source: Results from vintaging models developed based on shipment data. Shipment data from various sources including: AHAM, GAMA, ARI, LBL.

File: RSEFF01.

Comments: Values in this table give the average efficiencies of equipment expected to be retired in each year. They are calculated in an external FORTRAN program that vintages efficiencies from the shipment data.

Equipment classes included:

Electric Furnace	Nat Gas Heat Pump	Water Heaters Distill
Electric Heat Pump	Room Air Conditioner	Water Heaters LPG
Gas Furnace	Central Air Conditioner	Cooking Nat Gas
Gas Boil/Radiator	Electric Heat Pump	Cooking LPG
Kerosene Furnace	Geothermal Heat Pump	Cooking Electric
LPG Furnace	Nat Gas Heat Pump	Dryers Nat Gas
Distill Furnace	Clothes Washers	Dryers Electric
Distill Other	Dishwashers	Refrigerators
Wood Stoves	Water Heaters Nat Gas	Freezers
Geothermal Heat Pump	Water Heaters Electric	

Variables: $EQCEFF_{y,eg}$

Residential Unit Consumption of Energy

Definition: Unit Energy Consumption (UEC) for all Residential equipment classes and building types in each Census Division. Here, the equipment classes include the 29 major classes, plus lighting, furnace fans, color televisons, personal computers, 7 secondary heater types, and 4 appliance types.

Units: Classes 1-29: MMBtu/unit/yr; classes 30-44: MMBtu/household/yr.

Source: EIA, Residential Energy Consumption Survey 1997, DOE.EIA-0321 (97).

File: RSUEC10.

Comments: Each value in the body of the table represents the annual energy consumption of a single unit of the given type in the given building type, in the given Census division, in 1997.

Equipment Classes Included:

Space Heating: Elec Furnace
Space Heating: Elec Heat Pump
Space Heating: Gas Furnace
Space Heating: Gas Boiler/Rad
Space Heating: Kero Furnace
Space Heating: LPG Furnace
Space Heating: Dist Furnace
Space Heating: Dist Other
Space Heating: Wood Stoves
Space Heating: Geothermal HP
Space Heating: Natural Gas HP
Space Cooling: Room Air Cond
Space Cooling: Cent Air Cond
Space Cooling: Elec Cool Pump
Space Cooling: Geo Cool Pump
Space Cooling: Nat G Cool Pump
Clothes Washers
Dishwashers
Water Heater: Natural Gas
Water Heater: EL
Water Heater: Distillate
Water Heater: LPG
Cooking: Natural Gas
Cooking: LPG
Cooking: Electric
Drying: Natural Gas
Drying: Electric
Refrigeration
Freezing
Lighting
Furnace Fans
Color Televisions
Personal Computers
Electric Appliances
Secondary Heater: Natural Gas
Secondary Heater: Electric
Secondary Heater: Distillate
Secondary Heater: LPG
Secondary Heater: Kerosene
Secondary Heater: Coal
Secondary Heater: Wood
Appliance: Natural Gas
Appliance: LPG
Appliance: Distillate

Variables: $EQCUEC_{r,eg,b}$

Residential Heating Equipment Shares for New Equipment

Definition: Market share of general space heating equipment for new homes in the base year. Gives the share of each equipment class by building type and Census Division.

Units: Fraction of purchases.

Source: Bureau of the Census C25 data, as described in Characteristics of New Housing: 1997, C25/97-A.

File: RSHTSHR.

Comments: Shares of heating equipment classes in new homes. Each value in the body of the table represents a fraction of aggregated values from the C25 database. First, the Census data were aggregated to determine the number of new houses in each Census Division of each building type that used the designated equipment class. These values were divided by the number of new houses in each Census Division and building type.

Equipment Classes Included:

- Electric Furnace
- Electric Heat Pump
- Gas Furnace
- Gas Boiler/Radiator
- Kerosene Furnace
- LPG Furnace
- Distillate Furnace
- Distillate Other
- Wood Stoves
- Geothermal Heat Pump
- Natural Gas Heat Pump

Variables: $HSYSSHR_{1997,eg,b,r}$

Benchmarking Data from Short-Term Energy Outlook

Definition: Household energy consumption by fuel and Census Division for the years 1997, 1998, 1999 and 2000.

Units: Trillion Btu.

Source: Short-Term Integrated Forecasting System 1999Q3.

File: RSSTEO.

Comments: National total energy consumption by fuel and year comes from STIFS, based on 1997 through 2000 forecasts. These forecasts are allocated to Census divisions using SEDS historical data for 1990-1996 average, broken out by fuel and Census division. Calculations are in spreadsheet

SEDS96.XLS

Variables: $STEOCN_{y,f,r}$

Residential Technology Equipment Class Description File

Definition: Technology choice parameters for classes of equipment.

Units: See discussion of individual variables below.

Source: RTECH.WB1

File: RTEKCL.

Comments: Each of the 29 lines of this data file gives the important user-modifiable parameters for one equipment class. Used by the RDM for allocating equipment choice among the individual equipment classes.

Variable Descriptions:

$RTCLENDU_{eg}$ End use number. Equipment classes having the same end use compete with one another. The RDM allocates equipment among them in the technology choice process.

1=Space Heating
2=Space Cooling
3=Clothes Washers
4=Dishwashers
5=Water Heating
6=Cooking
7=Clothes Drying
8=Food Refrigeration
9=Food Freezing

Matches $RTTYENDU_{es}$ in the RTEKTY file.

$RTCLEQCL_{eg}$ Equipment class number. Appears on all records. Matches $RTTYEQCL_{es}$ in the RTEKTY file for one or more equipment types: there are one or more equipment types in RTEKTY for each class in RTEKCL.

$RTCLTYPT_{eg}$ Required pointer from equipment class to a representative equipment type. This is the only pointer from RTEKCL to RTEKTY. Selects the equipment type used in the log-linear formula for choice of equipment class for newly constructed housing units and replacements in single-family houses. Its value is the $RTEQTYPE_{es}$ in RTEKTY of the representative equipment.

$RTCLPNTR_{eg}$ Class pointer. Required for end uses 1 through 3; zero otherwise.

If end use = 1: Required pointer from space heater class to associated water heater class linking water heater fuel choice to space heater fuel choice for newly constructed housing units.

If end use = 2: Required pointer from cooling heat pump class to same class of heating heat pump.

0 = Not a heat pump

Integer = Heater heat pump class number

If end use = 3: Required pointer from water heater class to matching cooking class linking cooking fuel choice to water heater fuel choice for newly constructed housing units. Also see $RTCLREPL_{eg}$ end use 3 below; only natural gas water heaters may point to 2 types of cookstoves.

$RTCLREPL_{eg}$ Replacement class. Required for end uses 1 and 3; zero otherwise.

If end use = 1: Flag for replacing the existing space heater class with a natural gas forced air space heater at retirement (subject to switching limits described under GSL).

If end use = 3: Second pointer from natural gas water heater class to matching cooking class. The model assumes that 65% of new homes with natural gas water heaters have natural gas stoves and 35% have electric stoves.

$RTFUEL_{eg}$ Fuel used by this equipment.

1=Distillate

2=LPG

3=Natural Gas

4=Electricity (wood priced to electricity)

5=Kerosene

$RTMAJORF_{eg}$ Major fuel flag. Used only for end use 1; zero otherwise. Space heater shares for systems using major fuels are calculated differently from space heater shares for systems using minor fuels. Set to 1 to indicate a major fuel. Set to 0 to indicate a minor fuel.

$RTFAN_{eg}$ Furnace fan flag. Value of 1 assigns use of a furnace fan with respective central heating/cooling technology; zero otherwise.

$RTBASEFF_{eg}$ Base efficiency for this equipment class. Defined differently for different end uses:

End uses 1,2,3,5: base efficiency for this equipment class.

End uses 4,6,7: 1 / base efficiency for this equipment class.

$RTALPHA_{eg}$ Equipment life α.

$RTMINLIF_{eg}$ Minimum life of this equipment class (years).

$RTMAXLIF_{eg}$ Maximum life of this equipment class (years).

$RTFCBETA_{eg}$ New home heating technology choice model log-linear parameter β. Used only for end use 1; zero otherwise.

$RTFCBIAS_{eg}$ New home heating technology choice model bias parameter. Used only for end use 1; zero otherwise.

$RTSWFACT_{eg}$ Maximum fraction of single-family homes which may switch away from this equipment class on replacement.

$RTSWBETA_{eg}$ Replacement technology choice model log-linear parameter β. Used only for single-family homes.

$RTSWBIAS_{eg}$ Replacement technology choice model bias parameter. Used only for single family homes.

$RTCLNAME_{eg}$ Unique name for each equipment class.

Residential Technology Equipment Type Description File

Definition: Technology choice parameters for types of equipment.

Units: See discussion of individual variables below.

Source: FTECH.WB1

File: RTEKTY.

Comments: Each of the lines of this data file gives the important user-modifiable parameters for one equipment type. Used by the RDM for allocating equipment choice among the individual equipment types.

Variable Descriptions:

$RTTYENDU_{es}$ End Use number as in RTEKCL. Matches RTCLENDU in the RTEKCL file.

$RTTYEQCL_{es}$ Equipment class for this equipment type. MUST match a class number, $RTCLEQCL_{eg}$, in the RTEKCL file.

$RTEQTYPE_{es}$ Equipment type number. Each equipment class may include multiple types. Each equipment type may have up to one record for each year of the forecast period. DO NOT overlap years. The user may add equipment types to existing classes. When adding new types, update the type numbers for the rest of that end use; also, adjust the RTTYPNTR pointer for cooling and the RTCLTYPT pointer in the RTEKCL file for heating. If adding heat pump types, add same type to both space heating and space cooling and adjust pointers.

$RTINITYR_{es}$ Initial calendar year for this model of this equipment type. The first $RTINITYR_{es}$ for a model within a type should be the NEMS base year (1993); subsequent initial years for a model must be previous $RTLASTYR_{es}$+1.

$RTLASTYR_{es}$ Last calendar year for this model of this equipment type. Must greater than or equal to $RTINITYR_{es}$ for this model; final $RTLASTYR_{es}$ should be the last year of the forecast period (2015).

$RTTYPNTR_{es}$ Required pointer from cooling heat pump type to same type of heating heat pump. Also used as a flag to mark room air conditioners and central air conditioners. Used by end use 2 only; zero otherwise. Modify as follows only if heat pumps added:

-1 = Room air conditioner

0 = Central air conditioner (not heat pump)

Other Integer = Matching heater heat pump type number

$LOADADJ_{es}$ Proportion of hot water heating load affected by efficiency gains is end-uses 3 and 4.

$RTEQEFF_{es}$ Defined differently for different end uses:

If end use = 1,2,3,4,5,7: Equipment type efficiency (AFUE, COP, etc.).

If end use = 6,8,9: Energy consumption for prototypical models (e.g., annual Kwh consumption for 18 cu ft refrigerators).

$RTEQCOST_{es}$ Installed capital cost in $1998 per unit for new homes.

$RTRECOST_{es}$ Retail capital cost in $1998 per unit for replacements.

$RTMATURE_{es}$ Technology maturity description.

`MATURE' = No further cost reductions expected; use above constants for installed wholesale and retail capital costs.

`ADOLESCENT' = Main cost reductions occurred before base year (1996); function *EQCOST* reduces installed wholesale and retail capital cost with 1996 (or first year of availability) as the inflection point.

`INFANT' = All cost reductions expected after first year of availability; function *EQCOST* reduces installed wholesale and retail capital cost with the inflection point in the future.

$RTCOSTP1_{es}$ If `MATURE' technology, not used.

If `ADOLESCENT' technology, representative year cost decline began (y_1 in code).

If `INFANT' technology, year of inflection of cost trend (y_0 in code).

$RTCOSTP2_{es}$ If `MATURE' technology, not used.

If `ADOLESCENT' or `INFANT' technology, logistic curve shape parameter (gamma in code).

RTCOSTP3$_{es}$ If `MATURE' technology, not used.

If `ADOLESCENT' technology, total possible proportional decline in equipment cost from y_0 onward (d in code).

If `INFANT' technology, total possible proportional decline in equipment cost from y_1 onward (d in code).

RTECBTA1$_{es}$ Efficiency choice model log-linear parameter β_1, weights capital cost.

RTECBTA2$_{es}$ Efficiency choice model log-linear parameter β_2, weights fuel cost.

RTECBTA3$_{es}$ Efficiency choice model log-linear parameter β_3, weights life cycle cost.

RTECBIAS$_{es}$ Efficiency choice model, consumer preference log-linear parameter; fits current market shares to shipment data.

RTTYNAME$_{es}$ Unique name for each equipment type. Do not modify existing names. Add unique names for new types.

Miscellaneous Residential Module Inputs

Definition: This file supplies a number of tables that define parameters for the RDM. Each of the tables is discussed individually below.

Units: Discussed for each variable.

Source: User Options.

File: RMISC.

Comments: These tables are all read line-by-line in the logic of the RDM. The shape of each is read by the logic that reads the data.

Variables:

HDR$_b$ Housing Demolition Rates by Building Type.

EH$_{1997,b,r}$ Existing Houses in 1997 by Building Type and Census Division (With Totals).

RACSAT$_{b,r}$ New Room Air Conditioner Saturation Level by Building Type and Census Division.

CACSAT$_{b,r}$ New Central Air Conditioner Saturation Level by Building Type and

Census Division.

$CACPR_r$ Central A/C Penetration Rate by Census Division (1.+x).

$FRZSAT_{b,r}$ New Home Freezer Saturation Level by Building Type and Census Division.

$ELDRYPR_{b,r}$ Electric Dryer Penetration Rate by Building Type and Census Division (1.+ x / 23.).

$SLSHR_{b,r}$ Solar Water Heating Share by Census Division.

$NEWSLSHR_{r,b}$ New Solar Water Heating Share by Census Division and Building Type.

$RENSHR_r$ Share of Total Photovoltaic Electricity Consumption Allocated to each Census Division.

$SHTSHR_{r,f,b}$ Secondary Heating Share by Fuel, building Type, and Census Division.

$OTSHR_{r,f,b}$ Other Uses Share by Fuel, building Type, and Census Division.

$EHSHELL_{1997,f,r,b}$ Existing Heating Shell Indices by Fuel, Building Type, and Census Division (First Year Only).

$ECSHELL_{1997,r,b}$ Existing Cooling Shell Indices by Building Type and Census Division (First Year Only).

$NHSHELL_{1998,f,r,b}$ New Heating Shell Indices by Fuel, Building Type, and Census Division (First Year Only).

$NCSHELL_{1998,r,b}$ New Cooling Shell Indices by Building Type and Census Division (First Year Only).

$SHELLCH_{f,r,b}$ Shell Efficiency Improvement rate by Fuel, Building Type, and Census Division (Calculated From Spreadsheet)

$HDDADJ_{y,r}$ Heating Degree Days by Census Division and Year (2000 is 2000 on).

$CDDADJ_{y,r}$ Cooling Degree Days by Census Division and Year (2000 is 2000 on).

$EPWINPCT_y$ Fraction of Existing Houses Affected by Window Labeling by Year.

$NEWDRYSAT_{eg,b,r}$ New Dryer Saturation By Type (Gas, Electric).

$RPINSCOST_{eg,egsw}$ Installation cost associated with switching from equipment class eg to equipment class egsw when equipment is replaced.

$PCSAT_{b,r}$ Number of personal computers by building type and Census Division in

1997.

$CTVSAT_{b,r}$	Number of color televisions per household by building type and Census Division in 1997.
$DISHNEW_{b,r}$	Percent of new households with dishwashers by building type and Census Division.
$WASHNEW_{b,r}$	Percent of new households with clothes washers by building type and Census Division.
ELAST	Elasticity Parameters for Calculating Model Price Elasticities.

Residential Average Stock Equipment Efficiencies of 1997 stock

Definition: Stock efficiencies for each of the 29 residential equipment classes in forecasted years.

Units: Dimensionless (energy out/energy in) except ref, frz, stoves.

Source: Results from vintaging models developed based on shipment data. Shipment data from various sources including: AHAM, GAMA, ARI, LBL.

File: RSSTKEFF.

Comments: Values in this table give the average efficiencies of equipment remaining from the 1997 stock expected to be retired in each year. They are calculated in an external spreadsheet that vintages efficiencies from the shipment data.

Equipment classes included:

Electric Furnace	Nat Gas Heat Pump	Water Heaters Distill
Electric Heat Pump	Room Air Conditioner	Water Heaters LPG
Gas Furnace	Central Air Conditioner	Cooking Nat Gas
Gas Boil/Radiator	Electric Heat Pump	Cooking LPG
Kerosene Furnace	Geothermal Heat Pump	Cooking Electric
LPG Furnace	Nat Gas Heat Pump	Dryers Nat Gas
Distill Furnace	Clothes Washers	Dryers Electric
Distill Other	Dishwashers	Refrigerators
Wood Stoves	Water Heaters Nat Gas	Freezers
Geothermal Heat Pump	Water Heaters Electric	

Variables:

$BASEFF_{y,eg}$ Stock efficiency for remaining 1997 equipment by year.

Residential Distributed Generation Equipment File

Definition: Cost, performance, and penetration parameters for fuel cells and photovoltaic equipment.

Units: Technology cost in 1998 dollars.

Source: U.S. Department of Energy (various program offices) and Arthur D. Little.

File: RGENTK.

Comments: This file contains baseline data for distributed generation technologies. The data include cost, performance, baseline penetration rates, and penetration parameters for fuel cells and photovoltaic equipment.

Variables:

$xdegred_{t,d}$ Degredation of conversion efficiency of technology.

$xeleff_{t,d}$ The electrical conversion efficiency of the technology and vintage.

$xeqlife_{t,d}$ Life of the equipment, specific to the equipment type as well as vintage.

$xwhrecovery_{t,d}$ waste heat recovery factor for technologies that burn fuel (i.e., not photovoltaics).

$xinstcost_{t}$ Installation cost in 1998 dollars per kw.

$xcapcost_{t,v}$ Capital cost of the investment in 1998 dollars per kw.

$xmaintcst_{t,v}$ Annual maintenance cost in 1998 dollars per kw.

$xavail_{t,v}$ Percentage of time available (1 – forced outage rate – planned outage rate) applied to typical operating hours

$xtxcrpct_{t,v}$ Tax credit percentage that applies to a given technology’s total installed cost (if any).

$xtxcrmax_{t,v}$ Cap on the total dollar amount of a tax credit (if any).

xkw_{tv} kw of typical system. Note capacity must remain constant across vintages for a given technology.

xoperhours Typical operating hours

xlossfac Conversion losses (for systems that are rated "at the unit" rather than per available alternating current wattage) if appropriate

xnetmeteradj For solar technologies a percentage scalar that applies to the retail rate of electricity for sales to the grid (i.e., reverse flows of energy into the grid), currently set to 1.0 to compensate sales at the retail price. Any data for other technologies should be ignored since a grid sales price is now provided by the NEMS Electric Market Module.

xsolarins Solar insolation for photovoltaics (in kWh per square foot per year) .

xintrate residential mortgage rate from the Macroeconomic Activity Module.

$pelrsout_{r,y,e}$ Air Conditioning Electricity price in 1987 dollars per millionBtu from NEMS Electric Utility Market Module.

$pelrs_{r,y}$ Residential electricity pricein 1987 dollars per million Btu from NEMS Electric Utility Market Module.

$pelme_{r,y}$ Marginal price for sales to grid in 1987 dollars per million Btu from NEMS Electric Utility Market Module.

mc_pcwgdp_{y} GDP chain weighted implicit price deflator for converting energy prices to 1998 dollars

xterm Loan term (currently set at 30 years).

xinflation Inflation assumption for converting constant dollar fuel costs and fuel cost savings into current dollars for the cashflow model in order to make the flows correspond to the nominal dollar loan payments. The current assumption is 3% annually.

xlife Equipment life for the specific technology and vintage being analyzed.

xdownpaypct Down payment percentage assumed to apply to the distributed generation investment, currently 10% of the installed cost.

xtaxrate Marginal combined federal and state income tax rate, currently assumed to be 34% for the typical homeowner.

xeqcost Sum of installation cost plus capital cost multiplied by total system kw.

xtaxcreditpct Set equal to the tax credit percentage for the specific technology and vintage being analyzed.

xtaxcreditmax	Set equal to the maximum dollar cap on the tax credit (if any) for the specific technology and vintage being analyzed.
xmaintcostbase	Set equal to the maintenance cost for the specific technology and vintage being analyzed.
xdegradation	Set equal to the degredation factor for the specific technology and vintage being analyzed.
xwhtgmmbtu	The lessor of: 1) average annual water heating UEC from RECS (rounded 25 million Btu per year), and 2) the available Btu of waste heat estimated from the distributed generation technology.
xelecavguec	Average annual single-family electricity usage in kWh from RECS (rounded 10,000kwh per year).
payment	Computed annual payment using loan amortization formula.
xdownpay	Computed as the downpayment percentage times the total installed cost for the specific technology and vintage being analyzed.
xoutlay	Loan payment made in a particular year (see xpayment above).
xintamt	Interest paid for the loan in each year of the analysis – determines tax deduction that can be taken (home loan interest deduction). This is computed as last year's ending principal balance, xloanbal(year-1), times the mortgage interest rate.
xprin	The amount principal paid on the loan in each year of the analysis – used to determine the loan balance for the next year of the analysis.
xloanba	Principal balance of the loan for each year of the analysis – used to compute the current year's xintamt.
xtaxcredit	Computed tax credit computed as the maximum of xtaxcreditmax and the xtaxcreditpct times the total installed cost.
xtaxdeduct	Combined tax rate times interest paid in the previous year plus any applicable tax credit.
xannualkwh	Represents annual system kWh generation for the specific technology and vintage being analyzed.

xkwh	kWh generated in each of the years of the cashflow analysis. Defined as annual kWh adjusted for degradation (i.e., if degradation factor is not equal to zero).
xgasinput	Million Btu of natural gas used by the technology (more generally this would be the MMBtu of the input fuel, currently the only fuel-using technologies are natural gas fuel cells).
xbtuwasteheat	Computed waste heat available for water heating (valid only for fuel cells or other fuel-consuming generating technology).
xbaseyrfuelcost	Initial fuel costs for operating the generation technology. Calculated from the fuel price and fuel input.
xfuelcost	Fuel cost for the technology net of any water heating cost savings from using waste heat.
xvalesavebase	Calculated value of generated electricity.
xvalesave	Computed as the nominal dollar value of xvalesavebase with an adjustment for output degradation (if appropriate)
xexcesskwh	Generated kWh in excess of average residential usage. Excess kWh are valued at the grid sales price (currently the residential retail rate for photovoltaics and the price of marginal electricity purchases, but the utility for other technologies).
xmaintcost	Set equal to the maintenance cost from the input file for the specific technology and vintage being analyzed.
xnetcashflow	The value of the electricity savings less outlays, fuel costs, and maintenance costs.
xcumflow	The accumulated sum of all prior xnetcashflow amounts.
xalpha	Penetration function shape parameter.
xpenparm	Penetration function used to calculate maximum market share into new construction parameter.
xmaxpen	Maximum market penetration for the technology.
xsimplepayback	Computed as the first year in the cashflow stream for which an investment

	has a positive net cashflow.
units	Accumulated total units employing the relevant type of generation technology.
trills	Total kWh (own use and grid sales) generation (converted to trills).
trillsownuse	Own use electricity generation. The minimum of 1) the average electric consumption (in trills) of a single family home, or 2) the actual kWh generation (converted to trills).
invest	Total amount of investment in distributed generation equipment in millions of 1998$.

Appendix B: Detailed Mathematical Description

This appendix presents the detailed calculations used in each of the module components. Table 1 shows the correspondence between each of the subscripts in the documentation and the subscripts in the FORTRAN source code. Please note the following conventions:

- The table of subscripts includes all of the major usages. In some minor instances, additional subscripts are defined as needed.

- The equations follow the logic of the FORTRAN code very closely to facilitate an understanding of the code and its structure. In several instances, a variable appears on both sides of an equation. This is a FORTRAN programming device that allows a previous calculation to be updated (for example, multiplied by a factor) and re-stored under the same

Table 1. Definitions of Subscripts

Subscript in Documentation	Subscript in the FORTRAN Code
r	R or D, refers to Census Division
t	Y, when Y is a year increment
f	F, fuel types
b	B, housing type
y	CURIYR, the annual index
y-1	PREVYR, CURIYR-1
eg	EQC, equipment class # within an end use (e.g., 1 - 11 for heat) RECCL, equipment class # from all end uses (currently 1 - 29)
egsw	EQCSW, equipment class # within an end use to switch to RECCLSW, equipment class # from all end uses to switch to
es	EQT, equipment type # within an end use RECTY, equipment type # from all end uses
v	Vintage of equipment

variable name (i.e., in the same memory location).

- The subscript, y, in the documentation refers to the year represented as 1990 through 2020. In the FORTRAN code, the subscript CURIYR represents array dimensions starting with an index of 1 to represent 1990.

- Some variables are documented having a “y'' dimension when in fact they do not. The most common instances are for the variables, LFCY, OPCOST, SA, SHARESN, and SHARESR. These variables are calculated on an annual basis, but are retained only for the current year. The “y'' dimension is used in the documentation to highlight 1) that the calculations do vary by year, and 2) to indicate the current year in formulas to avoid confusion.

- Summations over all relevant variables are usually written without upper and lower range limits on the summation signs.

- Unless otherwise stated, the range of y for an equation is 1990 through 2020.

Classification

The RDM regards the residential sector as a consumer of energy. It has classified this consumption into a series of *end uses* that represent the various ways in which energy is used by households. The end uses are defined within the logic of the RDM, and determine the organization of the data found the input data files discussed in this document. At present, the following end uses are covered, in the order shown:

1. Space Heating
2. Space Cooling
3. Clothes Washers
4. Dishwashers
5. Water Heating
6. Cooking
7. Clothes Drying
8. Food Refrigeration
9. Food Freezing
10. Lighting
11. Furnace Fans
12. Color Televisions
13. Personal Computers
14. Other Appliances

15. Secondary Heating
16. Distributed Generation

Further, the RDM assumes that a series of broad *equipment classes* are available to satisfy the demands within the end uses. Using input data files, the user can modify the definitions of equipment classes available for each of the first seven end uses (Lighting and Other Appliances are at present handled by the logic of the RDM, as described later in this appendix). In general, the equipment classes are each used to satisfy a particular end use. However, there are a few cases where one class of equipment (heat pumps, for example) satisfies more than one end use, or where the availability of one class of equipment makes another class more likely (a gas furnace is frequently accompanied by a gas water heater and a gas cookstove). The file RTEKCL (Residential Technology Classes), which is outlined below, defines 29 equipment classes.

