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

May 2009

Office of Integrated Analysis and Forecasting
Energy Information Administration
U.S. Department of Energy
Washington, DC 20585

Update Information

This is the thirteenth 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 2009*. These changes include:

- New and extended tax credits to account for the Energy Improvement and Extension Act of 2008 (EIEA 2008).
- Updates to the technology choice menu for lighting based on a new report by Navigant Consulting.
- Updates to the distributed generation sub-module to include wind technology and niches for solar photovoltaic technology.
- Updates to the heating shares and square footage based on new Census Bureau data.

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1. Introduction

Purpose of this Report

This report documents the objectives, analytical approach, and structure 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 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, model performance evaluations, and parameter refinements.

Model Summary

The NEMS Residential Sector Demand Module is currently used in developing long-term projections and energy policy analysis over the time horizon of 2005 through 2030. The model generates projections of energy demand, which is used interchangeably with the concept of energy consumption in this document, for the residential sector by end-use service, fuel type, and Census Division. If the user defines alternative input and parameter assumptions, the policy impacts that result from the introduction of new technologies, market incentives, and regulatory changes can be estimated using the module.

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 projections to compute equilibrium energy prices and quantities.

The Residential Sector Demand Module is an analytic 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
- 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 2008* (*AEO2008*) on a compact disc.

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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 in the NEMS system. Chapter 3 describes the rationale behind the design, fundamental assumptions regarding consumer behavior, module structure, and alternative modeling approaches. Chapter 4 describes the NEMS Residential Sector Demand Module structure, including flowcharts and major sub-routines.

Appendices to this report document the variables and equations contained in the FORTRAN source code. Appendix A consists of a model abstract. Appendix B provides mathematical equations that support the program source code in the module. Appendix C contains the key computations and equations for the model. Appendix D catalogues the input data used to generate projections in list and cross-tabular formats. Appendix E discusses the data quality issues. Appendix F is a bibliography of reference materials used in the development process.

2. Model Purpose

Module Objectives

The NEMS Residential Sector Demand Module has three fundamental objectives. First, the module generates disaggregated projections of energy demand in the residential sector for the period of 2005 through 2030 by housing type 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, the module is an integral component of the NEMS system, it provides inputs to the Electricity Market Module, Natural Gas Transmission and Distribution Module, and Petroleum Market Module of NEMS, and contributes to the calculation of the overall energy supply and demand balance.

The Residential Sector Demand Module projects residential sector energy demands in six sequential steps. These steps produce information on housing stocks, technology choices, appliance stocks, building shell integrity, distributed generation, 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 (installation or retail)-cost incentive programs (such as rebates used in demand-side management programs), can be modified at the equipment level. Housing stock attrition and equipment retirement assumptions can be modified to reflect varying equipment decay rates. Building shell characteristics can be modified to reflect varying policy options for building codes or the impact of energy-efficient mortgages.

Projected 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. In addition, the NEMS supply modules use the residential sector outputs to determine the patterns of consumption and the resulting prices for 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 (in real dollars), equipment efficiency, and expected minimum and maximum equipment lifetimes. The major inputs by module component are as follows:

Housing Stock Component

    Housing starts

    Existing housing stock for 2005

    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 existing housing shell integrity

    Cost and efficiency of various building shell measures for new construction

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 Energy Policy Act of 2005 (EPACT05)

Expected fuel savings based upon the Energy Independence and Security Act of 2007 (EISA 2007)

Population

Personal disposable income

Outputs

The primary module output is projected residential sector energy consumption by fuel type, end-use service, and Census Division. The module also projects housing stock and energy consumption per household. In addition, the module can produce a disaggregated projection of appliance stock and efficiency for most of the major appliances used in a home. The types of appliances included in this projection 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

Lighting (general service (reflector and standard), tubular fluorescent, halogen torchiere)

Fuel Cells

Solar Photovoltaic Systems

Wind Turbines

Variable Classification

The NEMS modules are designed to provide and use system data at the nine Census Division level of aggregation. The input data available from the Residential Energy Consumption Survey (RECS) conducted by EIA (which forms the basis for the Residential Sector Demand Module) are generally specified at 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 have the following categories within each of the four dimensions 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 projected population, personal disposable income, and housing starts by Census Division and housing type. The Residential Sector Demand Module uses fuel price projections generated by the NEMS supply modules previously listed as key drivers to calculate operating costs for technology selections, existing 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 prices for energy delivered to the residential sector.