Each equipment class can be satisfied by a variety of specific *equipment types* that each have their own technological characteristics, such as efficiency, cost, and year when the technology is expected to become available or to become superannuated. Examples of equipment types would be the array of available gas furnaces, the more expensive of which tend to have higher efficiencies. The RDM does not attempt to represent all manufacturers' products, but rather defines broad types that are similar to one another in their technological characteristics. The user has the ability to define and modify the definitions of these equipment types, by modifying the file RTEKTY (Residential Technology Types), which is also outlined below.

Each equipment type can be assigned different characteristics during different ranges of years. Each of these time-related galaxies of characteristics is sometimes referred to as an equipment *model* of the given equipment type.

These concepts, of equipment classes that can be satisfied by a number of different equipment types that each contain several models, underlie the entire discussion of this manual. In earlier editions of the documentation, these two classifications were referred to as *general equipment type* (equipment class), and *specific equipment type* (equipment type). These names survive in the subscripts assigned to the two concepts throughout the document, *eg* and *es*, respectively.

In order to reinforce the difference, we often add the modifier *specific* to the term *equipment type*, but we have avoided the use of the word *general* in relation to equipment classes.

Other RDM files define the characteristics of the mix of appliances that are in use in the base year, including relative numbers installed, efficiencies, and the rates at which they are expected to be replaced.

RTEKCL: Technology Classes

Within the present structure of the Residential Demand Module, there are 29 defined technology classes. These are listed in Table 2. Here, Clothes Washers, Dishwashers, Refrigeration and Freezing each have a single technology class for all installed equipment. The list is not exhaustive, in that there do exist, for example, a few homes that heat their domestic water with wood; the vast majority of equipment used to satisfy the seven major end uses can be fitted into at least one class. Recall that, as mentioned above, Lighting and Other Appliances are handled separately within the logic of the RDM. Eighteen variables, described below, are read from the RTEKCL data file.

$RTCLENDU_{eg}$: End use number. Equipment classes having the same end use compete with one another. The RDM allocates equipment among them in the technology choice process.

1=Space Heating
2=Space Cooling

Table 2. RDM Technology Classes.

Space Heating	**Space Cooling**	**Cooking**
Electric Furnaces	Room Air Conditioners	Natural Gas
Electric Heat Pumps	Central Air Conditioning	Electric
Natural Gas Forced Air	Electric Heat Pumps	LPG
Natural Gas Radiators	Geothermal Heat Pumps	
Kerosene Forced Air	Natural Gas Heat Pumps	**Drying**
LPG Forced Air		Natural Gas
Distillate Forced Air	**Water Heating**	Electric
Distillate Radiators	Natural Gas	
Wood Heaters	Electric	**Refrigeration**
Geothermal Heat Pumps	Distillate Oil	**Freezing**
Natural Gas Heat Pumps	LPG	**Clothes Washers**

3=Clothes Washers
4=Dishwashers
5=Water Heating
6=Cooking
7=Clothes Drying
8=Food Refrigeration
9=Food Freezing

Matches $RTTYENDU_{es}$ in the RTEKTY file.

$RTCLEQCL_{eg}$: Equipment class number. Appears on all records. Matches $RTTYEQCL_{es}$ in the RTEKTY file for one or more equipment types: there are one or more equipment types in RTEKTY for each class in RTEKCL.

$RTCLTYPT_{eg}$: Required pointer from equipment class to a representative equipment type. This is the only pointer from RTEKCL to RTEKTY. Selects the equipment type used in the log-linear formula for choice of equipment class for newly constructed housing units and replacements in single-family houses. Its value is the $RTEQTYPE_{es}$ in RTEKTY of the representative equipment.

$RTCLPNTR_{eg}$: Class pointer. Required for end uses 1 through 3; zero otherwise.

If end use = 1: Required pointer from space heater class to associated water heater class linking water heater fuel choice to space heater fuel choice for newly constructed housing units.

If end use = 2: Required pointer from cooling heat pump class to same class of heating heat pump.

0 = Not a heat pump

Integer = Heater heat pump class number

If end use = 3: Required pointer from water heater class to matching cooking class linking cooking fuel choice to water heater fuel choice for newly constructed housing units. Also see $RTCLREPL_{es}$ end use 3 below; only natural gas water heaters may point to 2 types of cookstoves.

$RTCLREPL_{eg}$: Replacement class. Required for end use 3; zero otherwise.

If end use = 3: Second pointer from natural gas water heater class to a cooking class. The model assumes that 65% of new homes with natural gas water heaters have natural gas stoves and 35% have electric stoves.

$RTFUEL_{eg}$: Fuel used by this equipment.

1=Distillate
2=LPG
3=Natural Gas
4=Electricity (wood priced to electricity)
5=Kerosene

$RTMAJORF_{eg}$: Major fuel flag. Used only for end use 1; zero otherwise. Space heater shares for systems using major fuels are calculated differently from space heater shares for systems using minor fuels. Set to 1 to indicate a major fuel. Set to 0 to indicate a minor fuel.

FAN_{eg}: Indicates the need for a furnace fan with the appropriate heating system.

$RTBASEFF_{eg}$: Base efficiency for this equipment class. Defined differently by end uses:

End uses 1,2,3,4,5,7: base efficiency for this equipment class.

End uses 6,8,9: 1 / base efficiency for this equipment class.

$RTALPHA_{eg}$: Equipment life expectancy function parameter.

$RTMINLIF_{eg}$: Minimum life of this equipment class (years).

$RTMAXLIF_{eg}$: Maximum life of this equipment class (years).

$RTFCBETA_{eg}$: New home heating technology choice model log-linear parameter β. Used only for end use 1; zero otherwise.

$RTFCBIAS_{eg}$: New home heating technology choice model bias parameter. Used only for end use 1; zero otherwise.

$RTSWFACT_{eg}$: Maximum fraction of single-family homes which may switch away from this equipment class on replacement.

$RTSWBETA_{eg}$: Replacement technology choice model log-linear parameter β. Used only for single-family homes.

$RTSWBIAS_{eg}$: Replacement technology choice model bias parameter. Used only for single family homes.

$RTCLNAME_{eg}$: Unique name for each equipment class.

RTEKTY: Technology Types

Within each of the equipment classes defined in the RTEKCL file, the Residential Demand Module accepts one or more types of equipment. The module chooses among the equipment types according to energy costs, equipment costs, and the relative efficiencies of the available types.

The RTEKTY file contains the data used by the model for selecting which of the types are used. In general, the module does not exclusively select one of the alternatives available within a class, but rather changes the proportions of each type according to its evaluation of the equipment characteristics.

The characteristics of each equipment type can change over time, so the RTEKTY file allows more than one set of characteristics for each equipment type. These are called *models*, and are tagged with the starting and ending year to which they are applicable. Nineteen variables, described below, are read from the RTEKTY file:

$RTTYENDU_{es}$: End Use number as in RTEKCL. Matches RTCLENDU in the RTEKCL file.

$RTTYEQCL_{es}$: Equipment class for this equipment type. MUST match a class number, $RTCLEQCL_{eg}$, in the RTEKCL file.

$RTEQTYPE_{es}$: Equipment type number. Each equipment class may include multiple types. Each equipment type may have up to one record for each year of the forecast period. DO NOT overlap years. The user may add equipment types to existing classes. When adding new types, update the type numbers for the rest of that end use; also, adjust the RTTYPNTR pointer for cooling and the RTCLTYPT pointer in the RTEKCL file for heating. If adding heat pump types, add same type to both space heating and space cooling and adjust pointers.

$RTINITYR_{es}$: Initial calendar year for this model of this equipment type. The first $RTINITYR_{es}$ for a model within a type should be the NEMS base year (1997); subsequent initial years for a model must be previous $RTLASTYR_{es}$+1.

$RTLASTYR_{es}$: Last calendar year for this model of this equipment type. Must greater than or equal to $RTINITYR_{es}$ for this model; final $RTLASTYR_{es}$ should be the last year of the forecast period (2020).

$RTTYPNTR_{es}$: Required pointer from cooling heat pump type to same type of heating heat pump. Also used as a flag to mark room air conditioners and central air conditioners. Used by end use 2 only; zero otherwise. Modify as follows only if heat pump types added:

-1 = Room air conditioner

0 = Central air conditioner (not heat pump)

Other Integer = Matching heater heat pump type number

$LOADADJ_{es}$: For end uses 3 and 4, the amount of hot water load needed relative to the 1997 stock.

$RTEQEFF_{es}$: Defined differently for different end uses:

If end use = 1,2,3,4,5,7: Equipment type efficiency (AFUE, COP, etc.).

If end use = 6,8,9: Energy consumption for typical models (e.g., annual Kwh consumption for 18 cu ft refrigerators).

$RTEQCOST_{es}$: Installed wholesale capital cost in $1998 per unit for new homes.

$RTRECOST_{es}$: Retail capital cost in $1998 per unit for replacements.

$RTMATURE_{es}$: Technology maturity description.

'MATURE' = No further cost reductions expected; use above constants for installed wholesale and retail capital costs.

'ADOLESCENT' = Main cost reductions occurred before base year (1996); function *EQCOST* reduces installed wholesale and retail capital cost with 1996 (or first year of availability) as the inflection point.

'INFANT' = All cost reductions expected after first year of availability; function *EQCOST* reduces installed wholesale and retail capital cost with the inflection point in the future.

$RTCOSTP1_{es}$: If 'MATURE' technology, not used.

If 'ADOLESCENT' technology, representative year cost decline began (y_1 in code).

If 'INFANT' technology, year of inflection of cost trend (y_0 in code).

$RTCOSTP2_{es}$: If 'MATURE' technology, not used.

If 'ADOLESCENT' or 'INFANT' technology, logistic curve shape parameter (gamma in code).

$RTCOSTP3_{es}$: If 'MATURE' technology, not used.

If 'ADOLESCENT' technology, total possible proportional decline in equipment cost from y_0 onward (d in code).

If 'INFANT' technology, total possible proportional decline in equipment cost from y_1 onward (d in code).

$RTECBTA1_{es}$: Efficiency choice model log-linear parameter β_1, weights capital cost.

$RTECBTA2_{es}$: Efficiency choice model log-linear parameter β_2, weights fuel cost.

$RTECBTA3_{es}$: Efficiency choice model log-linear parameter β_3, weights life cycle cost.

$RTECBIAS_{es}$: Efficiency choice model, consumer preference log-linear parameter; fits current market shares to shipment data.

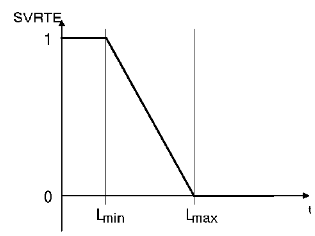
$RTTYNAME_{es}$: Unique name for each equipment type. Do not modify existing names. Add unique names for new types.

Equipment Survival, Housing Survival, and Housing Additions

SVRTE (Equipment Survival Function)

SVRTE is a function in the FORTRAN sense. It is a function that can be called with arguments and returns a single value as its result. The survival rate function is a simple piecewise linear decline, as shown in the picture. Its mathematical description is as follows:

$$
\begin{aligned}
SVRTE_{t,L_{\min},L_{\max}} &= 1 &&, \text{ if } t < L_{\min} \\
SVRTE_{t,L_{\min},L_{\max}} &= 0 &&, \text{ if } t > L_{\max} \\
SVRTE_{t,L_{\min},L_{\max}} &= 1. - \frac{t - L_{\min}}{L_{\max} - L_{\min}} &&, \text{ otherwise}
\end{aligned}
\qquad (1)
$$



where,

$SVRTE_{y-t,L_{\min},L_{\max}}$	is the proportion of surviving equipment after time *t*,
t	is the age of the equipment in years,
L_{min}	is the minimum equipment lifetime in years, and
L_{max}	is the maximum equipment lifetime in years.

Note that function calls to SVRTE in the FORTRAN code include a "place holder" as the first parameter. However, the first parameter is currently not used in the calculations. Since it is not used in the definition of the function in Equation Figure 1, it is not noted explicitly in the remainder of this documentation.

EXHSE (Existing Housing Demolition Rate Component)

Housing units are removed from the stock at a constant rate over time. The demolition rates for the household types (HDR_b) are as follows:

Single-Family Homes:	$HDR_1 = 0.996$
Multifamily Homes:	$HDR_2 = 0.996$
Mobile Homes:	$HDR_3 = 0.965$

The surviving pre-1998 housing stock is defined by:

$$EH_{y,b,r} = RECS\ data \quad , \ if\ y = 1997$$
$$EH_{y,b,r} = EH_{y-1,b,r} \times HDR_b \ , \ if\ y > 1997 \qquad (2)$$

where,

$EH_{y,b,r}$ is the pre-1998 housing stock surviving in year y,

HDR_b is the housing demolition rate, from the RMISC file.

NEWHSE (Calculate New Housing Component)

New houses are added to the stock each year, as defined by the NEMS Macroeconomic Module. The total number of new additions in a given year is defined as:

$$NH_{y,r} = HUSTS1_{y,r} + HUSTS2_{y,r} + SHUMBL_{y,r} \qquad (3)$$

where,

$NH_{y,r}$	is total new housing added by year and Census Division,
$HUSTS1_{y,r}$	is single-family housing added by year and Census Division,
$HUSTS2_{y,r}$	is multifamily housing added by year and Census Division,
$SHUMBL_{y,r}$	is mobile home shipments added by year and Census Division,

EPACTWD (Calculate EPACT Window Labeling Impact Component)

First aggregate the housing stock to the national level,

$$OLDHSES_y = \sum_{b,r} EH_{y,b,r} \tag{4}$$

$$NEWHSES_y = \sum_{b,r} NH_{y,b,r} \tag{5}$$

where,

$OLDHSES_y$ is the national total of remaining pre-1998 housing.

$NEWHSES_y$ is the national total of remaining post-1997 housing additions.

Then, calculate the EPACT window labeling impacts for both heating and cooling,

$$EPACTH_y = EPWINPCT_y \times EPSAVHT \tag{6}$$

$$EPACTC_y = EPWINPCT_y \times EPSAVCL \tag{7}$$

where,

$EPACTH_y$ is the national fractional heat savings to be expected from EPACT window labeling standards,

$EPACTR_y$ is the national fractional cooling savings to be expected from EPACT window labeling standards,

$EPWINPCT_y$ is the fraction of houses affected by window labeling standards, from the RMISC file,

EPSAVHT is the fraction of heat input to houses expected to be saved by improved window labeling, set in the program to a constant value of .08, and

EPSAVCL is the fraction of cooling input to houses expected to be saved by improved window labeling, set in the program to a constant value of .03.

RDSQFT (Read Floor Areas)

Read the historical and forecast data for average household area, $SQRFOOT_{y,b,r}$ from the RSSQRFT file, and calculate the ratios, $SQFTADJ_{y,b,r}$, between each area and the base year area, $SQRFOOT_{1997,b,r}$.

SQFTCALC (Calculate Average Floor Area Component)

Averages the floor areas of homes,

$$SQFTAVG_{1997} = \frac{\sum_{b,r} (SQRFOOT_{1997,b,r} \times EH_{1997,b,r})}{OLDHSES_{1997}} \tag{8}$$

$$SQFTAVG_{y} = \frac{\sum_{b,r} (SQRFOOT_{1997,b,r} \times EH_{y,b,r} + SQRFOOT_{y,b,r} \times NH_{y,b,r})}{OLDHSES_{y} + NEWHSES_{y}} \tag{9}$$

where,

$SQFTAVG_y$ is the average floor area of houses of all types, and

$SQRFOOT_{y,b,r}$ is a table of historical and projected housing floor areas, from the RSSQRFT file, by year, housing type and Census Division.

RDHTREQC (Project 1997) Vintage Equipment for all End-Use Services)

This routine reads in the 1997 equipment stock for all services from external files, then calculates surviving equipment in the pre-1998 housing stock for 1998 through the end of the forecast.

For y > 1997,

$$EQCESE_{y,eg,b,r} = EQCESE_{1997,eg,b,r} \times HDR_b^{y-1997} \times EQCRET_{y,eg} \tag{10}$$

where,

$EQCESE_{y,eg,b,r}$ is the amount of surviving pre-1998 vintage equipment in pre-1998 housing by housing type and Census Division,

HDR_b is the housing demolition rate by housing type, and

$EQCRET_{y,eg}$ are the annual equipment retirement fractions for the equipment classes, from file RSRET01.

Space Heating

Technology Choice Component

The Technology Choice Component uses a log-linear function to estimate technology market shares. The module is able to calculate market shares based on consumer behavior as a function of bias, capital costs, and operating costs or as a function of life-cycle costs.

The nine major services modeled are:

- Space Heating
- Space Cooling
- Water Heating
- Cooking
- Clothes Drying
- Food Refrigeration
- Food Freezing
- Clothes Washers
- Dishwashers

Lighting, color televisions, personal computers, and other appliance decisions are modeled differently from the major services listed above.

New equipment operating costs are computed by the expression,

$$OPCOST_{y,es,b,r,v} = PRICES_{f,r,y} \times EQCUEC_{r,eg,b} \times HDDFACT_{r,y} \times RTEFFAC_{eg,v} \tag{11}$$

where,

$OPCOST_{y,es,b,r,v}$	is the operating cost for the specific equipment type by year, housing type, and Census Division, and vintage,
$PRICES_{f,r,y}$	is the fuel prices for the equipment by fuel, by region and forecast year,
$EQCUEC_{r,eg,b}$	is the unit energy consumption by Census Division, equipment class and housing type,
$HDDFACT_{r,y}$	is a factor, the ratio between heating degree days in the current year and in the base year, for adjusting for abnormal weather in either the base year or in the current year, and
$RTEFFAC_{eg,v}$	is the efficiency adjustment for the general equipment class and vintage.

The consumer is allowed to choose among the various levels of cost and efficiency for a given class of equipment. Electric heat pumps are an example of an equipment class (denoted by eg). Equipment type (denoted by es) refers to the same class of equipment with different efficiency ratings (e.g., high vs low efficiency electric heat pumps).

EQCOST is a time-dependant function for computing the installed capital cost of equipment in new construction and the retail replacement cost of equipment in existing housing. It is called if the cost trend switch COSTTRSW = 1 in COMMON RTEK (which is the default). Its mathematical description is as follows:

$$EQCOST_{es,y,CAP} = RTEQCOST_{es} \quad , \; if \; RTMATURE_{es} = MATURE$$
$$EQCOST_{es,y,RET} = RTRECOST_{es} \quad , \; if \; RTMATURE_{es} = MATURE \qquad \textbf{(12)}$$

$$EQCOST_{es,y,CAP} = \frac{RTEQCOST_{es} \times 2 \times d}{1 + \left(\frac{y - y_1}{y_0 - y_1}\right)^{\gamma}} + (1-d) \times RTEQCOST_{es} \quad , \; if \; RTMATURE_{es} = ADOLESCENT$$
$$EQCOST_{es,y,RET} = \frac{RTRECOST_{es} \times 2 \times d}{1 + \left(\frac{y - y_1}{y_0 - y_1}\right)^{\gamma}} + (1-d) \times RTRECOST_{es} \quad , \; if \; RTMATURE_{es} = ADOLESCENT \qquad \textbf{(13)}$$

$$EQCOST_{es,y,CAP} = \frac{RTEQCOST_{es} \times d}{1.0 + \left(\frac{y - y_1}{y_0 - y_1}\right)^{\gamma}} + (1.0-d) \times RTEQCOST_{es} \quad , \; if \; RTMATURE_{es} = INFANT$$
$$EQCOST_{es,y,RET} = \frac{RTRECOST_{es} \times d}{1.0 + \left(\frac{y - y_1}{y_0 - y_1}\right)^{\gamma}} + (1.0-d) \times RTRECOST_{es} \quad , \; if \; RTMATURE_{es} = INFANT \qquad \textbf{(14)}$$

where,

$EQCOST_{es,y,ctype}$ is time-dependant installed capital cost of equipment in new construction or the retail replacement cost of equipment in existing housing,

ctype tells function type of equipment cost to return,

CAP = Return installed capital cost in new construction,

RET = Return retail replacement cost in existing housing,

$RTMATURE_{es}$ Technology maturity description,

MATURE = No further equipment cost reductions expected,

ADOLESCENT = Major cost reductions occurred before base year,

INFANT = All cost reductions expected after first year available,

$RTEQCOST_{es}$ Installed wholesale capital cost in $1998 per unit for new homes, remains

	constant for MATURE technologies only (used when ctype = CAP),
$RTRECOST_{es}$	Retail capital cost in \$1998 per unit for replacements, remains constant for MATURE technologies only (used when ctype = RET),
y_0	is the year of inflection of cost trend, $RTINITYR_{es}$ if ADOLESCENT, $RTCOSTP1_{es}$ if INFANT,
y_1	is the year cost decline began, $RTCOSTP1_{es}$ if ADOLESCENT, $RTINITYR_{es}$ if INFANT,
d	is the total possible proportional decline in equipment cost, $RTCOSTP3_{es}$, from y_0 onward if ADOLESCENT, from y_1 onward if INFANT,
γ	is the logistic curve shape parameter, $RTCOSTP2_{es}$.

Starting with the AEO2000 version of the NEMS residential model, the concept of price induced technology change has been included in the formulation of equipment costs. This concept allows future technologies faster diffusion into the marketplace if fuel prices increase markedly and remain high over a multi-year period. First, compare the average fuel price for a given fuel over a three year period to the price observed in 1997:

$$PRICEDELTA_{y,f} = \frac{.334 \times (PRICE_{y,f} + PRICE_{y-1,f} + PRICE_{y-2,f})}{PRICE_{1997,f}} \quad \textbf{(15)}$$

Under a "persistent" doubling of energy prices (defined in the models as three consecutive years, as note in (15) above), the most advanced technologies (i.e., those only available beginning in 2015 and beyond) will advance forward by 10 years to 2005 (as long as the doubling starts by 2002). Shifts from 0 to 10 years are allowed in the current model formulations. For nearer term technologies (e.g., 2005 projections) shifts are limited to a lessor number of years by the algorithm to ensure that "over-shifting" does not occur (i.e., future technologies can not become available before the persistent price change is projected to occur). The formulation only allows technologies potentially to shift toward earlier availability, and once shifted, they never shift back. This shift is represented as:

$$SHIFTYEARS_t = \frac{(PRICEDELTA_{y,f} - 1.0)}{0.10} \quad \textbf{(16)}$$

subject to the constraints listed above. The technology data presented in equations (12) to (14) are adjusted according to the results obtained in equation (16).

The module includes the option to use life-cycle costing to calculate market share weights. The life cycle cost calculation is,

$$LFCY_{y,es,b,r,v} = CAPITAL_{es} + OPCOST_{y,es,b,r,v} \times \left[\frac{1 - (1 + DISRT)^{-HORIZON}}{DISRT} \right] \quad \textbf{(17)}$$

where,

$LFCY_{y,es,b,r,v}$	is the life cycle cost of an equipment type by forecast year, housing type, and Census Division, and vintage,
$CAPITAL_{es}$	is the installed capital cost of an equipment type based on calling EQCOST with $RTEQCOST1_{es}$,
HORIZON	is the number of years into the future that is used to compute the present value of future operating cost expenditures presently set to seven years, and
DISRT	is the discount rate applied to compute the present value of future operating costs presently at 20 percent.

A weight for each equipment class is calculated to estimate the market share for each of the 11 heating systems for new construction based on the cost factors computed above. The functional form is expressed as,

$$HEATSYS_{y,eg,b,r} = e^{[\,RFTCBIAS_{eg} + RFTCBETA_{eg} \times LFCY_{y,eg,b,r,v}\,]} \quad \textbf{(18)}$$

where,

$HEATSYS_{y,eg,b,r}$	is the equipment weight for a heating equipment class for new housing by year, housing type, and Census Division,
$RTFCBIAS_{eg}$	is a consumer preference parameter that fits the current market share to historical shipment data,
$LFCY_{y,eg,b,r,v}$	is the life cycle cost for the equipment class by year, housing type, and Census Division, and vintage, and

$RTFCBETA_{eg}$ is a parameter value of the log-linear function.

The sum over the heating equipment classes gives the total weight for all of the heating equipment:

$$SYSTOT_{y,b,r} = \sum_{eg=1}^{eg=11} HEATSYS_{y,eg,b,r} \qquad \textbf{(19)}$$

where,

$SYSTOT_{y,b,r}$ is the sum of equipment class weights for the all equipment classes.

The equipment class fuel share is computed by

$$\begin{aligned} HTYSSHR_{y,eg,b,r} &= \frac{HEATSYS_{y,eg,b,r}}{SYSTOT_{y,b,r}}, \quad \text{if } SYSTOT_{y,b,r} > 0 \\ HTYSSHR_{y,eg,b,r} &= 0, \quad \text{otherwise} \end{aligned} \qquad \textbf{(20)}$$

where,

$HTYSSHR_{y,eg,b,r}$ is the equipment class fuel share by year, building type, and Census Division.

For each equipment type within each class, a weight is calculated based on the cost factors computed above. The functional form is expressed as,

$$EQWTN_{y,es,b,r} = e^{[\,RTECBIAS_{es} + RTECBTA2_{es} \times OPCOST_{y,es,b,r} + RTECBTA3_{3} \times LFCY_{y,es,b,r}\,]} \qquad \textbf{(21)}$$

$$EQWTR_{y,es,b,r} = e^{[\,RTECBIAS_{es} + RTECBTA2_{es} \times OPCOST_{y,es,b,r} + RTECBTA3_{3} \times LFCY_{y,es,b,r}\,]} \qquad \textbf{(22)}$$

where,

$EQWTN_{y,es,b,r}$ is the equipment weight for new equipment type by year, housing type, and Census Division,

$EQWTR_{y,es,b,r}$ is the equipment weight for replacement equipment type by year, housing type, and Census Division,

$OPCOST_{y,es,b,r,v}$ is the operating cost for the equipment type by year, housing type, Census Division, and vintage

$LFCY_{y,es,b,r,v}$ is the life cycle cost for the equipment type by year, housing type, Census Division, and vintage,

$RTECBIAS_{es}$ is a consumer preference parameter that fits the current market share to shipment data, and

$RTECBTA2_{es}$, $RTECBTA3_{es}$ are parameter values of the same fit.

Sums over the equipment types within each class give total weights for the equipment classes:

$$TOTEWTN_{y,eg,b,r} = \sum_{es=low\ eff}^{hi\ eff} EQWTN_{y,es,b,r} \quad \textbf{(23)}$$

$$TOTEWTR_{y,eg,b,r} = \sum_{es=low\ eff}^{hi\ eff} EQWTR_{y,es,b,r} \quad \textbf{(24)}$$

where,

$TOTEWTN_{y,eg,b,r}$ is the sum of weights for the new equipment types within equipment classes,

$TOTEWTR_{y,eg,b,r}$ is the sum of weights for the replacement equipment types within equipment classes.

The equipment type fuel share is computed by

$$\begin{aligned} EQFSHRN_{y,es,b,r} &= \frac{EQWTN_{y,es,b,r}}{TOTEWTN_{y,eg,b,r}}, \ if\ TOTEWTN_{y,eg,b,r} > 0 \\ EQFSHRN_{y,es,b,r} &= 0, \ otherwise \end{aligned} \quad \textbf{(25)}$$

$$\begin{aligned} EQFSHRR_{y,es,b,r} &= \frac{EQWTR_{y,es,b,r}}{TOTEWTR_{y,eg,b,r}}, \ if\ TOTEWTR_{y,eg,b,r} > 0 \\ EQFSHRR_{y,es,b,r} &= 0, \ otherwise \end{aligned} \quad \textbf{(26)}$$

where,

$EQFSHRN_{y,es,b,r}$ is the new equipment type fuel share by year, building type, and Census Division.

$EQFSHRR_{y,es,b,r}$ is the replacement equipment type fuel share by year, building type, and Census Division.

This value is multiplied by the market share of the equipment type to yield the new market share for the equipment type. The relationship is expressed as,

$$NEQTSHR_{y,es,b,r} = EQFSHRN_{y,es,b,r} \quad (27)$$

$$REQTSHR_{y,es,b,r} = EQFSHRR_{y,es,b,r} \quad (28)$$

where,

$NEQTSHR_{y,es,b,r}$ is the new market share for the new equipment type by year, housing type, and Census Division.

$REQTSHR_{y,es,b,r}$ is the new market share for the replacement equipment type by year, housing type, and Census Division.

The weighted average equipment efficiencies for the equipment types within each equipment class are then computed as,

$$WTEQCEFFN_{y,eg,b,r} = \frac{\sum_{es}\left[\frac{NEQTSHR_{y,es,b,r}}{RTEQEFF_{y,es}}\right]}{\sum_{es} NEQTSHR_{y,es,b,r}} \quad , \text{ if } \sum_{es} NEQTSHR_{y,es,b,r} > 0$$

$$WTEQCEFFN_{y,eg,b,r} = \frac{1}{RTBASEFF_{eg}} \quad , \text{ otherwise} \quad (29)$$

$$WTEQCEFFR_{y,eg,b,r} = \frac{\sum_{es}\left[\frac{REQTSHR_{y,es,b,r}}{RTEQEFF_{y,es}}\right]}{\sum_{es} REQTSHR_{y,es,b,r}} \quad , \text{ if } \sum_{es} REQTSHR_{y,es,b,r} > 0$$

$$WTEQCEFFR_{y,eg,b,r} = \frac{1}{RTBASEFF_{eg}} \quad , \text{ otherwise} \quad (30)$$

where,

$WTEQCEFFN_{y,eg,b,r}$ is the weighted average efficiency of new equipment type within each equipment class by year, housing type, and Census Division.

$WTEQCEFFR_{y,eg,b,r}$ is the weighted average efficiency of replacement equipment types within each equipment class by year, housing type, and Census Division.

Appliance Stock Component

The appliance stock component tracks the major energy-consuming equipment by housing vintage and equipment vintage for additions, replacements, and surviving equipment. Table 5 depicts the equipment accounting methodology. For simplicity, this discussion omits the details of the variable subscripts, which is explained later. The equipment accounting system partitions equipment into two major categories, depending on the vintage of the housing unit: equipment installed in housing units built before 1998 (at the beginning of a model run) and equipment added to new housing units (those added during the model run). Equipment is further partitioned into three additional survival/replacement categories: equipment that survives, equipment purchased to replace other equipment, and equipment purchased for new construction. The categorization of equipment by housing vintage and surviving/replacement type results in six categories of equipment that are tracked.

Table 5. Heating Equipment, UEC and Housing Shell Accounting Scheme

Housing Units that Existed in 1997			**Housing Units Added From 1998 through 2020**		
Equipment	UEC	Shell	Equipment	UEC	Shell
EQCRP90RP	EQCNUEC	EHSHELL			
EQCRP90	EQCRUEC	EHSHELL			
EQCSR90	EQCAUEC	EHSHELL			
			EQCADD	EQCNUEC	NHSHELL
			EQCREP	EQCNUEC	AHSHELL
EQCESE	EQCSUEC	EHSHELL	EQCSUR	EQCAUEC	AHSHELL

The equipment categories for pre-1998 housing units are:

EQCESE denotes the surviving pre-1998 equipment stock in pre-1998 homes,

EQCSR90 represents equipment stock in pre-1998 homes that has been replaced after 1997 and that still survives, and

EQCRP90 is current-year replacement equipment for pre-1998 housing.

EQCRP90RP is current-year replacements for the EQCRP90 equipment.

Note: EQCND90 is the sum of EQCESE, EQCSR90, EQCRP90RP, and EQCRP90.

The equipment categories for post-1997 housing units are:

EQCSUR denotes equipment that has been modeled as added and still survives,

EQCREP is equipment that has been modeled as added and is in need of replacement in the current year, and

EQCADD is equipment for housing units added in the current year.

Unit energy consumption (UEC) is tracked for equipment added by category of housing unit:

EQCUEC is the average UEC for the original 1997 equipment in housing units that existed in 1997,

EQCSUEC is the average UEC for surviving equipment in pre-1998 housing units,

EQCAUEC is the average UEC for surviving equipment in post-1998 housing units,

EQCRUEC is the UEC for all equipment added in the current year to replace pre-1998 equipment, and

EQCNUEC is the UEC for all equipment added in the current year, other than EQCRP90.

Shell indices are modeled for three categories of housing units:

EHSHELL is the shell index applicable to pre-1998 housing units,

AHSHELL is the shell index applicable to housing units added in all but the current year, and

NHSHELL is the shell index for housing units added in the current year.

For example, in accounting for the heating energy consumption of surviving equipment installed in pre-1998 housing units, the equipment stock, HTESE, would be multiplied by the unit energy consumption, HTUEC, and by the shell index EHSHELL. This explanation was designed to account for heating equipment, but the accounting principle is used throughout the residential module. For the pre-1998 housing example above, the appropriate space cooling variables would be CLESE, CLUEC and ECSHELL. The shell indices apply only to heating and cooling, thus, for example, for refrigeration the accounting requires only RFESE and RFUEC.

The housing decay rate is used in conjunction with the equipment survival rate to determine the number of equipment units that survive/retire each year in the forecast. A linear function is used to model the retirement of equipment after a minimum age is reached up to its maximum age. The linear function is expressed by,

$$SVRTE_{y-t,L_{min},L_{max}} = 1.0 \quad , \text{ if } y-t \le L_{min}$$

$$SVRTE_{y-t,L_{min},L_{max}} = \frac{L_{max} - (y-t)}{L_{max} - L_{min}} \quad , \text{ if } L_{min} < y-t < L_{max} \qquad \textbf{(31)}$$

$$SVRTE_{y-t,L_{min},L_{max}} = 0.0 \quad , \text{ if } y-t \ge L_{max}$$

where,

$SVRTE_{y-t,L_{min},L_{max}}$ is the equipment survival function,

y-t is the age of the equipment,

L_{min} is the minimum equipment lifetime in years, and

L_{max} is the maximum equipment lifetime in years.

Equipment in post-1997 (new) houses is the product of the number of new houses and the market share of each equipment class. This is expressed as,

$$EQCADD_{y,t,eg,b,r} = HSEADD_{y,b,r} \times SHARESN_{y,eg,b,r} \qquad \textbf{(33)}$$

where,

$EQCADD_{y,t,eg,b,r}$ is the number of post-1997 vintage equipment units added to new houses in year *y*, vintaged to year *t*, by housing type and Census Division,

$HSEADD_{y,b,r}$ is the number of new housing units constructed in the forecast year by housing type and Census Division,

$SHARESN_{y,eg,b,r}$ is the current year market share for each equipment class by housing type and Census Division.

The number of replacements for the post-1997 equipment units in post-1997 houses is calculated as:

$$EQCREP_{y,t,eg,b,r} = \sum_{t=1998}^{y-1} \left(EQCADD_{t,eg,b,r} \times HDR_b^{y-t} \times (1 - SVRTE_{eg}) \right) \quad \textbf{(34)}$$

where,

$EQCREP_{y,t,eg,b,r}$	is the number of equipment replacements of post-1997 equipment in post-1997 houses,
HDR_b	is the housing survival rate by housing type, and
y-t	represents the age of the equipment.

Post-1997 replacement units required for pre-1998 houses in the current year are calculated as,

$$EQCRP90_{y,t,eg,b,r} = EQCESE_{1997,eg,b,r} \times EQCRET_{y,eg} \times HDR_b^{y-1997} \quad \textbf{(35)}$$

where,

$EQCRP90_{y,t,eg,b,r}$	is the number of replacement units required for pre-1998 homes in year *y*, vintaged to year *t* by housing type and Census Division,
$EQCRET_{y,eg}$	is the equipment retirement rate for pre-1998 houses by forecast year,
$EQCESE_{1997,eg,b,r}$	is the pre-1998 vintage stock of equipment in pre-1998 vintage houses in 1997 by housing type and Census Division.

Within the forecast period, some of the EQCRP90 will also need to be replaced. This is represented as,

$$EQCRP90RP_{y,t,eg,b,r} = \sum_{y=1998}^{t-1} \left(EQCRP90_{y,t,eg,b,r} + EQCRP90RP_{y,t,eg,b,r} \right) \times (1 - SVRTE_{eg}) \times HDR_b^{y-t} \quad \textbf{(36)}$$

where,

$EQCRP90RP_{y,t,eg,b,r}$	is the number of replacement units required to replace post-1997 equipment in pre-1998 houses by forecast year, housing type and Census Division.

Next, a series of calculations is made to determine the number of replacement units that switch to a different technology type. For each type of replacement (EQCRP90, EQCRP90RP, EQCREP), first calculate the number of eligible switches (single-family houses only).

$$ELIGIBLE_{y,eg,b,r} = \sum_{eg} \left(EQCRP90_{y,t,eg,b,r} + EQCRP90RP_{y,t,eg,b,r} + EQCREP_{y,t,eg,b,r} \right) \times SWFACT_{eg} \tag{37}$$

where,

$ELIGIBLE_{y,eg,b,r}$	is the nubmer of replacements eligible to switch technology types by housing type and Census Division, and
$RTSWFACT_{eg}$	is the fraction who may switch from equipment class eg.

The “switching” weight for each equipment type is calculated as,

$$RPWEIGHT_{y,egsw,b,r} = e^{[\ RTSWBIAS_{egsw} + RTSWBETA_{egsw} \times (\ LFCY_{y,essw,b,r,v} + RPINSCOST_{eg,egsw}\ )\ ]} \tag{38}$$

Summing over all equipment types,

$$TOTSH_{y,b,r} = \sum_{egsw=1}^{egsw=11} RPWEIGHT_{y,egsw,b,r} \tag{39}$$

allows for shares summing to 100 percent.

$$\begin{aligned} RPSHARE_{y,egsw,b,r} &= \frac{RPWEIGHT_{y,egsw,b,r}}{TOTSH_{y,b,r}}, \quad if\ TOTSH_{y,b,r} > 0 \\ RPSHARE_{y,egsw,b,r} &= 0, \quad otherwise \end{aligned} \tag{40}$$

where,

$RPSHARE_{y,egsw,b,r}$	is the share that will switch to equipment class *egsw* on replacement by year, housing type, and Census Division,
$RPWEIGHT_{y,egsw,b,r}$	is the weight assigned to each equipment class *egsw* by year, housing type, and Census Division,

$RTSWBIAS_{egsw}$	is the consumer preference parameter for switching to this equipment class,
$RTSWBETA_{egsw}$	is the parameter value for the same fit,
$LFCY_{y,essw,b,r,v}$	is the lifecycle cost of the equipment type switching to (essw) by year, building type, region , and vintage,
$RPINSCOST_{eg,egsw}$	is the cost of switching from equipment class eg to egsw on switching, and
$TOTSH_{y,b,r}$	is the sum of the switch weigts.

The equipment classes are then reconciled by "from" and "to" switching categories and redistributed to the correct equipment class.

The surviving post-1997 vintage equipment in pre-1998 houses is computed as,

$$EQCSR90_{y,eg,b,r} = \sum_{t=1998}^{y-1} \left(\left(EQCRP90_{t,y,eg,b,r} + EQCRP90RP_{t,y,eg,b,r} \right) \times SVRTE_{y-t,Lmin,Lmax} \times HDR_b^{y-t} \right) \quad \textbf{(41)}$$

where,

$EQCSR90_{y,eg,b,r}$	is the equipment stock in pre-1998 homes that has been replaced after 1997 and still survives by housing type and Census Division,
$EQCRP90_{t,y,eg,b,r}$	is the number of replacement (post-1997 vintage) equipment units demanded each year in pre-1998 houses by housing type and Census Division,
$EQCRP90RP_{t,y,eg,b,r}$	is the number of replacements of the EQCRP90 equipment units demanded each year by housing type and Census Division,
SVRTE	is the equipment survival function,
HDR_b	is the housing survival rate by housing type, and
y-t	represents the age of the equipment.

Surviving post-1997 equipment, originally purchased as additions or replacements in post-1997 houses, is calculated as,

$$EQCSUR_{y,eg,b,r} = \sum_{t=1998}^{y-1} [(EQCADD_{y,t,eg,b,r} + EQCREP_{y,t,eg,b,r}) \times SVRTE_{y-t,Lmin,Lmax} \times HDR_b^{y-t}] \quad (42)$$

where,

$EQCSUR_{y,eg,b,r}$	is the surviving post-1997 equipment purchased as additions or replacements in post-1997 houses by housing type and Census Division,
$EQCADD_{y,t,eg,b,r}$	is the quantity of post-1997 vintage equipment added to post-1997 houses by forecast year, housing type and Census Division,
$SVRTE_{y-t,Lmin,Lmax}$	is the equipment survival function,
HDR_b	is the housing survival rate by housing type,
$EQCREP_{y,t,eg,b,r}$	is the number of equipment replacements of post-1997 equipment in post-1997 houses, and
y-t	represents the age of the equipment.

Shell Integrity Component

The shell integrity component uses three indices to capture the increases in the energy efficiency of building shells over time. One index corresponds to the pre-1998 housing stock, and two indices correspond to the post-1997 stock, one for housing constructed in the current year and the other for the average post-1997 stock. The shell indices are adjusted each year to account for fuel price increases (decreases have no effect on shell integrity, i.e., shell efficiency increases as price increases) and technology improvements.

An important part of shell integrity is the quality of windows. In the Energy Policy Act, there are regulations that require that all new windows be labeled with an index that describes their insulation properties. These regulations will be phased in over a period of years, beginning in 1995. The residential module evaluates the impacts of these regulations by means of an annual input variable, $EPWINPCT_y$, that gives the proportion of existing houses expected to be subject to window labeling. This quantity, when multiplied by the fraction of heat savings expected to be afforded by labeled windows, currently set at .08, gives the expected savings rate due to window labeling, $EPACTH_y$.

The first step in the algorithm calculates the percentage price change for all heating fuels as,

$$PRIDELTA_{f,r} = \frac{PRICES_{f,r,y} - PRICES_{f,r,1997}}{PRICES_{f,r,1997}} \times \frac{1}{PSTEP} \tag{43}$$

where,

$PRIDELTA_{f,r}$	is the percentage change in price from the base year by fuel and Census Division converted to 5 percentage point increments,
PSTEP	is a constant that is set to 0.05 to convert the percentage change in fuel price to the number of 5 percentage point increments of price change,
$PRICES_{f,r,y}$	is the fuel price by fuel, Census Division and year, and
$PRICES_{f,r,1997}$	is the 1997 (base year) fuel price by fuel and Census Division.

The PRIDELTA variable is calculated over a five year period to allow for a lagged response to price increases for shell improvements.

The existing housing heating shell index is calculated as,

$$\begin{aligned} EHSHELL_{y,f,r,b} &= EHSHELL_{y-1,f,r,b} &&, \text{ if } EHSHELL_{y,f,r,b} > EHSHELL_{y-1,f,r,b} \\ EHSHELL_{y,f,r,b} &= LIMIT &&, \text{ if } EHSHELL_{y,f,r,b} \geq LIMIT \\ EHSHELL_{y,f,r,b} &= (EHSHELL_{1997,f,r,b} - PRIDELTA_{f,r} \times SSTEP) \times TECHG_{e,r,b} \times (1. - EPACTH_{y}) &&, \text{ otherwise} \end{aligned} \tag{44}$$

where,

$EHSHELL_{y,f,r,b}$	is the shell integrity index for existing housing by year, fuel, Census Division, and building type,
LIMIT	limits the maximum shell index efficiency to 0.3 (i.e., maximum shell efficiency is limited to a 70-percent improvement on the base year value), and
SSTEP	is set to 0.01 and is a component of the shell elasticity with respect to heating fuel price,
$TECHG_{1,d,b}$	is a parameter that represents the annual increase in existing shell integrity due to technology improvements, and
$EPACTH_{y}$	is the projected national fractional savings in heating energy consumption from the EPACT window labeling program in year y, from the RMISC file.

PSTEP converts the percentage change in price to the number of 5 percentage point increments of price change in Equation Figure 1. In equation Figure 1, PRIDELTA is multiplied by SSTEP and converted to the shell efficiency index. Every 5 percentage point increase in fuel price relative to the base year results in a shell efficiency index decrease of 1 percentage point of the base year shell efficiency up to the limit of 0.3.

The new housing heating shell index is calculated as,

$$\begin{aligned} NHSHELL_{y,f,r,b} &= NHSHELL_{y-1,f,r,b} &&, \text{ if } NHSHELL_{y,f,r,b} > NHSHELL_{y-1,f,r,b} \\ NHSHELL_{y,f,r,b} &= LIMIT &&, \text{ if } NHSHELL_{y,f,r,b} < LIMIT \\ NHSHELL_{y,f,r,b} &= NHSHELL_{1998,f,r,b} - (\, TECHG_{e,r,b} + PRIDELTA_{f,r} \times SSTEP \,) &&, \text{ otherwise} \end{aligned} \tag{45}$$

where,

$NHSHELL_{y,f,r,b}$	is the new housing units shell integrity index by year, fuel, Census Division, and building type,
$TECHG_{2,d,b}$	is a parameter that represents the annual increase in new shell integrity due to technology improvements,
$PRIDELTA_{f,r}$	is the percent change in price of the fuel by Census Division in 5 percentage point increments,
SSTEP	is set to 0.01 and is a component of the shell elasticity with respect to heating fuel price.

The average post-1997 housing heating shell index is calculated as,

$$AHSHELL_{y,f,r,b} = \frac{\sum_{eg} [NHSHELL_{y,f,r,b} \times EQCADD_{y,t,eg,b,r} + AHSHELL_{y-1,f,r,b} \times (\, EQCREP_{y,t,eg,b,r} + EQCSUR_{y,eg,b,r})]}{\sum_{eg} [EQCADD_{y,t,eg,b,r} + EQCREP_{y,t,eg,b,r} + EQCSUR_{y,eg,b,r}]} \tag{46}$$

where,

$AHSHELL_{y,f,r,b}$	is the average post-1997 heating shell index by year, fuel, Census Division, and building type, equal to NHSHELL in 1998,
$NHSHELL_{y,f,r,b}$	is the new housing units shell integrity index by year, fuel, Census Division, and building type,
$EQCADD_{y,t,eg,b,r}$	is the number of equipment units installed in new construction by forecast year, housing type and Census Division,
$EQCREP_{y,t,eg,b,r}$	is the number of equipment replacements of post-1997 equipment in post-

1997 houses, and

$EQCSUR_{y,eg,b,r}$ is the surviving post-1997 equipment purchased as additions or replacement in post-1997 houses by forecast year, housing type and Census Division.

In addition to the calculation shown above, the module places two additional restrictions upon $AHSHELL_y$: it may never increase, and it must not fall below LIMIT. If ever $AHSHELL_y$ is calculated to increase, its value is set to the prior year's value; if it falls below LIMIT, it is set equal to LIMIT.

Consumption and UEC Component

Final end-use fuel consumption is determined by the fuels demanded by the equipment to provide households with the demanded services. For each equipment class, the UEC for new equipment, replacement equipment, and the average of all equipment is computed. New equipment UEC values are calculated as:

$$EQCNUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \times WTEQCEFFN_{y,eg,b,r} \times RTBASEFF_{1997,eg} \times HDDFACT_r \times SQFTADJ_{y,b,r} \quad , \text{ if } WTEQCEFFN_{y,eg,b,r} > 0$$

$$EQCNUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \times HDDFACT_r \times SQFTADJ_{y,b,r} \quad , \text{ otherwise} \qquad \textbf{(47)}$$

where,

$EQCNUEC_{y,eg,b,r}$ is the unit energy consumption for new equipment by forecast year, housing type and Census Division,

$WTEQCEFFN_{y,eg,b,r}$ is the equipment class efficiency weighted by the market share of the specific equipment as computed in the logistic function in the technology choice component by housing type and Census Division,

$RTBASEFF_{1997,eg}$ is the 1997 stock-average efficiency of the equipment class,

$EQCUEC_{r,eg,b}$ is unit energy consumption for original 1997 stock of the equipment class by Census Division and housing type,

$HDDFACT_r$ is the heating degree day adjustment factor by Census Division to correct for the unusually warm weather during the RECS survey year, and

$SQFTADJ_{y,b,r}$ is the adjustment for increasing floor area of new houses.

Replacement equipment UEC values are calculated as:

$$
\begin{aligned}
EQCRUEC_{y,eg,b,r} &= EQCUEC_{r,eg,b} \times WTEQCEFFR_{y,eg,b,r} \\
&\quad \times RTBASEFF_{1997,eg} \times HDDFACT_{r} \quad , \ if\ WTEQCEFFR_{y,eg,b,r} > 0 \\
EQCRUEC_{y,eg,b,r} &= EQCUEC_{r,eg,b} \times HDDFACT_{r} \quad , \ otherwise
\end{aligned}
\tag{48}
$$

where,

$EQCRUEC_{y,eg,b,r}$ is the unit energy consumption for replacement equipment by housing type and Census Division,

$RTBASEFF_{1997,eg}$ is the efficiency of the weighted average of retiring units from the 1997 existing stock, and

$WTEQCEFFR_{y,eg,b,r}$ is the replacement equipment efficiency weighted by the market share of the specific equipment as computed in the logistic function in the technology choice component by housing type and Census Division.

And the UEC for the surviving stock must be adjusted, according to:

$$
EQCSUEC_{y-1,eg,b,r} = EQCUEC_{r,eg,b} \times HDDFACT_{r} \times \frac{RTBASEFF_{1997,eg}}{RTBASEFF_{y,eg}}
\tag{49}
$$

where,

$EQCSUEC_{y,eg,b,r}$ is the average unit energy consumption of the original 1997 equipment stock that remains after the replacements have taken place.

The average UEC for all equipment is calculated as:

$$
\begin{aligned}
EQCAUEC_{y,eg,b,r} &= EQCNUEC_{y,eg,b,r} \times HDDFACT_{r} \quad , \ if\ y=1997 \\
EQCAUEC_{y,eg,b,r} &= EQCNUEC_{y,eg,b,r} \quad , \ if\ the\ equipment\ stock \leq 0 \\
EQCAUEC_{y,eg,b,r} &= \frac{\begin{array}{r} EQCRP90_{y,t,eg,b,r} \times EQCRUEC_{y,eg,b,r} \\ + (EQCREP_{y,t,eg,b,r} + EQCADD_{y,t,eg,b,r} + EQCRP90RP_{y,t,eg,b,r}) \times EQCNUEC_{y,eg,b,r} \\ + (EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r}) \times EQCAUEC_{y-1,eg,b,r} \end{array}}{\begin{array}{r} EQCRP90_{y,t,eg,b,r} + EQCREP_{y,t,eg,b,r} + EQCADD_{y,t,eg,b,r} \\ + EQCRP90RP_{y,t,eg,b,r} + EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r} \end{array}} \quad , \ otherwise
\end{aligned}
\tag{50}
$$

The final step of this algorithm is to calculate consumption for the service category. This is accomplished in two steps. The first year of the forecast is computed initially as,

$$HTRCON_{y=1998,f,r} = \sum_{b}\sum_{eg}\left[\begin{pmatrix} EQCESE_{y,eg,b,r} \times EQCUEC_{eg,b,r} \times EHSHELL_{y,f,r} \\ + EQCADD_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \times NHSHELL_{y,f,r} \\ + EQCRP90RP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \times EHSHELL_{y,f,r} \\ + EQCRP90_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \times EHSHELL_{y,f,r} \end{pmatrix} \times \left(\frac{PRICES_{y,f,r}}{PRICES_{y-1,f,r}}\right)^{\alpha}\right] \quad \textbf{(51)}$$

and subsequent consumption as,

$$HTRCON_{y,f,r} = \sum_{b}\sum_{eg}\left[\begin{pmatrix} EQCESE_{y,eg,b,r} \times EQCUEC_{eg,b,r} \times EHSHELL_{y,f,r} \\ + EQCADD_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \times NHSHELL_{y,f,r} \times RBN_{y,eg,b,r} \\ + EQCRP90_{y,t,eg,b,r} \times EQCRUEC_{y,eg,b,r} \times EHSHELL_{y,f,r} \times RBR_{y,eg,b,r} \\ + EQCRP90RP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \times EHSHELL_{y,f,r} \times RBN_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} \times EQCAUEC_{y,eg,b,r} \times EHSHELL_{y,f,r} \times RBA_{y,eg,b,r} \\ + EQCREP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \times AHSHELL_{y,f,r} \times RBN_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} \times EQCAUEC_{y,eg,b,r} \times AHSHELL_{y,f,r} \times RBA_{y,eg,b,r} \end{pmatrix} \times \left(\frac{PRICES_{y,f,r}}{PRICES_{1997,f,r}}\right)^{\alpha}\right] \quad \textbf{(52)}$$

where,

α is the short-term price elasticity, presently valued at -0.25 and

Here, there is a new concept called the “rebound effect" that accounts for the fact that increasing equipment efficiency for a particular equipment class causes a corresponding change in the price elasticity for the class. Three variables represent this effect:

$$RBA_{y,eg,b,r} = WTEQCEFFA_{y,eg,b,r} \times RTBASEFF_{1997,eg}^{\alpha_1} \quad \textbf{(53)}$$

$$RBR_{y,eg,b,r} = WTEQCEFFR_{y,eg,b,r} \times RTBASEFF_{1997,eg}^{\alpha_1} \quad \textbf{(54)}$$

$$RBN_{y,eg,b,r} = WTEQCEFFN_{y,eg,b,r} \times RTBASEFF_{1997,eg}^{\alpha_1} \quad \textbf{(55)}$$

where,

$RBA_{y,eg,b,r}$ is the rebound effect factor for surviving equipment,

$RBR_{y,eg,b,r}$ is the rebound effect factor for replacement equipment, and

$RBN_{y,eg,b,r}$ is the rebound effect factor for new equipment.