Figure 1. Relationship to Other NEMS Modules
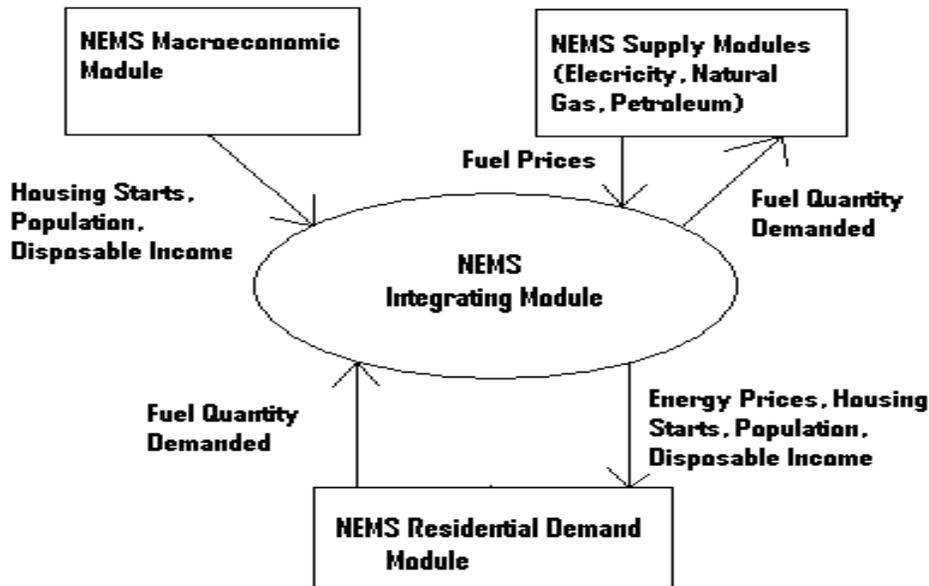
3. Model Rationale

Theoretical Approach

The NEMS Residential Sector Demand Module is an integrated dynamic modeling system based on accounting principles and residential consumer economic behavior that generate projections of residential sector energy demand, appliance stocks, and market shares.

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 projection. The housing stock changes each projection year as houses are retired from the stock and new construction is added. The equipment stock changes each projection year as appliances fail and are replaced, through increases in the saturation of existing appliances, and as new technologies enter the market. A logistic function[1] 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 conditioning (heating, cooling, building shell), clothes washers, dishwashers, water heating, cooking, clothes drying, lighting, 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. Color televisions, furnace fans, personal computers, set-top boxes, VCR/DVD, home audio equipment, ceiling fans, microwave ovens, spas, security systems, coffee makers, rechargeable devices, distributed generation, and miscellaneous equipment choices are modeled based upon alternative technology assumptions discussed below.

Base year information developed from the 2005 RECS data base forms the foundation of modeling changes to the equipment and housing stock over the projection period. Market share information

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[1]This function is described in depth in Appendix B.

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 projection 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.

General Model 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, 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, and switching cost.

- New housing stock building shell efficiency is a function of the life-cycle cost of competing building shell packages.

- Life-cycle costs used in the cost calculations for new home HVAC systems are computed over a 7-year time horizon with a discount rate of 20 percent.

- Two housing vintages are assumed: pre-2006 (existing housing) and post-2005 (new housing).

- The type of fuel used for water heating and cooking in new housing units is assumed to be a function of the main space heating fuel in most cases. For example, if natural gas is the main space heating fuel, then it is assumed that natural gas will be the water heating fuel. However, only 65 percent of those homes are assumed to use natural gas as the main cooking fuel. This is based on recent RECs data. If an oil or electric furnace is installed as the main space heating system, then electricity will be the water heating and cooking 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 percent for single-family homes, 99.8 percent for multifamily homes, and 97.5 percent for mobile homes. These rates are based on an analysis of historical household growth and housing starts.

- It is assumed that a constant 1.2 percent of existing housing units are renovated each year, increasing the square footage of the heated living area by about one-third.