α_1 is the rebound effect elasticity, presently valued at -0.15

Consumption by furnace fans, FANCON, is computed in a similar fashion for those systems that require them.

Space Cooling

RCLTEC (Air Conditioning Equipment Choice Component)

Space cooling equipment choice begins with the calculation of a factor that adjusts for biased temperatures in either the base year or in the year under consideration, in each region,

$$CDDFACT_r = \frac{CDDADJ_{y,r}}{CDDADJ_{1997,r}} \tag{56}$$

where,

- $CDDFACT_r$ is a set of regional factors to be used in this year to adjust for abnormal temperatures either in this year or in the base year, and
- $CDDADJ_{y,r}$ are regional population-adjusted cooling degree-days by Census division and historical year, with forecast years filled in with the latest historical year, from the RMISC file.

Operating costs for cooling equipment are calculated like those for heating equipment, with the exception of the degree-days factor:

$$OPCOST_{y,es,b,r,v} = PRICES_{f,r,y} \times EQCUEC_{r,eg,b} \times CDDFACT_{r,y} \times RTEFFAC_{eg,v} \times CSHELL_{y-1,r,v} \tag{57}$$

where,

- $OPCOST_{y,es,b,r,v}$ is the operating cost for the air conditioner equipment type by housing type, Census Division, and vintage in the forecast year,
- $PRICES_{f,r,y}$ are the fuel prices by region and forecast year, from elsewhere in the NEMS system,
- $EQCUEC_{r,b}$ is the electricity unit energy consumption of 1997 room air conditioning equipment by Census Division and housing type, and
- $RTEFFAC_{eg,v}$ is the efficiency adjustment for the generic equipment type.
- $CSHELL_{y-1,r,v}$ is the shell efficiency adjustment to account for building shell improvements over time (which reduce cooling loads).

The following variables are computed as in the equations indicated:

- $LFCY_{y,es,b,r,v}$ is the room air conditioner type's life cycle cost by year, housing type and Census Division. It is computed as in (17) above.

$EQWTN_{y,es,b,r}$	is the equipment weight for new equipment types by housing type, Census Division and year. It is computed as in (21) above.
$EQWTR_{y,es,b,r}$	is the equipment weight for replacement equipment types by housing type, Census Division and year. It is computed as in (22) above.
$TOTEWTN_{y,eg,b,r}$	is the sum of equipment types' weights for the new equipment class. It is computed as in (23) above.
$TOTEWTR_{y,eg,b,r}$	is the sum of equipment types' weights for the replacement equipment class. It is computed as in (24) above.

Market shares for equipment types within the cooling equipment classes distinguish also between heat pumps, whose numbers have been determined in the heating choice component, and other cooling equipment. For heat pumps,

$$\begin{aligned} NEQTSHR_{y,es,b,r} &= NEQTSHR_{y,RTTYPNTR_{es},b,r} \\ REQTSHR_{y,es,b,r} &= REQTSHR_{y,RTTYPNTR_{es},b,r} \end{aligned} \quad (58)$$

and for other cooling equipment,

$$NEQTSHR_{y,es,b,r} = \frac{EQWTN_{y,es,b,r}}{TOTEWTN_{y,eg,b,r}} \quad (59)$$

$$REQTSHR_{y,es,b,r} = \frac{EQWTR_{y,es,b,r}}{TOTEWTR_{y,eg,b,r}} \quad (60)$$

where,

$NEQTSHR_{y,es,b,r}$	is the new market share for the new air conditioner equipment type by year, housing type and Census Division,
$REQTSHR_{y,es,b,r}$	is the new market share for the replacement air conditioner equipment type by year, housing type and Census Division,
$TOTEWTN_{y,eg,b,r}$	is the sum of equipment type weights for the new equipment class,
$TOTEWTR_{y,eg,b,r}$	is the sum of equipment type weights for the replacement equipment class,
$EQWTN_{y,es,b,r}$	is the equipment weight for new equipment, and
$EQWTR_{y,es,b,r}$	is the equipment weight for replacement equipment.

Weighted average inverse efficiencies of the types of cooling equipment into their classes are calculated exactly as in the heating component:

$WTEQCEFFN_{y,eg,b,r}$ is the weighted average inverse efficiency of new equipment types within each equipment class by year, housing type, and Census Division, computed as in (29).

$WTEQCEFFR_{y,eg,b,r}$ is the weighted average inverse efficiency of replacement equipment types within each equipment class by year, housing type, and Census Division, computed as in (30).

RCLADD (Additions and Replacements of Cooling Equipment Component)

Given the complex dependencies between choices of heating and cooling equipment, the cooling additions logic begins very differently from that for heating. Central air conditioner additions are calculated from housing additions and a set of saturation levels:

$$EQCADD_{y,t,CAC,b,r} = HSEADD_{y,b,r} \times CACSAT_{b,r} \quad \textbf{(61)}$$

where,

$EQCADD_{y,t,CAC,b,r}$ is the number of central air conditioners added to new (post-1997) housing units by year, housing type and Census Division,

$HSEADD_{y,b,r}$ is the amount of housing additions by year, housing type and Census Division, and

$CACSAT_{b,r}$ is the market penetration level or saturation of the market for central air conditioning equipment by housing type and Census Division, from the RMISC file.

For room air conditioners, there are similar saturation levels:

$$EQCADD_{y,t,RAC,b,r} = HSEADD_{y,b,r} \times RACSAT_{b,r} \quad \textbf{(62)}$$

where,

$EQCADD_{y,t,RAC,b,r}$ is the number of room air conditioners added to new (post-1997) housing units by year, housing type and Census Division,

$HSEADD_{y,b,r}$ is the amount of housing additions by year, housing type and Census Division, and

$RACSAT_{b,r}$ is the market penetration level or saturation of the market for room air conditioning equipment by housing type and Census Division.

For heat pumps, however, additions are determined by the number of associated furnaces installed in the heating additions component:

$$EQCADD_{y,t,eg,b,r} = EQCADD_{y,t,RTCLPNTR_{eg},b,r} \tag{63}$$

where,

$EQCADD_{y,t,eg,b,r}$ is the number of heat pumps used for space cooling added to new (post-1997) housing units by year, housing type and Census Division,

$EQCADD_{y,t,HP,b,r}$ is the number of heat pumps used for space heating added to new housing units by year, housing type and Census Division, and

$RTCLPNTR_{eg}$ is the pointer to the heating equipment class associated with the cooling equipment class.

The number of central air conditioners calculated from the saturation level in equation (61) included electric heat pumps. To convert that to non-heat pump central air conditioners, the component subtracts off electric heat pumps, but leaving ten percent, if heat pumps exceed total central air conditioners:

$$\begin{aligned} EQCADD_{y,t,CAC,b,r} &= 0.1 \times EQCADD_{y,t,HP,b,r} &&, \ if \ EQCADD_{y,t,CAC,b,r} \leq EQCADD_{y,t,eg,b,r} \\ EQCADD_{y,t,CAC,b,r} &= EQCADD_{y,t,CAC,b,r} - EQCADD_{y,t,HP,b,r} &&, \ otherwise \end{aligned} \tag{64}$$

where,

$EQCADD_{y,t,eg,b,r}$ is the number of central air conditioners in each equipment class added to new (post-1997) housing units by year, housing type and Census Division,

eg is the space cooling equipment class where the RTEKCL file defines that 1=RAC, 2=CAC, 3=Electric heat pump, 4=Geothermal heat pump, and 5=Natural gas heat pump.

Surviving equipment follows the same dichotomy as the other calculations, between heat pumps and other equipment. For non heat pumps, it is computed as in (41) above. For heat pumps, the stock is equated to that calculated in the space heating subroutines:

$$EQCSR90_{y,eg,b,r} = EQCSR90_{y,RTCLPNTR_{eg},b,r} \qquad (65)$$

where,

$EQCSR90_{y,eg,b,r}$ is the surviving post-1997 cooling equipment in pre-1998 housing units by year, housing type and Census Division, equated to the stock calculated in the space heating subroutines.

For centrally air-conditioned single-family houses, there is a penetration rate that describes new units added in pre-1998 houses:

$$EQCND90_{y,eg,b,r} = EQCND90_{y,eg,b,r} \times CACPR_r \times HDR_b \qquad (66)$$

where,

$EQCND90_{y,eg,b,r}$ is the number of air conditioning units needed in pre-1998 housing each year by housing type and Census Division,

HDR_b is the housing demolition rate by housing type.

$CACPR_r$ are regional penetration rates for central air conditioners from the RMISC file.

The replacement equipment types, EQCRP90, EQCRP90RP, and EQCREP are computed as in (35), (36), and (34) respectively. The surviving new additions, EQCSUR is computed as in (42) above.

Since replacements for heat pump air conditioners equal replacements for heat pump furnaces, and switching was allowed on replacement of heat pump furnaces, switching on replacement of heat pump air conditioners occurred in RHTRADD. No switching on replacement of central or room air conditioners is allowed since these numbers are based on historical data. Therefore, Subroutine RCLADD does not call Subroutine REPLACE.

RCLCON (Cooling Energy Consumption Component)

Energy consumption for space cooling is calculated much like the comparable quantities for space heating. Space cooling equipment consumption begins with the calculation of a factor that adjusts for biased temperatures in either the base year or in the year under consideration, in each region, as computed in (56) above.

Unit energy consumption is calculated for each of the vintages of homes. For surviving equipment in pre-1998 vintage homes,

$$EQCSUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \times CDDFACT_r \times \frac{RTBASEFF_{1997,eg}}{RTBASEFF_{y,eg}} \qquad \textbf{(67)}$$

where,

$EQCSUEC_{y,eg,b,r}$	is the unit energy efficiency of surviving equipment in pre-1998 vintage homes, by year, equipment class, housing type and Census Division,
$EQCUEC_{r,eg,b}$	is the unit energy efficiency of equipment in homes that existed in 1997, by Census Division, equipment class, and housing type,
$CDDFACT_r$	are the regional heading degree-day adjustment factors, and
$RTBASEFF_{y,eg}$	are the annual average efficiencies for the equipment classes.

For new equipment:

$$\begin{aligned} EQCNUEC_{y,eg,b,r} &= EQCUEC_{r,eg,b} \times CDDFACT_r \times SQFTADJ_{y,b,r} \\ & \quad WTEQCEFFN_{y,eg,b,r} \times RTBASEFF_{1997,eg} \quad , \; if\ WTEQCEFFN_{y,eg,b,r} > 0 \\ EQCNUEC_{y,eg,b,r} &= EQCUEC_{r,eg,b} \times CDDFACT_r \times SQFTADJ_{y,b,r} \quad , \; otherwise \end{aligned} \qquad \textbf{(68)}$$

where,

$EQCNUEC_{y,eg,b,r}$	is the unit energy consumption by year for new equipment by housing type and Census Division,
$WTEQCEFFN_{y,eg,b,r}$	is the equipment inverse efficiency by year, equipment class, housing type and Census Division,
$RTBASEFF_{y,eg}$	is the average efficiency of the equipment class,
$EQCUEC_{r,eg,b}$	is unit energy consumption for equipment in 1997 housing by Census Division, equipment class and housing type,

$CDDFACT_r$ is the heating degree day adjustment factor by Census Division to correct for the unusually warm weather during the RECS survey year, and

$SQFTADJ_{y,b,r}$ adjusts for the increasing average floor area of new homes, as compared with the RECS base year.

Replacement equipment UEC values are calculated in the same way as new equipment, but without the floor area adjustment:

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \times WTEQCEFFR_{y,eg,b,r} \times RTBASEFF_{1997,eg} \times CDDFACT_r \quad , \text{ if } WTEQCEFFR_{y,eg,b,r} > 0$$

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \times CDDFACT_r \quad , \text{ otherwise} \tag{69}$$

where,

$EQCRUEC_{y,eg,b,r}$ is the unit energy consumption for replacement equipment by housing type and Census Division,

$RTBASEFF_{1997,eg}$ is the efficiency of the weighted average of retiring units from the 1997 existing stock, and

$WTEQCEFFR_{y,eg,b,r}$ is the replacement equipment inverse efficiency weighted by the market share of the equipment type as computed in the log-linear function in the technology choice component by housing type and Census Division.

The average UEC, EQCAUEC, for all cooling equipment is calculated as in (50) above.

Cooling shell efficiency is calculated similarly to heating shell efficiency computed in equations (43) through (46), substituting the EPACT cooling effects for the heating effects.

The final step of this component is to calculate consumption for the service category. This is accomplished in two steps. The first year of the forecast is computed as,

$$COOLCN_{y=1998,f,r} = \sum_{b}\sum_{eg}\left[\begin{pmatrix} EQCESE_{y,eg,b,r} \times EQCSUEC_{eg,b,r} \times ECSHELL_{y,b,r} \\ + EQCADD_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \times NCSHELL_{y,b,r} \\ + EQCRP90_{y,t,eg,b,r} \times EQCRUEC_{y,eg,b,r} \times ECSHELL_{y,b,r} \\ + EQCRP90RP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \times ECSHELL_{y,b,r} \end{pmatrix} \times \left(\frac{PRICES_{y,f,r}}{PRICES_{y-1,f,r}}\right)^{\alpha}\right] \qquad \textbf{(70)}$$

and subsequent consumption as,

$$COOLCN_{y,f,r} = \sum_{b}\sum_{eg}\left[\begin{pmatrix} EQCESE_{y,eg,b,r} \times EQCSUEC_{y,eg,b,r} \times ECSHELL_{y,b,r}^{1+\alpha} \\ + EQCADD_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \times NCSHELL_{y,b,r}^{1+\alpha} \times RBN_{y,eg,b,r} \\ + EQCRP90_{y,t,eg,b,r} \times EQCRUEC_{y,eg,b,r} \times ECSHELL_{y,b,r}^{1+\alpha} \times RBR_{y,eg,b,r} \\ + EQCRP90RP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \times ECSHELL_{y,b,r}^{1+\alpha} \times RBR_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} \times EQCAUEC_{y,eg,b,r} \times ECSHELL_{y,b,r}^{1+\alpha} \times RBA_{y,eg,b,r} \\ + EQCREP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \times ACSHELL_{y,b,r}^{1+\alpha} \times RBN_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} \times EQCAUEC_{y,eg,b,r} \times ACSHELL_{y,b,r}^{1+\alpha} \times RBA_{y,eg,b,r} \end{pmatrix} \times \left(\frac{PRICES_{f,r,y}}{PRICES_{f,r,1997}}\right)^{\alpha}\right] \qquad \textbf{(71)}$$

where,

α is the short-term price elasticity, presently valued at .25.

The “rebound effect'' that was introduced in the space heating section is also represented in the space cooling consumption equation. The “rebound effect” is represented in equations (53) through (55).

Clothes Washers

RCWTEC (Clothes Washer Technology Choice Component)

Compute current year operating costs,

$$OPCOST_{y,es,b,r,v} = PRICES_{f,r,y} \times EQCUEC_{r,eg,b} \times \frac{RTBASEFF_{1997,eg}}{RTEQEFF_{es}} \qquad \textbf{(72)}$$

where,

$OPCOST_{y,es,b,r,v}$ is the operating cost for the equipment type by year, housing type, Census Division, and vintage,

$PRICES_{f,r,y}$ is the fuel prices for the equipment from NEMS, by fuel, by region and forecast year,

$EQCUEC_{r,eg,b}$ is the unit energy consumption by Census Division, equipment class and housing type,

$RTEQEFF_{es}$ is the equipment efficiency,

$RTBASEEFF_{1997,eg}$ is the 1997 stock-average efficiency.

The following variables are computed as in the equations indicated:

$LFCY_{y,es,b,r,v}$ is the clothes washer's life cycle cost by year, housing type Census Division, and vintage. It is computed as in (17) above.

$EQWTN_{y,es,b,r}$ is the equipment weight for new equipment type by housing type, Census Division, and year. It is computed as in (21) above.

$EQWTR_{y,es,b,r}$ is the equipment weight for replacement equipment by housing type, Census Division, and year. It is computed as in (22) above.

$TOTEWTN_{y,eg,b,r}$ is the sum of equipment weights for the new equipment class. It is computed as in (23) above.

$TOTEWTR_{y,eg,b,r}$ is the sum of equipment weights for the replacement equipment class. It is computed as in (24) above.

Market shares for new and replacement clothes washers are next:

$$NEQTSHR_{y,es,b,r} = \frac{EQWT_{y,es,b,r}}{TOTEWT_{y,eg,b,r}} \quad (73)$$

where,

$NEQTSHR_{y,es,b,r}$ is the new market share of clothes washer equipment types by housing type and Census Division in the current year,

$TOTEWT_{eg}$ is the sum of equipment weights for the new equipment class,

$EQWT_{es}$ is the equipment weight for new equipment,and

Since efficiency improvements in clothes washers tend to affect the amount of hot water used in a household, establishing a link between clothes washers and water heaters is essential. The impact of the load reduction with respect to installing more efficient clothes washers is calculated as follows:

$$TEMP = \sum_{es} EQWT_{y,es,b,r}$$

$$NCWLOAD_{y,eg,b,r} = \frac{\sum_{es} \left(EQWT_{y,es,b,r} \times LOADADJ_{es} \right)}{TEMP} \quad , \text{ if } TEMP>0, \tag{74}$$

$$NCWLOAD_{y,eg,b,r} = NCWLOAD_{y-1,eg,b,r} \quad , \text{ otherwise}$$

where,

$NCWLOAD_{y,es,b,r}$ is the weighted average load adjustment of new clothes washers with respect to water heating load in the current year by housing type and Census Division,

$EQWT_{es}$ is the equipment weight for each type of new equipment, and

$LOADADJ_{es}$ is the fraction of hot water needed to provide the same level of service, relative to the base year average.

RCWADD (Clothes Washer Additions Component)

New clothes washing equipment is calculated using a saturation level for newly-bought equipment

$$EQCADD_{y,t,eg,b,r} = HSEADD_{y,b,r} \times \frac{WASHNEW_{b,r}}{100} \tag{75}$$

where,

$EQCADD_{y,t,eg,b,r}$ is the amount of new (post-1997 vintage) equipment added in new housing units in the current year by housing type and Census Division, vintaged to year *t*,

$HSEADD_{y,b,r}$ is the number of new housing additions in the year by housing type and Census Division,

$NEWWASH_{b,r}$ is the share of clothes washers in newly constructed houses by housing type and Census Division in the current year, and

The next step is to calculate the numbers of clothes washers of each vintage category. The following variables were computed as in the equations indicated:

$EQCSR90_{y,eg,b,r}$ is the surviving post-1997 vintage equipment in pre-1998 housing units in the current year by housing type and Census Division. It is computed as in

(41) above.

$EQCSUR_{y,eg,b,r}$ is the surviving new (post-1997 vintage) equipment in the current year by housing type and Census Division. It is computed as in (42) above.

$EQCREP_{y,t,eg,b,r}$ is the number of replacement units (post-1997 vintage) equipment demanded in post-1997 vintage housing units by housing type and Census Division. It is computed as in (34) above.

$EQCRP90_{y,t,eg,b,r}$ is the number of replacement units demanded in pre-1998 housing units each year by housing type and Census Division. It is computed as in (35) above.

$EQCRP90RP_{y,t,eg,b,r}$ is the number of replacement units for the EQCRP90 units demanded each year by housing type and Census Division. It is computed as in (36) above.

RCWCON (Clothes Washer Energy Consumption Component)

To calculate the energy consumption attributable to clothes washers, first calculate the unit energy consumption for each vintage of home. These are calculated similarly as those presented in equations (47) through (50). Namely,

$EQCSUEC_{y,eg,b,r}$ is the UEC for surviving 1997 equipment in each equipment class, by housing type and Census Division,

$EQCNUEC_{y,eg,b,r}$ is the unit energy consumption by year for new equipment by housing type and Census Division,

$EQCRUEC_{y,eg,b,r}$ is the unit energy consumption by year for replacement equipment by housing type and Census Division, and

$EQCAUEC_{y,eg,b,r}$ is the average unit energy consumption for all equipment by housing type and Census Division.

Finally, the energy consumption calculation is simpler than most of the other end uses:

$$CSWCON_{y,r} = \sum_{b} \begin{bmatrix} EQCESE_{y,eg,b,r} \times EQCSUEC_{r,eg\ b} \\ + EQCADD_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,t,eg,b,r} \times EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \end{bmatrix}, \ if\ y=1998 \qquad \textbf{(76)}$$

$$CSWCON_{y,r} = \sum_{b} \begin{bmatrix} EQCESE_{y,eg,b,r} \times EACSUEC_{y,eg,b,r} \\ + EQCADD_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,t,eg,b,r} \times EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} \times EQCAUEC_{y,eg,b,r} \\ + EQCREP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} \times EACAUEC_{y,eg,b,r} \end{bmatrix}, \ otherwise \tag{77}$$

Dishwashers

RDWTEC (Dishwasher Technology Choice Component)

The following variables are computed as in the equations indicated:

$OPCOST_{y,es,b,r,v}$ is the operating cost for the equipment type by year, housing type, Census Division, and vintage. It is computed as in (72) above.

$LFCY_{y,es,b,r,v}$ is the dishwasher's life cycle cost by year, housing type Census Division, and vintage. It is computed as in (17) above.

$EQWTN_{y,es,b,r}$ is the equipment weight for new equipment type by housing type, Census Division, and year. It is computed as in (21) above.

$EQWTR_{y,es,b,r}$ is the equipment weight for replacement equipment by housing type, Census Division, and year. It is computed as in (22) above.

$TOTEWTN_{y,eg,b,r}$ is the sum of equipment weights for the new equipment class. It is computed as in (23) above.

$TOTEWTR_{y,eg,b,r}$ is the sum of equipment weights for the replacement equipment class. It is computed as in (24) above.

Market shares for new and replacement dishwashers are next:

$$NEQTSHR_{y,es,b,r} = \frac{EQWT_{y,es,b,r}}{TOTEWT_{y,eg,b,r}} \tag{78}$$

where,

$NEQTSHR_{y,es,b,r}$ is the new market share of dishwasher equipment types by housing type and Census Division in the current year,

$TOTEWT_{eg}$ is the sum of equipment weights for the new equipment class, and

$EQWT_{es}$ is the equipment weight for new equipment.

RDWADD (Dishwasher Additions Component)

New dishwashing equipment is calculated using a saturation level for newly-bought equipment

$$EQCADD_{y,t,eg,b,r} = HSEADD_{y,b,r} \times \frac{DISHNEW_{b,r}}{100} \tag{79}$$

where,

$EQCADD_{y,t,eg,b,r}$ is the amount of new (post-1997 vintage) equipment added in new housing units in the current year by housing type and Census Division, vintaged to year *t*,

$HSEADD_{y,b,r}$ is the number of new housing additions in the year by housing type and Census Division, and

$NEWWASH_{b,r}$ is the share of clothes washers in newly constructed houses by housing type and Census Division in the current year.

The next step is to calculate the numbers of dishwashers of each vintage category. The following variables were computed as in the equations indicated:

$EQCSR90_{y,eg,b,r}$ is the surviving post-1997 vintage equipment in pre-1998 housing units in the current year by housing type and Census Division. It is computed as in (41) above.

$EQCSUR_{y,eg,b,r}$ is the surviving new (post-1997 vintage) equipment in the current year by housing type and Census Division. It is computed as in (42) above.

$EQCREP_{y,t,eg,b,r}$ is the number of replacement units (post-1997 vintage) equipment demanded in post-1997 vintage housing units by housing type and Census Division. It is computed as in (34) above.

$EQCRP90_{y,t,eg,b,r}$ is the number of replacement units demanded in pre-1998 housing units each year by housing type and Census Division. It is computed as in (35) above.

$EQCRP90RP_{y,t,eg,b,r}$ is the number of replacement units for the EQCRP90 units demanded each year by housing type and Census Division. It is computed as in (36) above.

RDWCON (Dishwasher Energy Consumption Component)

To calculate the energy consumption attributable to dishwashers, first calculate the unit energy consumption for each vintage of home. These are calculated similarly as those presented in equations (47) through (50). Namely,

$EQCSUEC_{y,eg,b,r}$ is the UEC for surviving 1997 equipment in each equipment class, by housing type and Census Division,

$EQCNUEC_{y,eg,b,r}$ is the unit energy consumption by year for new equipment by housing type and Census Division,

$EQCRUEC_{y,eg,b,r}$ is the unit energy consumption by year for replacement equipment by housing type and Census Division, and

$EQCAUEC_{y,eg,b,r}$ is the average unit energy consumption for all equipment by housing type and Census Division.

Finally, the energy consumption calculation is simpler than most of the other end uses:

$$DSWCON_{y,r} = \sum_{b} \begin{bmatrix} EQCESE_{y,eg,b,r} \times EQCSUEC_{r,eg\ b} \\ + EQCADD_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,t,eg,b,r} \times EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \end{bmatrix}, \ if\ y = 1998 \quad \mathbf{(80)}$$

$$DSWCON_{y,r} = \sum_{b} \begin{bmatrix} EQCESE_{y,eg,b,r} \times EACSUEC_{y,eg,b,r} \\ + EQCADD_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,t,eg,b,r} \times EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} \times EQCAUEC_{y,eg,b,r} \\ + EQCREP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} \times EACAUEC_{y,eg,b,r} \end{bmatrix}, \ otherwise \quad \mathbf{(81)}$$

Water Heating

Regional solar water heating equipment stock is calculated for 1997 as

$$SLESE_{1997,r} = \sum_{b} EH_{1997,b,r} \times SLSHR_{b,r} \tag{82}$$

where,

$SLESE_{1997,r}$ is the existing 1997 solar water heaters by Census Division,

$SLSHR_{b,r}$ is the 1997 market share of solar water heaters in pre-1998 housing units by housing type and Census Division, from the RMISC file, and

$EH_{1997,b,r}$ is the 1997 stock of housing by housing type and Census Division.

For years after 1997, the model projects solar heaters separately from other water heating equipment. For solar heaters,

$$SLESE_{y,r} = SLESE_{1997,r} \times SVRTE_{y-1997,0,30} \times HDR_b^{y-1997} \tag{83}$$

where,

$SLESE_{y,r}$ is the number of surviving pre-1998 vintage solar water heaters in pre-1998 single-family houses by year and Census Division,

$SVRTE_{y-1997,0,30}$ is the equipment survival rate, using minimum and maximum lifetimes not established in the input database, and

HDR_1 is the housing demolition rate for single-family homes.

RWHTEC (Water Heater Equipment Choice Component)

New water heaters are assumed to be distributed in proportion to associated space heating equipment, where the association between water heating equipment and space heating equipment is specified by the user in the $RTCLPNTR_{eg}$ pointer for each water heating equipment class in the RTEKCL file. (Replacement water heaters are not so constrained in single-family housing.) The component first adds up the market shares of all space heating equipment,

$$TOTN_{b,r} = \sum_{eg} HSYSSHR_{y,eg,b,r} \tag{84}$$

where,

$TOTN_{b,r}$	is the sum of the base year market shares for space heating equipment classes by housing type and Census Division, and
$HSYSSHR_{y,eg,b,r}$	is the current year market share for space heating equipment classes by housing type and Census Division.

New water heater market shares are therefore calculated by the sum of the market shares of the associated heating equipment,

$$NH2OSH_{y,eg_{wh},b,r} = \frac{\sum_{eg} HSYSSHR_{y,RTCLEQCL_{SH}=RTCLPNTR_{WH},b,r}}{TOTN_{b,r}} \tag{85}$$

where,

$NH2OSH_{y,eg,b,r}$	is the market share of each new water heater class by housing type and Census Division. There are four equipment classes for water heaters: natural gas, electric, distillate, and LPG.
$TOTN_{b,r}$	is the sum of the base year market shares for space heating equipment classes by housing type and Census Division,
$HSYSSHR_{y,eg,b,r}$	is the current year market share of the space heating equipment class by housing type and Census Division,
$RTCLEQCL_{SH}$	is the equipment class number for the space heater class, and
$RTCLPNTR_{wh}$	is the pointer to a space heater class from a water heater class.

The following variables are computed as in the equations indicated:

$OPCOST_{y,es,b,r,v}$	is the operating cost for the water heater equipment type by housing type, Census Division, vintage, and year. It is computed as in (72) above.
$LFCY_{y,es,b,r,v}$	is the water heater type's life cycle cost by year, housing type Census Division, and vintage. It is computed as in (17) above.
$EQWTN_{y,es,b,r}$	is the equipment weight for new equipment types by housing type, Census

Division, and year. It is computed as in (21) above.

$EQWTR_{y,es,b,r}$ is the equipment weight for replacement equipment types by housing type, Census Division, and year. It is computed as in (22) above.

$TOTEWTN_{y,eg,b,r}$ is the sum of the equipment types' weights for the new equipment class. It is computed as in (23) above.

$TOTEWTR_{y,eg,b,r}$ is the sum of the equipment types' weights for the replacement equipment class. It is computed as in (24) above.

$EQFSHRN_{y,f,b,r}$ is the fuel share of new equipment type by year, housing type and Census Division. It is computed as in (25) above.

$EQFSHRR_{y,f,b,r}$ is the fuel share of replacement equipment type by year, housing type and Census Division. It is computed as in (26) above.

The fuel shares are stored into their final places:

$$NEQTSHR_{y,f,b,r} = EQFSHRN_{y,es,b,r} \tag{86}$$

$$REQTSHR_{y,f,b,r} = EQFSHRR_{y,es,b,r} \tag{87}$$

where,

$NEQTSHR_{y,f,b,r}$ is the fuel shares of new water heaters by fuel, housing type and Census Division, and

$REQTSHR_{y,f,b,r}$ is the fuel shares of replacement water heaters by fuel, housing type and Census Division.

Weighted average class efficiencies by fuel can then be calculated from the individual equipment types for new and replacement equipment, using exactly the same formulas as for space heating equipment, as shown in equations (29) and (30):

$WTEQCEFFN_{y,eg,b,r}$ is the weighted average inverse efficiency for new water heating equipment classes by year, housing type and Census Division, and

$WTEQCEFFR_{y,eg,b,r}$ is the weighted average inverse efficiency for replacement water heating equipment classes by year, housing type and Census Division.

REUADD (Water Heating and Cooking Additions and Replacements Component)

There is only one component in the RDM for addition and replacement of water heating equipment and cooking equipment. This is an enhancement implemented in the module in 1996 that anticipates the day when integrated logic can handle all calculations for all equipment types.

The first operation is to calculate the total equipment in pre-1998 housing,

$$EQCND90_{y,eg,b,r} = EQCESE_{1997,eg,b,r} \times HDR_b \text{ , } if\ y{=}1998$$
$$EQCND90_{y,eg,b,r} = EQCND90_{y-1,eg,b,r} \times HDR_b \text{ , } if\ y{>}1998 \quad (88)$$

where,

$EQCND90_{y,eg,b,r}$	is the total equipment in pre-1998 housing each year by housing type and Census Division,
$EQCESE_{1997,eg,b,r}$	is the pre-1998 equipment stock in pre-1998 housing units in the base year by housing type and Census Division, and
HDR_b	is the housing demolition rate by housing type.

Next, calculate purchases for new housing,

$$EQCADD_{y,t,eq,b,r} = HSEADD_{y,b,r} \times SHARE \quad (89)$$

where,

$EQCADD_{y,t,eg,b,r}$	is the number new units originally purchased for new housing additions by year, housing type and Census Division,
$HSEADD_{y,b,r}$	is the number of housing additions by year, housing type and Census Division, and
$SHARE$	is the share of the particular equipment for which the component has been called, $NH2OSH_{y,eg,b,r}$ or $NCKSH_{y,eg,b,r}$:
$NH2OSH_{y,eg,b,r}$	is the market penetration level or saturation of the market for water heaters by housing type and Census Division,
$NCKSH_{y,eg,b,r}$	is the market penetration level or saturation of the market for cookstoves by housing type and Census Division.

The following variables are computed as in the equations indicated:

$EQCSR90_{y,eg,b,r}$ is the surviving post-1997 vintage equipment in pre-1998 housing units by year, housing type and Census Division. It is calculated as in (41) above.

$EQCSUR_{y,eg,b,r}$ is the surviving post-1997 vintage equipment in post-1997 housing by year, housing type and Census Division. It is computed as in (42) above.

$EQCREP_{y,t,eg,b,r}$ is the number of equipment replacements of post-1997 equipment in post-1997 housing units by year, housing type and Census Division. It is computed as in (34) above.

$EQCRP90_{y,t,eg,b,r}$ is the number of replacement units demanded in pre-1998 housing units by year, housing type and Census Division. It is computed as in (35) above.

$EQCRP90RP_{y,t,eg,b,r}$ is the number of replacement units for the EQCRP90 units demanded each year by housing type and Census Division. It is computed as in (36) above.

If the component has been called for water heating rather than for cooking, the solar water heating variables are calculated as follows:

$$\begin{aligned} SLND90_{1998,r,b} &= SLESE_{1997,r,b} \times HDR_b \quad , \; if\; y=1998 \\ SLND90_{y,r,b} &= SLND90_{y-1,r,b} \times HDR_b \quad , \; otherwise \end{aligned} \tag{90}$$

$$SOLADD_{y,r,b} = HSEADD_{y,b,r} \times NEWSLSHR_r,b \tag{91}$$

$$SLSR90_{y,r,b} = \sum_{t=1998}^{y-1} \left[SLRP90_{t,r,b} \times SVRTE_{y-t,5,30} \times HDR_b^{y-t} \right] \tag{92}$$

$$SOLSUR_{y,r,b} = \sum_{t=1998}^{y-1} \left(SOLADD_{t,r,b} + SOLREP_{t,r,b} \times HDR_b^{y-t} \times SVRTE_{y-t,5,30} \right) \tag{93}$$

$$SOLREP_{y,r,b} = \left(\sum_{t=1998}^{y-1} SOLADD_{t,r,b} \times HDR_b^{y-t} \right) - SOLSUR_{y,r,b} \tag{94}$$

$$SLRP90_{y,r,b} = SLESE_{1997,r,b} \times HDR_b^{y-1997} - SLESE_{y,r,b} - SLSR90_{y,r,b} \quad \textbf{(95)}$$

where,

$SLND90_{y,rb,}$	is the total amount of solar water heating equipment surviving in pre-1998 housing each year,
$SOLADD_{y,r,b}$	is the number of post-1998 solar water heaters by equipment class added to new housing units in this year,
$NEWSLSHR_{r,b}$	is the "new solar water heating share" from the RMISC file,
$SLSR90_{y,r,b}$	is the surviving post-1997 vintage solar water heating equipment in pre-1998 housing units by year and Census Division,
$SOLSUR_{y,r,b}$	is the number of surviving post-1997 solar water heaters by equipment class in post-1997 housing units by year, housing type and Census Division.
$SOLREP_{y,r,b}$	is the number of surviving post-1997 solar water heaters to be replaced in post-1997 housing units in this year by equipment class, housing type and Census Division, and
$SLRP90_{t,r,b}$	is the replacement (post-1997 vintage) solar water heating equipment demanded in pre-1998 housing units by year and Census Division.

RWHCON (Water Heater Energy Consumption Component)

Energy consumption for water heating is calculated much like the comparable quantities for space heating. Some of the most important determinants of the amount of hot water consumption in households is the number of inhabitants and the usage and efficiency of clothes washers. The component therefore calculates an average household size that will be used with an elasticity to account for this determinant,

$$HHSIZE_{y,r} = \frac{MC\_POP16_{y,r}}{\sum_b \left(EH_{y,b,r} + NH_{y,b,r}\right)} \quad \textbf{(96)}$$

where,

$HHSIZE_{y,r}$	is the average number of persons over age 16 per household by year and region,

$MC\_POP16_{y,r}$ is the number of persons over age 16 by year and region, from the NEMS Macroeconomic Module,

$EH_{y,b,r}$ is the number of pre-1998 vintage homes existing in year y, from the RMISC file, and

$NH_{y,b,r}$ is the number of post-1997 vintage homes remaining in year y, from the NEMS Macroeconomic Module, as shown in equations (3) through (6).

Unit energy consumption is calculated for the usual vintages. First, the surviving base-year homes,

$$EQCSUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \times \left(\frac{HHSIZE_{y,d}}{HHSIZE_{1997,d}}\right)^{HHSELAS} \times \frac{RTBASEFF_{1997,eg}}{RTBASEFF_{y,eg}} \quad \textbf{(97)}$$

where,

$EQCSUEC_{y,eg,b,r}$ is the unit energy efficiency of surviving water heating equipment in pre-1998 vintage homes, by year, equipment class, housing type and Census Division,

$EQCUEC_{r,eg,b}$ is the unit energy efficiency of equipment in homes that existed in 1997, by Census Division, equipment class, and housing type,

$HHSIZE_{y,r}$ is the average household size by year and Census Division,

$HHSELAS$ is an elasticity parameter for the increase in hot water intensity due to increases in household size, estimated at .315, and

$RTBASEFF_{y,eg}$ are the annual average efficiencies for the equipment classes.

For new purchases in year 1998,

$$\begin{aligned} EQCNUEC_{y,eg,b,r} &= EQCUEC_{r,eg,b} \times \left(\frac{HHSIZE_{y,r}}{HHSIZE_{1997,r}}\right)^{HHSELAS} \\ &\quad \times WTEQCEFFN_{y,eg,b,r} \times RTBASEFF_{1997,eg} \quad , \; if \; WTEQCEFFN_{y,eg,b,r} > 0 \\ EQCNUEC_{y,eg,b,r} &= EQCUEC_{r,eg,b} \times \left(\frac{HHSIZE_{y,r}}{HHSIZE_{1997,r}}\right)^{HHSELAS} \quad , \; otherwise \end{aligned} \quad \textbf{(98)}$$

For purchases after 1998,

$$EQCNUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \times \left(\frac{HHSIZE_{y,r}}{HHSIZE_{1997,r}} \right)^{HHSELAS} \times EPACT \times WTEQCEFFN_{y,eg,b,r} \times RTBASEFF_{1997,eg} \quad , \text{ if } WTEQCEFFN_{y,eg,b,r} > 0$$

$$EQCNUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \times \left(\frac{HHSIZE_{y,r}}{HHSIZE_{1997,r}} \right)^{HHSELAS} \times EPACT \quad , \text{ otherwise} \tag{99}$$

where,

$EQCNUEC_{y,eg,b,r}$	is the unit energy consumption for new equipment by year, housing type and Census Division,
$EQCUEC_{r,eg,b}$	is the unit energy consumption for the equipment class by housing type and Census Division,
$WTEQCEFFN_{y,eg,b,r}$	is the weighted average inverse efficiency for new water heating equipment types by year, class, housing type and Census Division,
$EPACT$	is the fraction by which the UEC must be adjusted to reflect mandated low-flow shower head standards as part of the Energy Policy Act of 1993,
$HHSIZE_{y,r}$	is the average household size by year and Census Division,
$HHSELAS$	is an elasticity parameter for the increase in hot water intensity due to increases in household size, estimated at .315, and
$RTBASEFF_{y,eg}$	is the efficiency of the water heating equipment classes.

For replacements in this year,

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \times \left(\frac{HHSIZE_{y,r}}{HHSIZE_{1997,r}} \right)^{HHSELAS} \times EPACT \times WTEQCEFFR_{y,eg,b,r} \times RTBASEFF_{1997,eg} \quad , \text{ if } WTEQCEFFR_{y,eg,b,r} > 0$$

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \times \left(\frac{HHSIZE_{y,r}}{HHSIZE_{1997,r}} \right)^{HHSELAS} \times EPACT \quad , \text{ otherwise} \tag{100}$$

where,

$EQCRUEC_{y,eg,b,r}$	is the unit energy consumption for replacement equipment by year, housing type and Census Division,

$WTEQCEFFR_{y,eg,b,r}$ is the weighted average inverse efficiency for replacement water heating equipment classes by year, housing type and Census Division, and

$EQCUEC_{r,eg,b}$ is the unit energy consumption for the equipment class by housing type and Census Division, and

$RTBASEFF_{y,eg}$ is the efficiency of retiring equipment from the 1997 stock by year.

And the average UEC is

$$TEMP = EQCRP90_{y,t,eg,b,r} + EQCRP90RP_{y,eg,t,b,r} + EQCREP_{y,t,eg,b} + EQCADD_{y,t,eg,b,r} + EQCSR90_{y,eg}$$

$$EQCAUEC_{y,eg,b,r} = EQCNUEC_{y,eg,b,r}$$

$$EQCAUEC_{y,eg,b,r} = \frac{+ (EQCRP90RP_{y,t,eg,b,r} + EQCADD_{y,t,eg,b,r} + \; + (EQCSR90_{y,eg,b,r} +}{TEMP} \quad (101)$$

where,

$EQCAUEC_{y,eg,b,r}$ is the average unit energy consumption for water heaters by year, equipment class, housing type and Census Division.

Water heater efficiency is calculated next. If y = 1998 or denominator ≤ 0,

$$WTEQCEFFA_{y,eg,b,r} = WTEQCEFFN_{y=1998,eg,b,r} \quad (102)$$

If y > 1998 and denominator >0,

$$WTEQCEFFA_{y,eg,b,r} = \frac{(EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r}) \times WTEQCEFFA_{y-1,eg,b,r} + EQCRP90_{y,t,eg,b,r} \times WTEQCEFFR_{y,eg,b,r} + (EQCRP90RP_{y,t,eg,b,r} + EQCADD_{y,t,eg,b,r} + EQCREP_{y,t,eg,b,r}) \times WTEQCEFFN_{y,eg,b,r}}{EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r} + EQCRP90_{y,t,eg,b,r} + EQCADD_{y,t,eg,b,r} + EQCRP90RP_{y,t,eg,b,r} + EQCREP_{y,t,eg,b,r}} \quad (103)$$

where,

$WTWEFFA_{y,eg,b,r}$ is the weighted average water heater efficiency by equipment class, housing type, Census Division, and year.

To account for changes in hot water demand over time, both the number and efficiency (with respect to hot water use) of clothes washers is very important. To resolve this issue, the water heating consumption subroutine relies on calculations that are generated in the clothes washer subroutine. First, the number of clothes washers must be shared to each of the competing fuel types for all vintages of equipment. Namely,

$$H2OSHRCW_{y,f,b,r,v} = H2OSHR_{y,f,b,r,v} \times NUMCW_{y,b,r,v} \tag{104}$$

where,

$H2OSHRCW_{y,f,b,r,v}$ is the number of clothes washers for each type of water heating fuel type by Census Division and building type for all vintages of equipment,

$H2OSHR_{y,f,b,r,v}$ is the share for each type of water heating fuel type by Census Division and building type for all vintages of equipment,

$NUMCW_{y,f,b,r,v}$ is the number of clothes washers by Census Division and building type for all vintages of equipment, and

Next, the consumption for water heating for homes with clothes washers is computed as follows:

$$H2OCONCW_{y,f,b,r,v} = H2OSHRCW_{y,f,b,r,v} \times H2OUEC_{y,f,b,r,v} \times LDADJCW_{y,b,r} \tag{105}$$

where,

$H2OCONCW_{y,f,b,r,v}$ is the water heating consumption for homes with clothes washers for each type of water heating fuel type by Census Division and building type for all vintages of equipment,

$H2OUEC_{y,f,b,r,v}$ is the unit energy consumption for each type of water heating fuel type by Census Division and building type for all vintages of equipment,

$LDADJCW_{y,b,r,v}$ is the adjustment to the water heating UEC to account for the efficiency of clothes washers with respect to hot water load by Census Division and building type for all vintages of equipment, and

$$H2OCON_{y,f,r} = \sum_b \left[\left(\left(\begin{array}{r} EQCESE_{y,eg,b,r} \times EQCSUEC_{r,eg,b} \\ + EQCADD_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,t,eg,b,r} \times EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \end{array} \right) + H2OCONCW_{y,f,b,r,v} \right) \times \left(\frac{PRICES_{f,r,y}}{PRICES_{f,r,1997}} \right)^{\alpha} \right]$$

(106)

Finally, energy consumption by fuel can be summed over the different housing types. If y = 1998,

If y > 1998,

$$H2OCON_{y,f,r} = \sum_b \left[\left(\left(\begin{array}{r} EQCESE_{y,eg,b,r} \times EQCSUEC_{r,eg,b} \\ + EQCADD_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,t,eg,b,r} \times EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCSR90_{y,t,eg,b,r} \times EQCAUEC_{y-1,eg,b,r} \\ + EQCREP_{y,t,eg,b,r} \times EQCRUEC_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} \times EQCAUEC_{y-1,eg,b,r} \end{array} \right) + H2OCONCW_{y,f,b,r,v} \right) \times \left(\frac{PRICES_{f,r,y}}{PRICES_{f,r,1993}} \right)^{\alpha} \right]$$

(107)

where,

$H2OCON_{y,f,r}$	is consumption for water heating by fuel, and
α	is the short-term price elasticity, presently valued at -0.25.

And for solar water heaters,

$$SLCON_{y,r} = \sum_b \left[\left(\begin{array}{r} SLESE_{y,r,b} + SOLADD_{y,r,b} \\ + SRLP90_{y,r,b} + SLSR90_{y-1,r,b} \\ + SOLREP_{y,r,b} + SOLSUR_{y,r,b} \end{array} \right) \times SLUEC_{r,b} \right] \quad \textbf{(108)}$$

where,

$SLCON_{y,r}$	is consumption for solar water heating.

Cooking Equipment

RSTVTEC (Choose Cooking Equipment Component)

The existing cooking equipment distribution is associated with the choice of a water heaters. Homes that heat water with natural gas are allowed to have either gas or electric stoves; homes that heat with LPG cook with LPG; homes that heat water with distillate oil cook with electricity. (Replacement stoves in single-family homes are not so constrained.) These constraints are embodied in the technology choice by using the water heater equipment market shares for calculating the cooking equipment market shares:

$$NCKSH_{y,eg,b,r} = NH2OSH_{y,eg,b,r} \times NGNGFACT \quad , \text{ if } eg = gas\ stove$$

$$NCKSH_{y,eg,b,r} = NH2OSH_{y,eg,b,r} \quad , \text{ if } eg = lpg\ stove$$

$$NCKSH_{y,eg,b,r} = \sum_{eg=other} \left(NH2OSH_{y,eg,b,r}\right) + NH2OSH_{y,ng,b,r} \times (1. - NGNGFACT) \quad , \text{ if } eg = elec\ stove \qquad (109)$$

where,

$NCKSH_{y,eg,b,r}$	is the new market share for cooking equipment in the current year by housing type and Census Division,
$NH2OSH_{y,eg,b,r}$	is the new market share for water heaters in the current year by equipment class, housing type and Census Division, and
$NGNGFACT$	is a factor that defines the fraction of new homes having gas water heaters that have gas cookstoves.

In the formula, the summation over *eg* = *other* refers to the market shares of all water heater classes other than natural gas and LPG: homes that heat water with any other equipment class than these, depending on which are defined in the RTEKCL file, are assumed to cook with electricity.

The following variables are computed as in the equations indicated:

$OPCOST_{y,es,b,r,v}$	is the operating cost for the water heater equipment type by housing type, Census Division, vintage, and year. It is computed as in (72) above.
$LFCY_{y,es,b,r,v}$	is the water heater type's life cycle cost by year, housing type Census

Division, and vintage. It is computed as in (17) above.

$EQWTN_{y,es,b,r}$ is the equipment weight for new equipment types by housing type, Census Division, and year. It is computed as in (21) above.

$EQWTR_{y,es,b,r}$ is the equipment weight for replacement equipment types by housing type, Census Division, and year. It is computed as in (22) above.

$TOTEWTN_{y,eg,b,r}$ is the sum of the equipment types' weights for the new equipment class. It is computed as in (23) above.

$TOTEWTR_{y,eg,b,r}$ is the sum of the equipment types' weights for the replacement equipment class. It is computed as in (24) above.

$EQFSHRN_{y,f,b,r}$ is the fuel share of new equipment type by year, housing type and Census Division. It is computed as in (25) above.

$EQFSHRR_{y,f,b,r}$ is the fuel share of replacement equipment type by year, housing type and Census Division. It is computed as in (26) above.

The final shares for the equipment types are the products of the market shares and the equipment type shares,

$$\begin{aligned} NEQTSHRD_{y,es,b,r} &= NCKSH_{y,eg,b,r} \times EQFSHRN_{y,es,b,r} \\ REQTSHRD_{y,es,b,r} &= NCKSH_{y,eg,b,r} \times EQFSHRR_{y,es,b,r} \end{aligned} \qquad (110)$$

where,

$NEQTSHRD_{y,es,b,r}$ is the new equipment type share for stoves by equipment type, housing type and Census Division,

$REQTSHRD_{y,es,b,r}$ is the replacement equipment type share for stoves by equipment type, housing type and Census Division,

$NCKSH_{y,eg,b,r}$ is the new market share for cooking equipment in the current year by housing type and Census Division,

$EQFSHRN_{y,es,b,r}$ is the new market share for stoves by equipment type, housing type and Census Division, and

$EQFSHRR_{y,es,b,r}$ is the replacement market share for stoves by equipment type, housing type and Census Division.

For cooking, the weighted average inverse efficiency of each equipment class is calculated differently from the foregoing end uses, because the RTEKTY file datum for $RTBASEFF_{es}$ is the usage, measured in kWh or MMBtu, of the equipment in the class:

$$WTEQCEFFA_{y,eg,b,r} = \frac{\sum_{es}\left(NEQTSHR_{y,es,b,r} \times RTEQEFF_{es}\right)}{\sum_{es} NEQTSHR_{y,es,b,r}} \quad , \text{ if denominator} > 0$$

$$WTEQCEFFA_{y,eg,b,r} = RTBASEFF_{1997,eg} \quad , \text{ if denominator} \leq 0. \qquad \textbf{(111)}$$

where,

$WTEQCEFFA_{y,eg,b,r}$ is the weighted average cooking equipment usage in the current year by housing type and Census Division, and

$RTBASEFF_{1997,eg}$ is the 1997 base equipment efficiency.

REUADD (Water Heating and Cooking Additions and Replacements Component)

As mentioned earlier, the capabilities for adding and replacing cooking equipment have been merged into a single component called *REUADD*. This component was documented above on pages B-49 through B-51.

RSTVCON (Cooking Energy Consumption Component)

The unit energy consumption for the surviving equipment is calculated by,

$$EQCSUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \times \frac{RTBASEFF_{y,eg}}{RTBASEFF_{1997,eg}} \qquad \textbf{(112)}$$

where,

$EQCNUEC_{y,eg,b,r}$ is the unit energy consumption for surviving cooking equipment in the current year by housing type and Census Division,

$EQCUEC_{r,eg,b}$ is the unit energy consumption for cooking equipment in the current year by housing type and Census Division, and

$RTBASEFF_{y,eg}$ are the annual average efficiencies for the equipment classes (represented as unit energy consumption for this service).

For new equipment,

$$EQCNUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \times \frac{WTEQCEFFN_{y,eg,b,r}}{RTBASEFF_{1997,eg}} \quad , \text{ if } WTEQCEFFN_{y,eg,b,r} > 0$$

$$EQCNUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \quad , \text{ otherwise} \tag{113}$$

where,

$EQCNUEC_{y,eg,b,r}$	is the unit energy consumption for new cooking equipment in the current year by housing type and Census Division,
$EQCUEC_{r,eg,b}$	is the unit energy consumption for cooking equipment by class, housing type and Census Division,
$WTEQCEFFN_{y,eg,b,r}$	is the weighted average cooking usage for new equipment in the current year by housing type and Census Division, and
$RTBASEFF_{1997,eg}$	is the 1997 efficiency of the cooking equipment class.

For replacement equipment,

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \times \frac{WTEQCEFFR_{y,eg,b,r}}{RTBASEFF_{1997,eg}} \quad , \text{ if } WTEQCEFFR_{y,eg,b,r} > 0$$

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \quad , \text{ otherwise} \tag{114}$$

where,

$EQCRUEC_{y,eg,b,r}$	is the unit energy consumption for replacement cooking equipment in the current year by housing type and Census Division,
$EQCUEC_{r,eg,b}$	is the unit energy consumption for cooking equipment by class, housing type and Census Division,
$WTEQCEFFR_{y,eg,b,r}$	is the weighted average cooking usage for replacement equipment in the current year by housing type and Census Division, and
$RTBASEFF_{1997,eg}$	is the 1997 efficiency of the cooking equipment class.

For the average efficiency, the initial year level is set to the new equipment efficiency:

If y = 1998,

$$EQCAUEC_{y,eg,b,r} = EQCNUEC_{y,eg,b,r} \tag{115}$$

If y > 1998,

$$EQCAUEC_{y,eg,b,r} = EQCNUEC_{y,eg,b,r} \quad , \text{ if } denominator \leq 0$$

$$EQCAUEC_{y,eg,b,r} = \frac{\begin{array}{r} EQCRP90_{y,t,eg,b,r} \times EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCREP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCADD_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} \times EQCAUEC_{y-1,eg,b,r} \\ + EQCSUR_{y,eg,b,r} \times EQCAUEC_{y-1,eg,b,r} \end{array}}{\begin{array}{c} EQCRP90_{y,t,eg,b,r} + EQCRP90RP_{y,t,eg,b,r} + EQCREP_{y,t,eg,b,r} \\ + EQCADD_{y,t,eg,b,r} + EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r} \end{array}} \quad , \text{ otherwise} \tag{116}$$

And energy consumption is also defined separately for the base year:

$$CKCON_{y,f,r} = \sum_b \begin{bmatrix} EQCESE_{y,eg,b,r} \times EQCSUEC_{y,eg,b,r} \\ + EQCADD_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,t,eg,b,r} \times EQCRUEC_{y,eg,b,r} \\ + EQCRP90_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \end{bmatrix}, \text{ if } y = 1997 \tag{117}$$

$$CKCON_{y,f,r} = \sum_b \begin{bmatrix} EQCESE_{y,eg,b,r} \times EQCSUEC_{y,r,eg,b} \\ + EQCADD_{y,t,eg,b,r} \times EQCNUEC_{y,r,eg,b} \\ + EQCRP90_{y,t,eg,b,r} \times EQCRUEC_{y,r,eg,b} \\ + EQCRP90RP_{y,t,eg,b,r} \times EQCNUEC_{y,r,eg,b} \\ + EQCSR90_{y,eg,b,r} \times EQCAUEC_{y-1,r,eg,b} \\ + EQCREP_{y,t,eg,b,r} \times EQCNUEC_{y,r,eg,b} \\ + EQCSUR_{y,eg,b,r} \times EQCAUEC_{y-1,r,eg,b} \end{bmatrix}, \text{ if } y > 1997 \tag{118}$$

Clothes Drying

RDRYTEC (Clothes Dryer Technology Choice Component)

The following variables are computed as in the equations indicated:

$OPCOST_{y,es,b,r,v}$ is the operating cost for the equipment type by year, housing type, Census Division, and vintage. It is computed as in (72) above.

$LFCY_{y,es,b,r,v}$ is the water heater type's life cycle cost by year, housing type Census

Division, and vintage. It is computed as in (17) above.

$EQWTN_{y,es,b,r}$ is the equipment weight for new equipment type by housing type, Census Division, and year. It is computed as in (21) above.

$EQWTR_{y,es,b,r}$ is the equipment weight for replacement equipment by housing type, Census Division, and year. It is computed as in (22) above.

$TOTEWTN_{y,eg,b,r}$ is the sum of equipment weights for the new equipment class. It is computed as in (23) above.

$TOTEWTR_{y,eg,b,r}$ is the sum of equipment weights for the replacement equipment class. It is computed as in (24) above.

Market shares for new and replacement dryers are next:

$$NEQTSHR_{y,es,b,r} = \frac{EQWT_{y,es,b,r}}{TOTEWT_{y,eg,b,r}} \qquad (119)$$

where,

$NEQTSHR_{y,es,b,r}$ is the new market share of clothes dryer equipment types by housing type and Census Division in the current year,

$TOTEWT_{eg}$ is the sum of equipment weights for the new equipment class,

$EQWT_{es}$ is the equipment weight for new equipment,and

The class averages of equipment type efficiencies for clothes drying equipment are calculated as for other end uses:

$$TEMP = \sum_{es} EQWT_{y,es,b,r}$$

$$WTEQCEFFA_{y,eg,b,r} = \frac{\sum_{es}\left(\frac{EQWT_{y,es,b,r}}{RTEQEFF_{es}}\right)}{TEMP}\ ,\ if\ TEMP>0. \qquad (120)$$

$$WTEQCEFFA_{y,eg,b,r} = \frac{1}{RTBASEFF_{eg}}\ ,\ otherwise$$

where,

$WTEQCEFFA_{y,es,b,r}$ is the weighted average usage of clothes dryer equipment classes in the current year by housing type and Census Division, and

$EQWT_{es}$	is the equipment weight for each type of new equipment.

DRYADD (Dryer Additions Component)

New clothes drying equipment is calculated using a saturation level for newly-bought equipment

$$EQCADD_{y,t,eg,b,r} = \sum_{es} \left(HSEADD_{y,b,r} \times NEQTSHR_{y,es,b,r} \times \frac{NEWDRYSAT_{b,r}}{100} \right) \quad \textbf{(121)}$$

where,

$EQCADD_{y,t,eg,b,r}$	is the amount of new (post-1997 vintage) equipment added in new housing units in the current year by housing type and Census Division,
$HSEADD_{y,b,r}$	is the number of new housing additions in the year by housing type and Census Division,
$NEQCSHR_{y,es,b,r}$	is the market share of new clothes dryer equipment types by housing type and Census Division in the current year, and
$NEWDRYSAT_{b,r}$	is the level of market penetration of new clothes dryer equipment by housing type and Census Division, expressed as a percent, from the RMISC file.

The next step is to calculate the numbers of dryers of each vintage category. The following variables were computed as in the equations indicated:

$EQCSR90_{y,eg,b,r}$	is the surviving post-1997 vintage equipment in pre-1998 housing units in the current year by housing type and Census Division. It is computed as in (41) above.
$EQCSUR_{y,eg,b,r}$	is the surviving new (post-1997 vintage) equipment in the current year by housing type and Census Division. It is computed as in (42) above.
$EQCREP_{y,t,eg,b,r}$	is the number of replacement units (post-1997 vintage) equipment demanded in multi-family or mobile post-1997 vintage housing units by housing type and Census Division, computed as in (34).
$EQCRP90_{y,t,eg,b,r}$	is the number of replacement units demanded in pre-1998 housing units each year by housing type and Census Division. It is computed as in (35) above.

$EQCRP90RP_{y,t,eg,b,r}$ is the number of replacement units for the EQCRP90 units demanded in the current year by housing type and Census Division. It is computed as in (36) above.

RDRYCON (Clothes Dryer Energy Consumption Component)

The unit energy consumption for surviving equipment is calculated as,

$$EQCSUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \times \frac{RTBASEFF_{1997,eg}}{RTBASEFF_{y,eg}} \tag{122}$$

where,

$EQCSUEC_{y,eg,b,r}$ is the UEC for surviving 1997 equipment in each equipment class, by housing type and Census Division, and

$RTBASEFF_{y,eg}$ is the base efficiency of the same equipment in each year.

For new equipment,

$$\begin{aligned} EQCNUEC_{y,eg,b,r} &= EQCUEC_{r,eg,b} \times WTEQCEFFN_{y,eg,b,r} \times RTBASEFF_{y,eg} \quad , \; if \; WTEQCEFFN_{y,eg,b,r} > 0 \\ EQCNUEC_{y,eg,b,r} &= EQCUEC_{r,eg,b} \quad , \; otherwise \end{aligned} \tag{123}$$

where,

$EQCNUEC_{y,eg,b,r}$ is the unit energy consumption by year for new equipment by housing type and Census Division,

$WTEQCEFFN_{y,eg,b,r}$ is the new equipment efficiency by year, equipment class, housing type and Census Division,

$RTBASEFF_{y,eg}$ is the base year efficiency of the equipment class, and

$EQCUEC_{r,eg,b}$ is unit energy consumption for equipment in 1997 housing by Census Division, equipment class and housing type.

For replacement equipment,

$$\begin{aligned} EQCRUEC_{y,eg,b,r} &= EQCUEC_{r,eg,b} \times WTEQCEFFR_{y,eg,b,r} \times RTBASEFF_{y,eg} \quad , \; if \; WTEQCEFFR_{y,eg,b,r} > 0 \\ EQCNUEC_{y,eg,b,r} &= EQCUEC_{r,eg,b} \quad , \; otherwise \end{aligned} \tag{124}$$

where,

$EQCRUEC_{y,eg,b,r}$ is the unit energy consumption by year for replacement equipment by housing type and Census Division,

$WTEQCEFFR_{y,eg,b,r}$ is the replacement efficiency by year, equipment class, housing type and Census Division,

$RTBASEFF_{y,eg}$ is the base year efficiency of the equipment class, and

$EQCUEC_{r,eg,b}$ is unit energy consumption for equipment in 1997 housing by Census Division, equipment class and housing type.

The average of the two unit energy consumption variables is,

$$EQCAUEC_{y,eg,b,r} = EQCNUEC_{y,eg,b,r} \quad , \text{ if } y=1998$$

$$EQCAUEC_{y,eg,b,r} = EQCNUEC_{y,eg,b,r} \quad , \text{ if the equipment stock} \leq 0$$

$$EQCAUEC_{y,eg,b,r} = \frac{\begin{array}{r} EQCRP90_{y,t,eg,b,r} \times EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCREP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCADD_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} \times EQCAUEC_{y-1,eg,b,r} \\ + EQCSUR_{y,eg,b,r} \times EQCAUEC_{y-1,eg,b,r} \end{array}}{\begin{array}{r} EQCRP90_{y,t,eg,b,r} + EQCREP_{y,t,eg,b,r} + EQCADD_{y,t,eg,b,r} \\ + EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r} + EQCRP90RP_{y,t,eg,b,r} \end{array}} \quad , \text{ otherwise} \qquad (125)$$

Finally, the energy consumption calculation is simpler than most of the other end uses:

$$DRYCON_{y,eg,r} = \sum_{b} \left[\begin{array}{r} EQCESE_{y,eg,b,r} \times EQCSUEC_{r,eg\ b} \\ + EQCADD_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,t,eg,b,r} \times EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \end{array} \right] , \text{ if } y=1998 \qquad (126)$$

$$DRYCON_{y,eg,r} = \sum_{b} \left[\begin{array}{r} EQCESE_{y,eg,b,r} \times EACSUEC_{y,eg,b,r} \\ + EQCADD_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,t,eg,b,r} \times EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} \times EQCAUEC_{y-1,eg,b,r} \\ + EQCREP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} \times EACAUEC_{y-1,eg,b,r} \end{array} \right] , \text{ Otherwise} \qquad (127)$$

Refrigeration

RREFTEC (Refrigerator Technology Choice Component)

Equipment operating cost for refrigerators is,

$$OPCOST_{y,es,r,v} = PRICES_{f,r,y} \times RTEQEFF_{eg} \times FACTOR \tag{128}$$

where,

$OPCOST_{y,es,r,v}$ is the operating cost of the equipment type by housing type, Census Division, and vintage in the current year,

$PRICES_{f,r,y}$ is the fuel price in the current year by Census Division, from the NEMS Integrating Module,

$RTEQEFF_{es}$ is the efficiency (represented as unit energy consumption for this service) of the refrigerator types, and

$FACTOR$ is a factor, MMBtu/kWh, that converts the units of $RTEQEFF_{es}$, which is expressed in kWh for refrigerators and freezers.

The following variables are computed as in the equations indicated:

$LFCY_{es,r,v}$ is the life cycle cost for the type of equipment by Census Division and vintage. It is computed as in (17) above.

$EQWTN_{es,b,r}$ is the equipment weight for new equipment type by housing type and Census Division. It is computed as in (21) above.

$EQWTR_{es,b,r}$ is the equipment weight for replacement equipment by housing type and Census Division. It is computed as in (22) above.

$TOTEWTN_{b,r}$ is the sum of the individual weights for each type of new equipment by housing type and Census Division. It is computed as in (23) above.

$TOTEWTR_{b,r}$ is the sum of the individual weights for each type of replacement equipment by housing type and Census Division. It is computed as in (24) above.

The two available classes of refrigerators, through-the-door and others, have market shares, distinguished by *TTDSHR*. For through-the-door refrigerators,

$$NEQTSHR_{y,es,b,r} = TTDSHR \tag{129}$$

$$REQTSHR_{y,es,b,r} = TTDSHR \tag{130}$$

And for all others,

$$NEQTSHR_{y,es,b,r} = \frac{EQWTN_{es,b,r}}{TOTEWTN_{b,r}} \times (1 - TTDSHR) \tag{131}$$

$$REQTSHR_{y,es,b,r} = \frac{EQWTR_{es,b,r}}{TOTEWTR_{b,r}} \times (1 - TTDSHR) \tag{132}$$

where,

$NEQTSHR_{y,es,b,r}$ is the market share for new refrigerators of the equipment type in the current year by housing type and Census Division,

$REQTSHR_{y,es,b,r}$ is the market share for the replacements of equipment type in the current year by housing type and Census Division, and

$TTDSHR$ is the share of side-by-side refrigerators with through-the-door access features.

$$WTEQCEFFN_{y,eg,b,r} = \frac{\sum_{es} \left[NEQTSHR_{y,es,b,r} \times RTEQEFF_{es}\right]}{\sum_{es} NEQTSHR_{y,es,b,r}} \tag{133}$$

$$WTEQCEFFR_{y,eg,b,r} = \frac{\sum_{es} \left[REQTSHR_{y,es,b,r} \times RTEQEFF_{es}\right]}{\sum_{es} REQTSHR_{y,es,b,r}} \tag{134}$$

where,

$WTEQCEFFN_{y,eg,b,r}$ is the weighted average usage of new refrigerator classes by housing type and Census Division,

$WTEQCEFFR_{y,eg,b,r}$ is the weighted average usage of replacement refrigerator classes by housing type and Census Division,

$RTEQEFF_{es}$ is the efficiency by refrigerator type, from the RTEKTY file,

$NEQTSHR_{y,es,b,r}$ is the new market share for the equipment types in the current year by housing type and Census Division,

$REQTSHR_{y,es,b,r}$ is the market share for the replacements of equipment types in the current year by housing type and Census Division.

RREFADD (Additions to the Refrigerator Stock Component)

Refrigerator additions allow for new single-family homes to have more than one refrigerator, as defined by RECS 1997. The additions are calculated as:

$$EQCADD_{y,t,eg,b,r} = HSEADD_{y,b,r} \times RFADDFAC \quad , \text{ if } b = \text{single family home}$$
$$EQCADD_{y,t,eg,b,r} = HSEADD_{y,b,r} \quad , \text{ otherwise} \qquad (135)$$

where,

$EQCADD_{y,t,eg,b,r}$ is the amount of new (post-1997 vintage) refrigerators added in new housing units in the current year by housing type and Census Division,

$HSEADD_{y,b,r}$ is the number of new housing units constructed in the current year by housing type and Census Division, and

RFADDFAC is the percent of new single-family housing units with two refrigerators.

The following variables are computed as in the equations indicated:

$EQCSR90_{y,t,eg,b,r}$ is the surviving new (post-1997 vintage) equipment in old (pre-1998 vintage) housing units by housing type and Census Division. It is computed as in (41) above.

$EQCRP90_{y,t,eg,b,r}$ is the number of replacement (post-1997 vintage) equipment in pre-1998 housing units in the current year by housing type and Census Division. It is computed as in (35) above.

$EQCRP90RP_{y,t,eg,b,r}$ is the number of replacement units for the EQCRP90 units demanded in the current year by housing type and Census Division. It is computed as in (36) above.

$EQCSUR_{y,eg,b,r}$ is the surviving new (post-1997 vintage) equipment in the current year by housing type and Census Division. It is computed as in (42) above.

$EQCREP_{y,t,eg,b,r}$ is the number of replacement units (post-1997 vintage) equipment demanded in new (post-1997 vintage) housing units by housing type and Census Division. It is computed as in (34) above.

RREFCON (Refrigerator Energy Consumption Component)

The unit energy consumption calculations for surviving, new, and replacement equipment, and their averages. are calculated as:

$$EQCSUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \times \frac{RTBASEFF_{y,eg}}{RTBASEFF_{1997,eg}} \tag{136}$$

where,

$EQCSUEC_{y,eg,b,r}$ is the UEC for surviving 1997 equipment in each equipment class, by housing type and Census Division, and

$EQCUEC_{r,eg,b}$ is the UEC for the original 1997 equipment in each equipment class, by housing type and Census Division, and

$RTBASEFF_{y,eg}$ is the base efficiency (represented by unit energy consumption for this service).

For new refrigerators,

$$EQCNUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \times \frac{WTEQCEFFN_{y,eg,b,r}}{RTBASEFF_{1997,eg}} \tag{137}$$

where,

$EQCNUEC_{y,eg,b,r}$ is the efficiency-weighted unit energy consumption for new refrigerators in the current year by housing type and Census Division,

$EQCUEC_{r,eg,b}$ is the unit energy consumption for 1997 refrigerators by housing type and Census Division,

$WTEQCEFFN_{y,eg,b,r}$ is the market share-weighted usage of new refrigerators in the current year by housing type and Census Division, and

$RTBASEFF_{1997,eg}$ is the 1997 stock-average efficiency of refrigerators.

For replacement refrigerators,

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} \times \frac{WTEQCEFFR_{y,eg,b,r}}{RTBASEFF_{1997,eg}} \tag{138}$$

where,

$EQCRUEC_{y,eg,b,r}$ is the efficiency weighted unit energy consumption for replacement

	refrigerators in the current year by housing type and Census Division,
$WTEQCEFFR_{y,b,r}$	is the market share weighted usage of replacement refrigerators in the current year by housing type and Census Division,
$RTBASEFF_{1997,eg}$	is the 1997 stock-average efficiency of refrigerators.

The weighted average of the three UEC sets is calculated here. In all of the calculations that follow, it is assumed that ten percent of refrigerators are second refrigerators in the home, running at the 1997 base UEC level. Thus, each expression calculates the consumption for .1 of the refrigerators at existing equipment rates, and .9 at current year new equipment rates.

$$EQCAUEC_{y,eg,b,r} = EQCNUEC_{y,eg,b,r} \quad , \ if \ y=1998$$

$$EQCAUEC_{y,eg,b,r} = \frac{\left(\begin{array}{r} EQCRP90_{y,t,eg,b,r} \times EQCRUEC_{y,eg,b,r} \\ + \ EQCRP90RP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + \ EQCADD_{y,t,eg,b,r} \times .1 \times EQCUEC_{r,eg,b} \\ + \ (EQCADD_{y,t,eg,b,r} \times .9 \ + \ EQCREP_{y,t,eg,b,r}) \times EQCNUEC_{y,eg,b,r} \\ + \ (EQCSR90_{y,eg,b,r} \ + \ EQCSUR_{y,eg,b,r}) \times EQCAUEC_{y-1,eg,b,r} \end{array}\right)}{\left(\begin{array}{l} EQCRP90_{y,t,eg,b,r} + EQCRP90RP_{y,t,eg,b,r} + EQCSR90_{y,eg,b,r} \\ + \ EQCADD_{y,t,eg,b,r} + EQCREP_{y,t,eg,b,r} + EQCSUR_{y,eg,b,r} \end{array}\right)} \quad , \ if \ y>1998 \qquad (139)$$

where,

$EQCAUEC_{y,b,r}$ is the average unit energy consumption of refrigerators in the current year by housing type and Census Division.

The weighted average usage is now calculated.

$$WTEQCEFFA_{y,eg,b,r} = WTREFFN_{y,b,r} \quad , \ if \ y=1998 \ or \ WTEQCEFFN_{y,eg,b,r} \leq 0$$

$$WTEQCEFFN_{y,eg,b,r} = \frac{\begin{array}{r} EQCSR90_{y,eg,b,r} \times WTEQCEFFA_{y-1,eg,b,r} \\ + \ EQCSUR_{y,eg,b,r} \times WTEQCEFFA_{y-1,eg,b,r} \\ + \ EQCRP90_{y,t,eg,b,r} \times WTEQCEFFR_{y,eg,b,r} \\ + \ EQCRP90RP_{y,t,eg,b,r} \times WTEQCEFFN_{y,eg,b,r} \\ + \ EQCADD_{y,t,eg,b,r} \times .9 \times WTEQCEFFN_{y,eg,b,r} \\ + \ EQCREP_{y,t,eg,b,r} \times WTEQCEFFN_{y,eg,b,r} \\ + \ EQCADD_{y,t,eg,b,r} \times .1 \times RTBASEFF_{1997\,eg} \end{array}}{\begin{array}{l} EQCSR90_{y,eg,} + EQCSUR_{y,eg,b,r} + EQCRP90RP_{y,t,es,b,r} \\ + \ EQCRP90_{y,t,es,b,r} + EQCADD_{y,t,eg,b,r} + EQCREP_{y,t,eg,b,r} \end{array}} \quad , \ otherwise \qquad (140)$$

And the energy consumption. If year = 1998,

$$REFCON_{y,r} = \sum_b \begin{pmatrix} EQCESE_{y,eg,b,r} \times EQCSUEC_{y,eg,b,r} \\ + EQCADD_{y,t,eg,b,r} \times .1 \times EQCUEC_{r,eg,b} \\ + EQCADD_{y,t,eg,b,r} \times .9 \times EACNUEC_{y,eg,b,r} \\ + EQCRP90_{y,t,eg,b,r} \times EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \end{pmatrix} \tag{141}$$

If year >1998,

$$REFCON_{y,r} = \sum_b \begin{pmatrix} EQCESE_{y,eg,b,r} \times EQCSUEC_{y,eg,b,r} \\ + EQCADD_{y,eg,b,r} \times .1 \times EQCUEC_{r,eg,b} \\ + EQCADD_{y,eg,b,r} \times .9 \times EACNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} \times EQCRUEC_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} \times EQCAUEC_{y,eg,b,r} \\ + EQCREP_{y,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCSUR_{u,eg,b,r} \times EQCAUEC_{y,eg,b,r} \end{pmatrix} \tag{142}$$

where,

$EQCCON_{y,r}$ is energy consumption for refrigeration,

$EQCESE_{y,b,r}$ is the surviving old (pre-1998 vintage) equipment in old (pre-1998 vintage) housing units in the current year by housing type and Census Division,

$EQCADD_{y,t,b,r}$ is the amount of new (post-1997 vintage) refrigerators added in new housing units in the current year by housing type and Census Division,

$EQCRP90_{y,t,b,r}$ is the number of replacement (post-1997 vintage) equipment in pre-1998 housing units in the current year by housing type and Census Division,

$EQCRP90RP_{y,t,b,r}$ is the number of replacements for the EQCRP90 equipment in the current year by housing type and Census Division,

$EQCRUEC_{y,b,r}$ is the efficiency weighted unit energy consumption for replacement refrigerators in the current year by housing type and Census Division, and

$EQCNUEC_{y,b,r}$ is the efficiency weighted unit energy consumption for new refrigerators in the current year by housing type and Census Division.

$EQCUEC_{r,b}$ is the unit energy consumption for refrigerators by housing type and Census Division.

Freezers

RFRZTEC (Freezer Technology Choice Component)

Again, the processing of the market share weights is like the other end uses. The following variables are computed as in the equations indicated:

$OPCOST_{y,es,r,v}$	is the operating cost of freezers by housing type and Census Division in the current year. It is computed as for refrigerators. See (128) above.
$LFCY_{es,r,v}$	is the life cycle cost for the type of equipment by Census Division. It is computed as in (17) above.
$EQWTN_{es,b,r}$	is the equipment weight for new equipment types by housing type and Census Division. It is computed as in (21) above.
$EQWTR_{es,b,r}$	is the equipment weight for replacement equipment by housing type and Census Division. It is computed as in (22) above.
$TOTEWTN_{b,r}$	is the sum of the individual weights for each type of new equipment by housing type and Census Division. It is computed as in (23) above.
$TOTEWTR_{b,r}$	is the sum of the individual weights for each type of replacement equipment by housing type and Census Division. It is computed as in (24) above.

Shares for equipment types, in normalized form, are calculated somewhat as usual:

$$NEQTSHR_{y,es,b,r} = UPSHR \quad , \text{ if } es = \text{upright freezer}$$
$$NEQTSHR_{y,es,b,r} = \frac{EQWTN_{es,b,r}}{TOTEWTN_{b,r}} \times (1 - UPSHR) \quad , \text{ otherwise} \tag{143}$$

$$REQTSHR_{y,es,b,r} = UPSHR \quad , \text{ if } es = \text{upright freezer}$$
$$REQTSHR_{y,es,b,r} = \frac{EQWTR_{y,es,b,r}}{TOTEWTR_{y,eg,b,r}} \times (1 - UPSHR) \quad , \text{ otherwise} \tag{144}$$

where,

$NEQTSHR_{y,es,b,r}$	is the new market share for the equipment type in the current year by housing type and Census Division,
$REQTSHR_{y,es,b,r}$	is the market share for replacement of equipment types in the current year

by housing type and Census Division, and

UPSHR is the market share for upright freezers.

The average efficiencies for new and replacement equipment are standard:

$$WTEQCEFFN_{y,eg,b,r} = \frac{\sum_{es} RTEQEFF_{es} \times NEQTSHR_{y,es,b,r}}{\sum_{es} NEQTSHR_{y,es,b,r}} \quad (145)$$

$$WTEQCEFFR_{y,eg,b,r} = \frac{\sum_{es} RTEQEFF_{es} \times REQTSHR_{y,es,b,r}}{\sum_{es} REQTSHR_{y,es,b,r}} \quad (146)$$

where,

$WTEQCEFFN_{y,eg,b,r}$ is the market share-weighted usage of new refrigerators in the current year by housing type and Census Division,

$WTEQCEFFR_{y,eg,b,r}$ is the market share-weighted usage of replacement refrigerators in the current year by housing type and Census Division,

$NEQTSHR_{y,es,b,r}$ is the new market share for the equipment type in the current year by housing type and Census Division, and

$REQTSHR_{y,es,b,r}$ is the market share for the replacements of equipment type in the current year by housing type and Census Division.

RFRZADD (Additions to the Freezer Stock Component)

Calculations of changes in the freezing equipment stock include all seven categories of vintages. Additions post-1998:

$$EQCADD_{y,eg,b,r} = HSEADD_{y,b,r} \times \frac{FRZSAT_{b,r}}{100} \quad (147)$$

where,

$EQCADD_{y,eg,b,r}$ is the amount of new (post-1997 vintage) equipment added in new housing units in the year by housing type and Census Division,

$HSEADD_{y,b,r}$ is the number of new housing units constructed in the current year by housing type and Census Division, and

$FRZSAT_{b,r}$ is the market penetration level of freezers by housing type and Census Division, from the RMISC file, expressed as percents.

The following variables are computed as in the equations indicated:

$EQCSR90_{y,b,r}$ is the surviving new (post-1997 vintage) equipment in old (pre-1998 vintage) housing units by housing type and Census Division. It is computed as in (41) above.

$EQCSUR_{y,b,r}$ is the amount of surviving new (post-1997 vintage) equipment in new (post-1997 vintage) housing units in the current year by housing type and Census Division. It is computed as in (42) above.

$EQCREP_{y,b,r}$ is the number of replacements for the current year in new (post-1997 vintage) housing units by housing type and Census Division. It is computed as in (34) above.

$EQCRP90RP_{y,t,b,r}$ is the number of replacements for the EQCRP90 equipment in the current year by housing type and Census Division. It is computed as in (36) above.

The number of freezers for replacement in existing houses is

$$EQCRP90_{y,t,eg,b,r} = \left(EQCESE_{1997,eg,b,r} \times HDR_b^{y-1997} \times EQCRET_{y,eg}\right) \times FZRPFAC \tag{148}$$

where,

$EQCRP90_{y,b,r}$ is the number of replacement (post-1997 vintage) equipment in pre-1998 housing units in the current year by housing type and Census Division,

$EQCRET_{y,eg}$ is the retirement rate for the existing stock in year *y*, and

FZRPFAC is the percent of retired freezers that are replaced. (Subroutine REPLACE is not called when replacing freezers.)

FRZCON (Freezer Energy Consumption Component)

The detailed unit energy consumption variables are computed exactly as for refrigerators:

$EQCSUEC_{y,eg,b,r}$ is the UEC for surviving 1997 equipment in each equipment class, by housing type and Census Division, calculated as in equation (136),

$EQCNUEC_{y,eg,b,r}$ is the efficiency-weighted unit energy consumption for new refrigerators in the current year by housing type and Census Division, calculated as in equation (137),

$EQCRUEC_{y,eg,b,r}$ is the efficiency weighted unit energy consumption for replacement refrigerators in the current year by housing type and Census Division, calculated as in equation (138).

Average UEC's are different, however. They follow the pattern of cooling equipment, given in equation (95).

Weighted average usages are then calculated,

$$WTEQCEFFA_{y,eg,b,r} = WTEQCEFFN_{y,eg,b,r} \quad , \text{ if } y=1998 \text{ or } WTEQCEFFA \le 0$$

$$WTEQCEFFA_{y,eg,b,r} = \frac{\begin{array}{r} EQCSR90_{y,eg,b,r} \times WTEQCEFFA_{y-1,eg,b,r} \\ + EQCSUR_{y,eg,b,r} \times WTEQCEFFA_{y-1,eg,b,r} \\ + EQCRP90_{y,t,eg,b,r} \times WTEQCEFFR_{y,eg,b,r} \\ + EQCRP90RP_{y,t,eg,b,r} \times WTEQCEFFN_{y,eg,b,r} \\ + EQCADD_{y,t,eg,b,r} \times WTEQCEFFN_{y,eg,b,r} \\ + EQCREP_{y,t,eg,b,r} \times WTEQCEFFN_{y,eg,b,r} \end{array}}{\begin{array}{r} EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r} + EQCRP90RP_{y,t,eg,b,r} \\ + EQCRP90_{y,t,eg,b,r} + EQCADD_{y,t,ec,b,r} + EQCREP_{y,t,eg,b,r} \end{array}} \quad , \text{ if } y>1998 \tag{149}$$

where,

$WTEQCEFFA_{y,eg,b,r}$ is the market share weighted average usage of freezers in the current year by housing type and Census Division.

Finally, the energy consumption calculation follows the usual pattern:

$$FRZCON_{y,eg,b,r} = \sum_b \left[\left(\begin{array}{r} EQCESE_{y,eg,b,r} \times EQCSUEC_{r,eg,b,r} \\ + EQCADD_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,t,eg,b,r} \times EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \end{array} \right) \times \left(\frac{PRICES_{f,r,y}}{PRICES_{f,r,1997}} \right)^{\alpha} \right] , \text{ if } y=1998 \tag{150}$$

$$FRZCON_{y,f,r} = \sum_{b} \left[\begin{pmatrix} EQCESE_{y,eg,b,r} \times EQCSUEC_{r,eg,b,r} \\ + EQCADD_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,t,eg,b,r} \times EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,t,eg,b,r} \times EQCNUEC_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} \times EQCAUEC_{y-1,eg,b,r} \\ + EQCREP_{y,t,eg,b,r} \times EQCRUEC_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} \times EQCAUEC_{y-1,eg,b,r} \end{pmatrix} \times \left(\frac{PRICES_{f,r,y}}{PRICES_{f,r,1997}} \right)^{\alpha} \right], \ if\ y > 1998 \tag{151}$$

Lighting

Lighting is handled entirely outside the user-modifiable environment, embodied in the RTEKCL and RTEKTY files, that is used for the major energy-consuming end uses. For lighting, there is a single component, as shown in the following section.

LTCNS (Lighting Energy Consumption Component)

Market shares for standard and tochiere lighting are computed as follows:

$$MKTSHR_{y,es,b,r} = \frac{e^{\beta_1 \times EQCOST_{y,es} + \beta_2 \times OPCOST_{es}}}{\sum_{es} e^{\beta_1 \times EQCOST_{y,es} + \beta_2 \times OPCOST_{es}}} \tag{152}$$

where,

$MKTSHR_{y,es,b,r}$ are annual market shares for standard lighting applications,

$EQCOST_{y,es}$ are lighting equipment costs, and

$OPCOST_{es}$ are the operating costs for specific lighting technologies.

Torchiere market shares are computed similarly. Next, weighted efficiency indicies are computed for both standard and torchiere lighting classes. Namely,

$$WTLEFF_{y,b,r} = \sum_{es} \left(\frac{1}{EFF_{es}} \times MKTSHR_{y,es} \right), \quad for\ es = 1,\ 2,\ 3 \tag{153}$$

where,

$WTLEFF_{y,b,d}$ are weighted-average usages for lighting, by year, housing type and Census Division,

EFF_{es} are efficiencies of the three classes of light bulbs, from the table above, and

$MKTSHR_{y,es}$ are annual market shares for the lighting classes, from the table above.

The weighted efficiency index for torchiere lighting is computed similarly.

Next, the component calculates unit energy consumption for standard and torchiere lighting,

$$LTNUEC_{y,r,b} = (1 - TCHSHR) \times LTUEC_{r,b} \times WTLEFF_{y,b,d} \times BASEFF \qquad \textbf{(154)}$$

where,

$LTNUEC_{y,r,b}$ is the unit energy consumption for lighting by year, Census Division and housing type,

$LTUEC_{r,b}$ is base year unit energy consumption for lighting by Census Division and housing type, from the RSUEC10 file,

$WTLEFF_{y,b,d}$ is the weighted-average usage for lighting calculated above, and

$BASEFF$ is the base efficiency for lighting equipment, set at present to .18 in the component.

Torchiere unit energy consumption is computed similarly. The final step of this component is to calculate consumption for the lighting service category. Namely,

$$LTCON_{y,r} = \sum_b \left[\left(\begin{array}{l} (EH_{y,b,r} + NH_{y,b,r} \times SQFTLTS_{y,b,r}) \times LTNUEC_{y,r,b} \\ + (EH_{y,b,r} + NH_{y,b,r}) \times TCHUEC_{y,b,r} \times DISPLACE \end{array} \right) \times \left(\frac{PRICES_{f,r,y}}{PRICES_{f,r,1997}} \right)^{\alpha} \right] \qquad \textbf{(155)}$$

where,

α is the short-term price elasticity, presently valued at -0.25.

$LTCON_{y,r}$ is the energy consumption for lighting by year and Census Division,

$EH_{y,b,r}$ is the number of old (pre-1998) housing units in the current year by housing type and Census Division,

$NH_{y,b,r}$ is the number of new (post-1997) housing units in the current year by housing type and Census Division,

$LTNUEC_{y,r,b}$ is the unit energy consumption for lighting by year, Census Division and housing type,

$SQFTLTS_{y,b,r}$ is the average floor area of homes, relative to 1997 floor areas, calculated from the floor areas given in the RSSQRFT file, used to adjust for increased lighted areas in future new homes, and

DISPLACE is the amount of lighting service demand displaced by using torchiere lamps.

PCCNS (Personal Computer Energy Consumption Component)

This submodule is similar in nature to the lighting submodule, however, market shares are assumed for the two efficiency levels for PCs. As an alternative approach, growth rates have been formulated offline in (roughly) five year increments. Using this approach, only the number of personal computers, the assumed level of efficiency, and the unit energy consumption (UEC), in addition to the aforementioned growth rates, are needed to calculate energy consumption. Specifically,

$$PCNUEC_{y,r,b} = PCUEC_{r,b} \times PCPEN_{y} \times PCEFF_{y} \tag{156}$$

where,

$PCNUEC_{y,r,b}$ is the unit energy consumption for personal computers by year, Census Division and housing type,

$PCUEC_{r,b}$ is base year unit energy consumption for personal computers by Census Division and housing type, from the RSUEC10 file,

$PCPEN_{y}$ is the estimated penetration of personal computers for future years, and

$PCEFF_{y}$ is the stock efficiency index for personal computers in year y.

Next, the component calculates the number of personal computers in the stock for future years. Since the growth rate is tied to the UEC, the saturation of personal computers will remain fixed. Therefore,

$$PCEQP_{y,r,b} = \left(\frac{PCSAT_{r,b}}{EH_{y=1997,r,b}} \right) \times \left(EH_{y,b,d} + NH_{y,b,d} \right) \tag{157}$$

where,

$PCEQP_{y,r,b}$ is the number of personal computers by year, Census Division and housing type.

The final step of this component is to calculate consumption for personal computers. Namely,

$$PCCON_{y,r} = \sum_b \left[\left(PCEQP_{y,b,r} \times PCNUEC_{y,b,r} \right) \times \left(\frac{PRICES_{f,r,y}}{PRICES_{f,r,1997}} \right)^{\alpha} \right] \quad (158)$$

where,

α	is the short-term price elasticity, presently valued at -0.25.
$PCCON_{y,r}$	is the energy consumption for personal computers by year and Census Division,

TVCNS (Color Television Energy Consumption Component)

This submodule is similar in nature to the personal computer submodule. Growth rates have been formulated offline in (roughly) five year increments. Using this approach, only the number of color televisions and the unit energy consumption (UEC), in addition to the aforementioned growth rates, are needed to calculate energy consumption. Specifically,

$$TVNUEC_{y,r,b} = TVUEC_{r,b} \times TVPEN_y \times TVEFF_y \quad (159)$$

where,

$TVNUEC_{y,r,b}$	is the unit energy consumption for color televisions by year, Census Division and housing type,
$TVUEC_{r,b}$	is base year unit energy consumption for color televisions by Census Division and housing type, from the RSUEC10 file,
$TVPEN_y$	is the estimated penetration of color televisions for future years, and
$TVEFF_y$	is the stock efficiency index for color televisions in year y.

Next, the component calculates the number of color televisions in the stock for future years. Since the growth rate is tied to the UEC, the number of color televisions per household will remain fixed. Therefore,

$$TVEQP_{y,r,b} = \left(EH_{y,b,d} + NH_{y,b,d} \right) \times TVPEN_y \quad (160)$$

where,

$TVEQP_{y,r,b}$ is the number of color televisions by year, Census Division and housing type, and
$CTVSAT_{r,b}$ is the number of color televisions per household by Census Division and housing

type.

The final step of this component is to calculate consumption for color televisions. Namely,

$$TVCON_{y,r} = \sum_{b} \left[\left(TVEQP_{y,b,r} \times TVNUEC_{y,b,r} \right) \times \left(\frac{PRICES_{f,r,y}}{PRICES_{f,r,1997}} \right)^{\alpha} \right] \tag{161}$$

where,

α	is the short-term price elasticity, presently valued at -0.25.
$TVCON_{y,r}$	is the energy consumption for color televisions by year and Census Division,

Other Electric Appliances

Other electrical appliances is a catch-all category that includes miscellaneous electrical uses such as small kitchen appliances, consumer electronics, and small motor devices that are used in homes, but do not fall into any of the other categories of equipment that have their own module components. The component distributes the residual electricity into three major categories, namely electronics, heating elements, and motors. Based on historical data, growth rates are estimated for each category, then applied to the unit energy consumption in the same manner as demonstrated in the color television subroutine.

APCNS (Electric Appliance Energy Consumption Component)

The three components of miscellaneous electric use are computed as follows:

$$ELTRCN_{y,r} = \sum_{b} \left[\left(NH_{y,b,r} + EH_{y,b,r} \right) \times ELTRUEC_{r,b} \times ELTRPEN_{y} \times ELTREFF_{y} \right] \tag{162}$$

$$MOTRCN_{y,r} = \sum_{b} \left[\left(NH_{y,b,r} + EH_{y,b,r} \right) \times MOTRUEC_{r,b} \times MOTRPEN_{y} \times MOTREFF_{y} \right] \tag{163}$$

$$COILCN_{y,r} = \sum_{b} \left[\left(NH_{y,b,r} + EH_{y,b,r} \right) \times COILUEC_{r,b} \times COILPEN_{y} \times COILEFF_{y} \right] \tag{164}$$

where,

$ELTRCN_{y,r}$	is home electronics energy consumption,
$MOTRCN_{y,r}$	is miscellaneous small motor energy consumption,

$COILCN_{y,r}$	is miscellaneous heating elements energy consumption,
$EH_{y,b,r}$	is the number of old (pre-1998) housing units in the current year by housing type and Census Division,
$NH_{y,b,r}$	is the number of new (post-1997) housing units in the current year by housing type and Census Division,
$ELTRUEC_{r,b}$	is base year unit energy consumption for home electronics by Census Division and housing type,
$MOTRUEC_{r,b}$	is base year unit energy consumption for miscellaneous small motors by Census Division and housing type,
$COILUEC_{r,b}$	is base year unit energy consumption for miscellaneous heating elements by Census Division and housing type,
$ELTRPEN_{y}$	is the penetration rate for home electronics,
$MOTRPEN_{y}$	is the penetration rate for miscellaneous small motors,
$COILPEN_{y}$	is the penetration rate for miscellaneous heating elements,
$ELTREFF_{y}$	is the stock efficiency index for home electronics in year y,
$MOTREFF_{y}$	is the stock efficiency index for miscellaneous small motors in year y, and
$COILEFF_{y}$	is the stock efficiency index for miscellaneous heating elements in year y.

Finally, the sum of these three components equals the total amount of electricity consumed for miscellaneous uses.

$$APCON_{y,r} = \left(ELTRCN_{y,r} + MOTRCN_{y,r} + COILCN_{y,r}\right) \times \left(\frac{PRICES_{f,d,y}}{PRICES_{f,d,1997}}\right)^{\alpha} \tag{165}$$

where,

$APCON_{y,r}$	is total electric appliance energy consumption,
$PRICES_{f,d,y}$	is the fuel price in year y, and
α	is the short term price elasticity valued at -0.25.

Secondary Space Heating

Secondary space heating refers to small supplemental heaters, normally portable, fired by electricity, kerosene or other fuels, that are used for spot heating or other occasional stopgaps.

SHTCNS (Secondary Heating Energy Consumption Component)

Energy consumption by secondary heaters is calculated directly from shares by fuel read into the model from a user file:

$$SHTCON_{y,f,r} = \sum_b \left[SHTSHR_{r,f} \times EH_{y,b,r} \times SHTUEC_{r,f,b} \times AHSHELL_{y,gas,r,b} \times \left(\frac{PRICES_{f,d,y}}{PRICES_{f,d,1997}} \right)^{\alpha} \right] \quad , \text{ if } f = coal$$
$$SHTCON_{y,f,r} = \sum_b \left[SHTSHR_{r,f} \times (NH_{y,b,r} + EH_{y,b,r}) \times SHTUEC_{r,f,b} \times ACSHELL_{y,r,b} \times \left(\frac{PRICES_{f,d,y}}{PRICES_{f,d,1997}} \right)^{\alpha} \right] \quad , \text{ if } f = wood$$
$$SHTCON_{y,f,r} = \sum_b \left[SHTSHR_{r,f} \times (NH_{y,b,r} + EH_{y,b,r}) \times SHTUEC_{r,f,b} \times AHSHELL_{y,f,r,b} \times \left(\frac{PRICES_{f,d,y}}{PRICES_{f,d,1997}} \right)^{\alpha} \right] , \text{ otherwise} \qquad (166)$$

where,

$SHTCON_{y,f,r}$ is the consumption of energy by secondary space heating equipment by year, fuel and Census Division,

$SHTSHR_{r,f}$ are shares of seven fuels for secondary space heating by Census Division,

$EH_{y,b,r}$ is the number of old (pre-1998) housing units in the current year by housing type and Census Division,

$NH_{y,b,r}$ is the number of new (post-1997) housing units in the current year by housing type and Census Division,

$SHTUEC_{r,f,b}$ is base year unit energy consumption for small electrical appliances by Census Division and housing type, from the RSUEC10 file,

$AHSHELL_{y,f,r,b}$ is the average post-1997 heating shell index by year, fuel, Census Division, and building type,

$ACSHELL_{y,r,b}$ is the average post-1997 cooling shell index by year, Census Division, and building type, and

$PRICES_{f,d,y}$ are fuel prices in year y, and

α Is the short-term price elasticity valued at -0.25.

The logic is designed as shown to constrain the component to disallow coal supplemental heat in post-1997 homes, and to use the cooling shell index for wood supplemental heat, rather than the heating one, because wood is not one of the fuels for heating shell indices due to the lack of a forecasted price for wood.

Other Appliances

Other appliances refers to small appliances not covered in the other categories that do not use electricity as their primary fuel, such as backyard grills. Consumption alone is calculated.

APPCNS (Appliance Energy Consumption Component)

The formula is a simple calculation from housing stock and unit energy consumption:

$$APLCON_{y,f,r} = \sum_{b} \left[\left(NH_{y,b,r} + EH_{y,b,r} \right) \times APPUEC_{r,f,b} \times \left(\frac{PRICES_{f,d,y}}{PRICES_{f,d,1997}} \right)^{\alpha} \right] \qquad (167)$$

where,

$APLCON_{y,f,r}$ is the energy consumption by other appliances by year, fuel and Census Division,

$EH_{y,b,r}$ is the number of old (pre-1998) housing units in the current year by housing type and Census Division,

$NH_{y,b,r}$ is the number of new (post-1997) housing units in the current year by housing type and Census Division,

$APPUEC_{r,f,b}$ are unit energy consumption estimates from the RSUEC10 file, by year, housing type, and Census Division,

$PRICES_{f,d,y}$ are fuel prices by year, fuel, and Census Division, and

α is the short-term price elasticity valued at -0.25.

Distributed Generation Submodule

For AEO 2000, the residential model now includes a submodule (subroutine rdistgen) with explicit characterizations and penetration estimates for distributed electric generation technologies. The model is structured to allow for three technologies and can be readily expanded to include more if needed. For AEO 2000, two technologies were characterized: photovoltaics and fuel cells.

Overview of the Technology Input File

The technology input file contains the following general categories of input data. These are described in more detail below.

- Cost and performance of specific technologies (system capacity, cost per kw, efficiencies, etc…)
- Tax credits, if any apply to a particular technology (this allows tax credit policies to be included in the economic considerations).
- The technology window of availability – technologies are assumed to be available for a fixed interval of time after which a new technology characterization becomes operable. This window is flexible in the number of years it represents, and new technologies don't necessarily have to be different from the previous version.
- Economic assumptions (tax rate, inflation rate for projecting results in the cashflow model, loan parameters).
- Program driven penetrations of technologies by census division. These are viewed as non-economic, supplemental to any economic penetrations.

Overview of the Cashflow Calculations

Technology penetration rates for distributed generating technologies installed in new construction are determined by how quickly an investment in a technology is estimated to recoup its flow of costs. This penetration rate is allowed to be as high as 30% for distributed technologies (if the investment pays back in 1 year or less). That is up to 30% of new construction in any one year can potentially include a distributed generation resource. For retrofitting distributed generation into existing construction, penetration is capped by assumption at a much smaller rate. The cap is the lessor of 0.25% or the penetration rate into new construction divided by 50 (the cap is in effect if penetration into new construction exceeds 12.5%).

For new construction, penetration rates are a direct function of the number of years required to achieve a cumulative positive cash flow for the investment. This approach is related to, but different from calculating the estimated "years to simple payback" concept. Simple paybacks are merely the investment cost divided by estimated annual savings. The cumulative positive cash flow approach incorporates financing assumptions in the calculations and can yield payback estimates that are faster than what would be computed as the simple payback (it can also yield "infinite" paybacks if the cumulative cash flow never becomes positive). The working assumption is that for new construction, investment in distributed generation technologies is rolled-in with the mortgage. The calculations for new construction assume the financing of such investments under residential mortgage rates supplied by the NEMS Macroeconomic Activity Module. In addition to energy savings, the timing and magnitude of tax effects are included in this calculation, thus allowing the modeling of tax policies.

For each potential investment decision, a cashflow analysis covering 30 years from the date of investment is made. The calculations include the costs (down payments, loan payments, maintenance costs and fuel costs) and returns (tax deductions, tax credits and energy cost savings) from the investment. In any particular year, the net of costs and returns can either be positive or negative. If the return is positive, then the cumulative net cashflow increases. For current technologies the purchase costs and investment returns are such that the first year's cash flow is negative. Thus, the technology starts out with a negative year 1 cash flow which will then either increase or decrease based on the net returns. Tax credits which are modeled as one-time payments back to the consumer in year 2 of the investment (this assumes that a wait on average of 1 year to receive any tax credits because of filings occur after year end) can have a major effect on increasing the cumulative net cash flow. For example, if an investment in photovoltaics costs $25,000, but it is financed with a 10% down payment at an interest rate of 7% for a term of 30 years, then by the end of the first year the loan-related costs will be $4,313 – the $2500 downpayment plus an annual loan amortization payment of $1813 (rounded). Against this negative cash flow will be balanced reductions in electricity costs and from the second year on, tax deductions for residential mortgage interest payments. If there is also a residential tax credit for the investment (assume it is also 10%), then the initial down payment is recouped in year 2, and the energy cost savings and interest savings only have to recoup the mortgage payments.

The Penetration Function

The penetration function for new construction has a “logistic” shape (slow initial penetration, followed by a period of more rapid growth, ending with a tapering off effect). The driving effect for this penetration is the number of years calculated until a positive cumulative cashflow is achieved (in many cases, this may never occur, and the number of years is set to 30). The result is that as economic returns improve, the period required to meet the positive cumulative cashflow requirement is shortened and penetration increases.

Outputs to Residential Main Module and NEMS

In terms of the NEMS projections, investments in distributed generation avoid purchases of electricity from the “supply-side” of NEMS. If the investment is photovoltaic, renewable energy replaces energy input to electric utilities for the self-generated amounts. If generated by fuel cells or other fuel-consuming technology, utility consumption of fuel is replaced by residential fuel consumption. Fuel consuming technologies also generate waste heat which is assumed to be partially captured and used to offset residential water heating energy use. Depending on a fuel consuming technology’s performance characteristics, the substitution of self-generation for utility generation could increase primary energy consumption. For photovoltaics, primary energy consumption is lower than what would otherwise be projected.

The following equations detail the distributed generation submodule in a representative fashion.

First, the annual payment made due to the investment in distributed generation is calculated as:

$$PAYMENT_y = \left(EQCOST_{y,e} - DOWNPMNT_e \right) \times \left(\frac{INTRATE_y}{1 - \left(1 + INTRATE_y \right)^{-TERM}} \right) \quad (168)$$

where,

$PAYMENT_y$	is the annual payment for the distributed generation equipment by year and equipment type,
$EQCOST_{y,e}$	is the first cost of the distributed generation equipment by year and equipment type,
$DOWNPMNT_e$	is the down payment made when the time of purchase,

$INTRATE_r$	is the interest rate for the loan to purchase the equipment, and
TERM	is the length of the loan.

To calculate when a positive cash flow for the investment is achieved, a series of energy-related computations must be made. The amount of electricity generated from solar photovoltaic systems is given by:

$$ANNUALKWH_y = ELEFF_{y,e} \times SOLARINS_r \times SQRFT \times LOSSFCT \times XKW \qquad (169)$$

where,

$ANNUALKWH_y$	is the system kilowatt hour generation by year,
$ELEFF_{y,e}$	is the electrical conversion efficiency by year and equipment type,
$SOLARINS_r$	is the solar insolation for photovoltaic units by region,
$SQRFT_r$	is the size of the solar collectors in square feet by region,
LOSSFCT	is the unit conversion losses (due to current), and
XKW	is the system kilowatt hour generation.

For technologies other than photovoltaic systems, the electricity generated is defined as:

$$ANNUALKWH_y = OPHOURS_{y,e} \times AVAIL \times LOSSFCT \times XKW \qquad (170)$$

where,

$OPHOURS_{y,e}$	is the number of hours of operation in a given year by equipment type, and
AVAIL	is the percent of time the system is available base on outage rates.

These technologies also need fuel input (usually natural gas) to run the system. The amount of fuel needed is represented by:

$$GASINPUT_y = .003412 \times \left(\frac{OPHOURS_{y,e} \times AVAIL}{ELEFF} \right) \times XKW \qquad (171)$$

where,

$GASINPUT_{y,e}$	is the annual fuel consumption to run the generation equipment by year and equipment type,

For these systems, the waste heat generated from the system can be used to supplant the hot water heating load for the house. The waste heat generated and used for hot water heating is given as:

$$WASTEHT_{y} = \left(GASINPUT_{y,e} - .003412 \times ANNUALKWH\right) \times WHRECOVER \tag{172}$$

where,

$WASTEHT_y$	is the amount of waste heat generated for hot water heating in a given year,
ANNUALKWH	is the amount of electricity generated by the generation equipment in a given year, and
WHRECOVER	is the waste heat recovery factor.

Once all of the energy and financial equations are computed, the number of distributed generation technologies purchased can be calculated. The penetration function for each of the distributed generation technologies is given by:

$$PENRATE_{y,e} = XMAXPEN_{e} - \frac{1}{\frac{1}{XMAXPEN_{e}} \times e^{\left(XALPHA_{e} \times \left(YEAR - 9 - PAYBACK_{e}\right)\right)}} \tag{173}$$

where,

$PENRATE_{y,e}$	is the penetration rate of the distributing generation technology by year and equipment type,
$XMAXPEN_e$	is the maximum penetration for the distributing generation technology in a given year by equipment type,
YEAR	is the current year of the model run, and
$PAYBACK_e$	is the number of years to a positive cashflow for the investment by equipment type.

Fuel Consumption Totals

FUELCN (Fuel Consumption Totals Component)

The total residential energy consumption for the nation is computed by summing end use service consumption by fuel for each Census Division. The division by a million converts units from million Btu per year to trillion Btu per year. The factor *LEAPYR* in each equation takes on the value of 1 in all years but leap years, when it has the value 366/365.

Natural Gas

$$RSFLCN_{y,ng,r} = \frac{\begin{array}{c} HTRCON_{y,ng,r} + H2OCON_{y,ng,r} + CKCON_{y,ng,r} + GASINPUT_{y,r} \\ + DRYCON_{y,ng,r} + COOLCN_{y,ng,r} + SHTCON_{y,ng,r} + APLCON_{y,ng,r} \end{array}}{1000000} \times LEAPYR \quad (174)$$

Electricity

$$RSFLCN_{y,electricity,r} = \frac{\begin{array}{c} HTRCON_{y,electricity,r} + COOLCN_{y,electricity,r} + H2OCON_{y,electricity,r} \\ + SHTTCON_{y,electricity,r} + CKCON_{y,electricity,r} + DRYCON_{y,electricity,r} \\ + REFCON_{y,r} + FRZCON_{y,r} + LTCON_{y,r} + TVCON_{y,r} + CSWCON_{y,r} \\ + DSWCON_{y,r} + FANCON_{y,r} + PCCON_{y,r} + APCCON_{y,r} - ANNUALKWH_{y} \end{array}}{1000000} \times LEAPYR \quad (175)$$

Distillate

$$RSFLCN_{y,distillate,r} = \frac{\begin{array}{c} APLCON_{y,distillate,r} + HTRCON_{y,distillate,r} \\ + H2OCON_{y,distillate,r} + SHTCON_{y,distillate,r} \end{array}}{1000000} \times LEAPYR \quad (176)$$

LPG

$$RSFLCN_{y,LPG,r} = \frac{SHTCON_{y,LPG,r} + APLCON_{y,LPG,r} + HTRCON_{y,LPG,r} + H2OCON_{y,LPG,r} + CKCON_{y,LPG,r}}{1000000} \times LEAPYR \quad (177)$$

Kerosene

$$RSFLCN_{y,kerosene,r} = \frac{HTRCON_{y,kerosene,r} + SHTCON_{y,kerosene,r}}{1000000} \times LEAPYR \quad (178)$$

Coal

$$RSFLCN_{y,coal,r} = \frac{SHTCON_{y,coal,r}}{1000000} \times LEAPYR \quad (179)$$

Wood

$$RSFLCN_{y,wood,r} = \frac{HTRCON_{y,wood,r} + SHTCON_{y,wood,r}}{1000000} \times LEAPYR \quad (180)$$

Geothermal

$$RSFLCN_{y,geothermal,r} = \frac{HTRCON_{y,geothermal,r} + COOLCN_{y,geothermal,r}}{1000000} \times LEAPYR \quad (181)$$

National Total

$$RSFLCN_{y,f,United\ States} = \sum_{r} \left(RSFLCN_{y,f,r} \right) \quad (182)$$

Appendix C: Bibliography

Air Conditioning and Refrigeration Institute, "Directory of Certified Cooling Equipment," Arlington, VA, 1994.

American Council for an Energy-Efficient Economy, "Energy Savings Estimates from the Energy Efficiency Provisions in the Senate and House Energy Bills," Washington, D.C., August, 1993.

American Gas Association, "Residential Natural Gas Market Survey: 1992," Arlington, VA, June, 1993.

Arthur D. Little, "EIA Technology Forecast Updates," 1998.

Arthur D. Little, "Electricity Consumption by Small End Uses in Residential Buildings," 1998.

Association of Home Appliance Manufacturers, "Freezers: Energy Efficiency and Consumption Trends," Chicago, IL, July, 1995.Association of Home Appliance Manufacturers, "Refrigerators: Energy Efficiency and Consumption Trends," Chicago, IL, July, 1995.

Electric Power Research Institute, "Draft Model Documentation for Residential End-use Energy Planning System (REEPS), Version 2.0," Palo Alto, CA, 1990.

Electric Power Research Institute, "Residential End-Use Energy Consumption: A Survey of Conditional Demand Estimates," Palo Alto, Ca, 1989.

Electric Power Research Institute, "Residential End-Use Energy Planning System (REEPS), Version 1.0, Palo Alto, CA, 1982.

Energy Information Administration, "A Recommended Design for the National Energy Modeling System," 1991.

Energy Information Administration, "Residential Sector Component Design Report," January 19, 1993.

Energy Systems and Policy, "The LBL Residential Energy Model: An Improved Policy Analysis Tool," 1987.

Federal Register, "Part III: Department of Energy," May 14, 1991.

Gas Appliance Manufacturers Association, "Consumers' Directory for Certified Efficiency Ratings," Arlington, VA, 1994.

Gas Research Institute, "1991 Edition of the GRI Baseline Projection Methodology and Assumptions Topical Report," Lexington, MA, 1990.

Gas Research Institute, "Baseline Projection Data Book," 1990.

Koomey, J.G., et. al., "The Potential for Electricity Efficiency Improvements in the U.S. Residential Sector," Lawrence Berkeley Laboratory, Berkeley, CA, July, 1991.

Lawrence Berkeley Laboratory, "Energy Data Sourcebook for the U.S. Residential Sector," Berkeley, CA, May, 1997.

Turiel, I., et. al., "U.S. Residential Sector Appliance Energy Efficiency: Present Status and Future Directions," Lawrence Berkeley Laboratory, Berkeley, CA, December, 1992.

U.S. Bureau of the Census, "Annual Housing Survey: 1983," 1983.

U.S. Bureau of the Census, "Components of Inventory Change," 1980.

U.S. Bureau of the Census, "Current Construction Reports-Series C25 Characteristics of New Housing: 1997," 1998.

U.S. Department of Energy, Energy Information Administration, *A Look at Residential Energy Consumption in 1997*, DOE/EIA-0314(97), Washington, DC, 1999.

U.S. Department of Energy, *Technical Support Document: Energy Conservation Standards for Consumer Products: Dishwashers, Clothes Washers, and Clothes Dryers*, DOE/CE-0267, Washington, D.C., July 1989.

U.S. Department of Energy, *Technical Support Document: Energy Conservation Standards for Consumer Products: Refrigerators and Furnaces*, DOE/CE-0277, Washington, D.C., November, 1989.

Independent Expert Reviews Conducted:

Independent expert reviews of the *Residential Sector Component Design Report, May 28,1992* were conducted by Inderjit Kundra, Office of Statistical Standards; Fred Joutz, Office of Statistical Standards; Ronald D. Sands, Batelle Pacific Northwest Laboratory, James E. McMahon, Lawrence Berkeley Laboratory; and Francis X. Johnson, Lawrence Berkeley Laboratory.

Status of Evaluation Efforts by Sponsor:

None.

Appendix D: Model Abstract

Model Name:

NEMS Residential Sector Demand Module

Model Acronym:

None

Description:

The NEMS Residential Sector Demand Module is an integrated dynamic modeling system that projects residential energy demand by service, fuel, and Census Division. The modeling methodology is based on accounting principles and considers important issues related to consumer behavior. Housing and equipment stocks are tracked over the forecast period for seven major services. The major services considered are space heating, space cooling, clothes washing, dishwashing, water heating, cooking, clothes drying, refrigeration, freezers, and lighting. A logit function is used to estimate market shares of each equipment technology within each major service based on either the installed capital and operating costs or the life-cycle cost. Miscellaneous appliance consumption is calculated as a function of Unit Energy Consumption (UEC), a measure of energy intensity developed from the Residential Energy Consumption Survey (RECS) data base. Distributed generation technologies considered are fuel cells and photovoltaic equipment.

Purpose of the Model:

As a component of the National Energy Modeling System, the Residential Sector Demand Module generates mid-term forecasts of residential sector energy demand for the period 1997 through 2020. The model facilitates policy analysis of energy markets, technological development, and regulatory development.

Most Recent Model Update:

October 1999.

Component of Another Modeling System:

The Residential Sector Demand Module is designed, executed, and maintained as part of the National Energy Modeling System (NEMS).

Model Interfaces:

The NEMS Residential Sector Demand Module receives population and housing construction input data from the NEMS Macroeconomic Activity Module (MAM). Outputs in the form of quantities of fuel demanded in the residential sector are provided to the NEMS Integrating Module and the NEMS Supply Modules: Electricity Market Module, Petroleum Market Module, and Natural Gas Supply Module.

Office Model Representative:

John H. Cymbalsky
Office of Integrated Analysis and Forecasting
Energy Demand Analysis Branch
(202) 586-4815

Documentation:

Model Documentation Report: Residential Sector Demand Model of the National Energy Modeling System, December 1998.

Archive Media and Installation Manual:

The NEMS Residential Sector Demand Module has been archived as part of the NEMS production runs that generate the Annual Energy Outlook 2000 (AEO2000) on the EIA IBM RS-6000 workstation.

Energy System Described:

U.S. residential sector energy consumption.

Scope of Coverage:

- Geographic: Nine Census Divisions: New England, Middle Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, and Pacific
- Time Unit/Frequency: Annual, 1997 through 2020 is the current mid-term horizon
- Products: Fuel consumption including: electricity, natural gas, distillate, liquefied petroleum gas, kerosene, geothermal, wood, solar thermal, and coal. Energy consumption per household. Equipment stock and efficiency.
- Economic Sectors: Domestic residential sector
- Services: Space heating, space cooling, clothes washers, dishwashers, water heating, cooking, clothes drying, refrigeration, freezers, lighting, other color televisions, furnace fans, personal computers, electric appliances, other appliances, and secondary space heating. Distributed generation technologies are also considered.
- Housing Types: Single-Family, Multifamily, and Mobile Homes

Model Features:

- Model Structure: Sequential algorithm composed of housing and equipment stock flow algorithms, technology choice algorithm, housing shell integrity algorithm, end-use consumption, and emissions calculations.

- Modeling Technique: Housing and equipment stock turnover are modeled using linear decay functions. Market shares for each type of equipment choice are based on a logit function employing installed capital costs and operating costs. Unit energy consumption estimates, fuel prices, and equipment market shares are user inputs that drive the calculation of final end-use consumption.
- Special Features: Technology choice logit function has the ability to use installed capital, and operating costs or life-cycle costs to determine new market shares.

Non-DOE Input Sources:

American Home Appliance Manufacturers Association.

- Shipment-weighted efficiency ratings for refrigerators, freezers, and room air conditioners.

U.S. Bureau of the Census, "Current Construction Reports-Series C25 Characteristics of New Housing: 1994," 1995.

- New housing and base year market shares for some services and equipment types.

Gas Appliance Manufacturers Association, "Consumers' Directory for Certified Efficiency Ratings," 1994.

Lawrence Berkeley Laboratory, "Energy Data Sourcebook for the U.S. Residential Sector," 1997

- Residential equipment technical characterization data.
- Expected minimum and maximum appliance lifetimes.

- Expected lifetimes of housing types.

The major data input sources are discussed in this Appendix. Appendix C provides additional bibliographic citations of data sources used in the Residential Sector Demand Module.

DOE Input Sources:

U.S. Department of Energy, Energy Information Administration, *A Look at Residential Energy Consumption in 1997.*

- Base year market shares for services and equipment types.
- Base year housing stock.
- Unit energy consumption values (UECs)

The major data input sources are discussed in this Appendix. Appendix C provides additional bibliographic citations of data sources used in the Residential Sector Demand Module.

Computing Environment:

- Hardware Used: IBM RS-6000 370 Series
- Operating System: AIX 3.2.5
- Language/Software Used: IBM XL FORTRAN Compiler/6000, Version 3.1.1
- Memory Requirement: 3,000K
- Storage Requirement: Since the Residential Sector Demand Module has not yet been archived at the time of this writing, the number of tracks of an IBM 3380 disk pack that are required are currently unknown. This information will be provided upon completion of the archival process.
- Estimated Run Time: 0.3 seconds CPU time per iteration
- Special Features: None

Independent Expert Reviews Conducted:

Independent expert reviews of the *Residential Sector Component Design Report, May 28,1992* were conducted by Inderjit Kundra, Office of Statistical Standards; Fred Joutz, Office of Statistical Standards; Ronald D. Sands, Batelle Pacific Northwest Laboratory, James E. McMahon, Lawrence Berkeley Laboratory; and Francis X. Johnson, Lawrence Berkeley Laboratory.

Status of Evaluation Efforts by Sponsor:

None.

Appendix E: Data Quality

This Appendix discusses the quality of the survey data source from which the majority of the historical housing stock, appliance stock, and technology information that drives the NEMS Residential Sector Demand Module is drawn. This survey is the 1997 Residential Energy Consumption Survey (RECS). Data quality information pertinent to additional sources used in the module development is not available for this report. The parameter estimates included in the Residential Sector Demand Module are user-specified. A sensitivity analysis of the major parameters is included in Appendix F, **Model Sensitivities**.

Quality of Input Data

RECS Implementation

The RECS procedure is composed of two instruments: the household survey and the energy supplier survey. Data is collected from a representative sample of households through personal interviews. Billing data is next collected through mail questionnaires from the energy supplier to the participating household, provided that authorization is obtained from the household. The results of the household and energy supplier surveys are presented in the Department of Energy documentation of the RECS 1997 survey[1].

Stage I of RECS consists of a personal interview. The sample for the interviews is developed based on all units occupied as a primary residence in the 50 states and the District of Columbia. The sample design process is composed of five steps that

---

[1] U.S. Department of Energy, Energy Information Administration, A Look at Residential Energy Consumption in 1997, DOE/EIA-0314(97), Washington, D.C., 1999.

disaggregate the geographic scope into housing clusters of approximately 5 housing units to be surveyed.

The interview responses provide information on housing structure including insulation, doors, windows, space conditioning systems, use of wood fuel, energy conservation improvements, household appliances, household vehicles, receipt of government assistance for the cost of space heating, and demographics. Householders were also asked to sign authorization forms to allow access to their billing records with energy suppliers.

Stage II of the survey design consists of a mail questionnaire for energy suppliers of the households interviewed in Stage I. Suppliers of residential electricity, natural gas, fuel oil, kerosene, and liquified propane gas (LPG) are contacted in Stage II. For the 1997 RECS, each supplier was asked to supply billed quantities and expenditures for the households interviewed in Stage I.

Data verification begins with a manual verification of the interview data from Stage I. The questionnaires are checked for completeness and consistency. Interview responses are compared to energy supplier data, and respondents are contacted in the event that an inconsistency persists. These data collection and verification procedures ensure the quality of the survey data.

Appendix F: Model Sensitivities

Solution Methodology

As the description in Section 4, Model Structure, and Appendix B, Detailed Mathematical Description, shows, the solution methodology of the NEMS Residential Module is a direct, one-pass, computation of linear and non-linear systems of equations to develop the residential module outputs such as quantity demanded by fuel type. Consequently, convergence within the NEMS Residential Module is never an issue nor is it relevant since the algorithm within the residential module is not iterative.

The model requires no estimate of the current-year solution to compute the solution to the NEMS Residential Module since the current year solution depends on only the values of the solution in the previous year plus the current economic conditions and other inputs from the rest of NEMS. Listed in descending order of model sensitivity (as will be shown below), variation in weather patterns, equipment efficiencies, housing starts and fuel prices do influence the residential module equipment purchase decisions and total quantity of fuel consumed. This appendix contains a series of sensitivity analyses for the purpose of illustrating the behavior of the residential module. These sensitivities illustrate how the model responds to changes in key model inputs.

Although rigorous tests have not been performed to determine the maximal meaningful values for the key model inputs, an indication of values for which the model has proven to be valid is given by those used in the sensitivity analyses. It must be stressed that care must be exercised in selecting input values so that the model produces meaningful results.

Theoretical Considerations

Because of the direct (rather then iterative) solution algorithm and because all of the functions in the NEMS Residential Module are continuous and differentiable in the domain of applicability of the model (that is, when "reasonable and consistent inputs" are provided into the model) the model always produces a unique solution. Existence and convergence are not an issue. As previously mentioned, some of the inputs to the model may be correlated (as in certain demographic and macro-economic inputs) and if inconsistent pairs of such inputs or negative prices are chosen, then the model will produce meaningless results. This behavior, however, is consistent with the well know reality in computer models of "garbage in -- garbage out". When the model is run in a stand-alone fashion, the user must be certain that the inputs are consistent and credible.

Examples of input assumptions that will cause the model to produce meaningless results include:

- severely altering base year data, e.g., doubling the existing 1997 housing stock,
- characterizing unrealistically "super-efficient" technologies with low acquisition costs, and
- modifying prices considerably in excess of variations historically experienced, such as quadrupling prices in one year.

Sensitivity Analyses

To demonstrate the NEMS Residential Module's behavior under a variety of situations, several model runs were made to test its sensitivity to altered values for key input variables. These runs were then compared with the Reference Case forecast used for the AEO 2000. The sections below describe the six major inputs and outputs chosen for this exercise, as well as the results of the analysis in tabular form.

Input Variables

The five input variables chosen for the sensitivity analyses were selected based upon their perceived importance in producing the AEO 2000 forecast. The five variables and the magnitude of variation are given below.

Electricity, natural gas, and distillate prices. Prices for the three major residential fuels were each increased by 25 percent over their values in the AEO 2000 Reference Case in every year of the forecast (2000 through 2020). Fuel prices affect the projected consumption levels in two ways. First, there is an immediate "short-run" response best thought of as immediate behavioral changes. For example, higher heating fuel prices will result in lower thermostat settings. These near term behavioral responses are captured through the model's short-term price elasticities. Over a longer interval, the efficiency level of both the building shell and the energy-using equipment inside the house will also vary in response to prices. For example, when the replacement of space heating equipment is necessary, higher fuel prices lead to greater efficiency for purchased equipment and lower energy consumption. The longer-term equipment-related responses will alter fuel consumption over an extended number of years in contrast to the immediate short-run effects. Based on these two price-related responses (which operate in the same direction but over different intervals), it is expected that continued higher fuel prices will lower fuel consumption and energy intensity and that the effects will tend to increase over time.

Housing starts. Housing starts by Census Division and housing type (single-family, multifamily, and mobile homes) are the macroeconomic variables which drive the NEMS Residential Model. For each Census Division and housing type, starts were increased by 10 percent every year, relative to the AEO 2000 Reference Case beginning in 2000. Logically, these variables represent household formation and are consistent with a scenario with implicitly higher population growth. New residential construction embodies new techniques and technologies and tends to be more efficient than the average existing stock. Thus, it is expected that increasing housing starts will increase overall energy consumption, but at a rate which is less than proportional. Thus, energy consumption per household (energy intensity) will decline for this model run.

Equipment efficiencies. The efficiency of new equipment entering the stock plays a central role in determining the average level of energy intensity for the residential sector. For this sensitivity analysis, every equipment efficiency represented in the model was increased 10 percent relative to the AEO 2000 Reference Case beginning in 2000. It is expected that higher equipment efficiencies will cause both energy consumption and energy intensity to decline. It is further expected that the decline in consumption and intensity will deviate further from the Reference Case over time as equipment purchases make up larger and larger shares of total equipment.

Output Variables

For each input selected, six outputs were chosen to test their sensitivities to these inputs. The six outputs chosen are:

- the quantity demanded of electricity,
- the quantity demanded of natural gas,
- the quantity demanded of distillate oil,
- the quantity demand for all fuels in total,
- the number of occupied households (relevant only to increased housing starts case), and
- the space heating intensity in million Btu per household per year.

Tables F-1 through F-3 show the relationship between the inputs and outputs for the years 2010 and 2020. Table F-1 summarizes the absolute change of each output relative to the AEO 2000 Reference Case with separate panels for 2010 and 2020. Similarly, Table F-2 shows the percent change of each output relative to the AEO 2000 Reference Case. Table F-3 provides the elasticities (the percent change of the output divided by the percent change of the input) of the selected output variables with respect to the selected input variables. The summary and conclusions section discusses the results presented in the tables.

Table F-1.

Input/Output Matrix--Change in Quantity Year 2010						
INPUTS	OUTPUTS (qBtu)					
	Distillate	Natural Gas	Electricity	Total Consumption	Households (Million Units)	Heating Intensity (Million Btu/hh)
Distillate Price (25% Increase)	-0.07	0.02	0	-0.05	N/A	-0.42
Natural Gas Price (25% Increase)	0.01	-0.45	0.02	-0.41	N/A	-2.63
Electricity Price (25% Increase)	0	0.06	-0.30	-0.23	N/A	-0.04
Housing Starts (10% Increase)	0	0.08	0.08	0.19	1.97	-0.08
Equipment Efficiency (10% Increase)	-0.02	-0.21	-0.11	-0.33	N/A	-1.17

Input/Output Matrix-Absolute Change in Quantity Year 2020						
INPUTS	OUTPUTS (qBtu)					
	Distillate	Natural Gas	Electricity	Total Consumption	Households (Million Units)	Heating Intensity (Million Btu/hh)
Distillate Price (25% Increase)	-0.08	0.03	0	-0.05	N/A	-0.36
Natural Gas Price (25% Increase)	0.02	-0.54	0.04	-0.48	N/A	-2.83
Electricity Price (25% Increase)	0	0.11	-0.37	-0.24	N/A	0.21
Housing Starts (10% Increase)	0	0.15	0.15	0.33	3.55	-0.12
Equipment Efficiency (10% Increase)	-0.03	-0.34	-0.16	-0.52	N/A	-1.85

Table F-2.

Input/Output Matrix--Percent Change Year 2010						
INPUTS	OUTPUTS					
	Distillate	Natural Gas	Electricity	Total Consumption	Households	Heating Intensity
Distillate Price (25% Increase)	-10.19%	0.32%	0.03%	-0.45%	N / A	-0.87%
Natural Gas Price (25% Increase)	1.63%	-8.21%	0.52%	-3.44%	N / A	-5.48%
Electricity Price (25% Increase)	0 .38%	1.09%	-6.31%	-1.90%	N / A	0.08%
Housing Starts (10% Increase)	0 .47%	1.54%	1.79%	1.57%	1.68%	-0.16%
Equipment Efficiency (10% Increase)	-2.54%	-3.81%	-2.35%	-2.81%	N / A	-2.43%

Input/Output Matrix--Percent Change Year 2020						
INPUTS	OUTPUTS					
	Distillate	Natural Gas	Electricity	Total Consumption	Households	Heating Intensity
Distillate Price (25% Increase)	-12.26%	0.44%	0.04%	-0.39%	N / A	-0.78%
Natural Gas Price (25% Increase)	2.78%	-9.23%	0.82%	-3.76%	N / A	-6.17%
Electricity Price (25% Increase)	0.64%	1.88%	-6.98%	-1.88%	N / A	0.46%
Housing Starts (10% Increase)	0.76%	2.52%	2.92%	2.59%	2.78%	-0.27%
Equipment Efficiency (10% Increase)	-4.01%	-5.80%	-2.93%	-4.06%	N / A	-4.02%

Table F-3.

Input/Output Matrix--Elasticities Year 2010						
INPUTS	OUTPUTS					
	Distillate	Natural Gas	Electricity	Total Consumption	Households	Heating Intensity
Distillate Price (25% Increase)	-0.41	0.01	0	-0.02	N / A	-0.03
Natural Gas Price (25% Increase)	0.07	-0.33	0.02	-0.14	N / A	-0.22
Electricity Price (25% Increase)	0.02	0.04	-0.25	-0.08	N / A	0.003
Housing Starts (10% Increase)	0.05	0.15	0.18	0.16	0.17	-0.02
Equipment Efficiency (10% Increase)	-0.25	-0.38	-0.23	-0.28	N / A	-0.24

Input/Output Matrix--Elasticities Year 2020						
INPUTS	OUTPUTS					
	Distillate	Natural Gas	Electricity	Total Consumption	Households	Heating Intensity
Distillate Price (25% Increase)	-0.49	0.02	0	-0.02	N / A	-0.03
Natural Gas Price (25% Inrease)	0.11	-0.37	-0.03	-0.15	N / A	-0.25
Electricity Price (25% Increase)	0.03	0.08	-0.28	-0.08	N / A	0.02
Housing Starts (10% Increase)	0.08	0.25	0.29	0.26	0.28	-0.03
Equipment Efficiency (10% Increase)	-0.40	-0.58	-0.29	-0.41	N / A	-0.40

Summary and Conclusions

Price Responsiveness

As shown on Table F-3, the NEMS Residential Module exhibits major fuel own-price elasticities for 2020 in the range of -0.28 (electricity) to -0.49 (distillate). Intuitively speaking, electricity demand is expected to exhibit a smaller price elasticity than the other major fuels. This is because the use of electricity is spread across many end uses which are less directly controllable than is space heating, which is readily adjusted via the thermostat setting. Since distillate and natural gas use are dominated by space heating, their price elasticities are expected to be somewhat greater than those for electricity.

Responsiveness to Altered Housing Starts

As shown in Table F-1, increased housing starts result in the expected decline in heating intensity. This is because new homes on average use less energy per unit for space heating than older homes because of increased shell efficiency. Thus, as the forecast for housing starts is adjusted upward (downward), sectoral energy intensity will decline (increase). In this scenario, a 10 percent increase in housing starts between 2000 and 2020 results in a 0.2 percent decline in average energy intensity relative to the AEO 2000 Reference Case -- total energy consumption in 2020 is 2.6 percent higher while total households are 2.8 percent higher.

Responsiveness to Altered Equipment Efficiency

In terms of total energy consumption, the model is most sensitive to equipment efficiency. This is because over the 20-year forecast horizon, a substantial amount of residential equipment will be replaced. For example, roughly two-thirds of all furnace equipment and all of the existing heat pumps and air conditioning equipment will be replaced, along with all existing water heaters and refrigerators. Nearly all replacements occur at higher efficiency levels so that over time the assumed 10 percent increase in new equipment efficiencies will have greater and greater effects on energy consumption levels. By the year 2020, total energy consumption is 4.1 percent lower that the AEO 2000 Reference Case as shown in Table F-2.