- 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.

- It is assumed that the volumetric size of new construction is larger than existing homes, which increases the heating and cooling loads in new construction, all else equal.

Area Specific Model Assumptions

Energy Independence and Security Act of 2007 (EISA 2007)

The passage of the EISA 2007 in December 2007 provides additional minimum efficiency standards for various types of residential equipment. The standards contained in EISA2007 include: nearly a 30 percent reduction in the wattage of general service lighting in 2012-2014 and about 65 percent reduction in 2020; boiler standards in 2012; wattage reductions for external power supplies after 2008; and standards for clothes washers, dishwashers, and dehumidifiers between 2010 and 2012.

Energy Policy Act of 2005 (EPACT05) and Energy Improvement and Extension Act of 2008 (EIEA 2008)

The passage of the EPACT05 in August 2005 provides additional minimum efficiency standards for residential equipment and provides tax credits to producers and purchasers of energy efficient equipment and builders of energy efficient homes. The standards contained in EPACT05 include: 190 watt maximum for torchiere lamps in 2006; Dehumidifier standards for 2007 and 2012; and ceiling fan light kit standards in 2007. Manufactured homes that are 30 percent better than the latest code, a $1000 tax credit can be claimed in 2006 and 2007. Likewise, builders of homes that are 50 percent better than code can claim a $2000 credit over the same period. Production tax credits are assumed to be passed through to the consumer in the form of lower purchase cost. EPACT05 includes production tax credits for energy efficient refrigerators, dishwashers, and clothes washers in 2006 and 2007, with dollar amounts varying by type of appliance and level of efficiency met, subject to annual caps. Consumers can claim a 10 percent tax credit in 2006 and 2007 for several types of appliances specified by EPACT05, including: Energy efficient gas, propane, or oil furnace or boiler, energy efficient central air conditioners, air and ground source heat pumps, hot water heaters, and windows. Lastly, consumers can claim a 30 percent tax credit in 2006, 2007, and 2008 for purchases of solar PV, solar water heaters, and fuel cells (subject to $2000 cap). EIEA 2008 extends the tax credits specified in EPACT 2005 through 2010. In addition, the $2000 cap for solar PV, solar water heaters, and fuel cells was removed, and the credit for ground-source heat pumps was increased to $2000.

Technology Choice

The efficiency choices made for residential equipment are based on a log-linear function. The function assigns market shares for competing technologies based on the relative weights of

capital/installed (first cost) and discounted operating (annual fuel) costs. A time dependant function calculates the installed capital cost of equipment in new construction based also on a log-linear function. If fuel prices increase markedly and remain high over a multi-year period, more efficient appliances will be available earlier in the projection period than would have been 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 2005 survey performance period. The average of the last 10 years (1997-2006) heating and cooling degree-days, which is a proxy for normal weather, is adjusted in the projection period based on shifts in state population.

Technology Switching

Space heaters, air conditioners (heat pumps and central air conditioners), water heaters, stoves, and clothes dryers may be replaced with competing technologies in single-family homes. It is assumed that 20 percent of the replacement market in single-family homes is eligible to switch fuels in any projection year. 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 2005 RECS database. The module currently assumes that solar energy provides 50 percent of the energy needed to satisfy hot water

demand, and an electric back-up unit satisfies the remaining 50 percent in solar water heating systems.

Through-the-Door Refrigeration Units

Many residential food refrigerators have through-the-door access panels for ice and water. This added convenience results in greater energy use than conventional refrigerator models. The Residential Sector Demand Module assumes that about 30 percent of all post-2005 refrigerators incorporate the through-the-door access feature, based upon recent appliance shipment data.[2]

Clothes Dryer Saturation

The module currently assumes that clothes dryer market penetration increases over the projection 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 database.

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.

Lighting

The module partitions lighting into four main categories of use: general purpose, general purpose reflector, linear fluorescent, and torchiere. Within the general use category, several hours of use bins further partition this category, allowing bulb choice to vary with the amount of time each fixture is used on an annual basis. The reflector, torchiere and fluorescent categories assume an average hours of use for lamp choice purposes.

Color Televisions, Set-top Boxes, and Personal Computers

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

Furnace Fans

The number of households that have fossil fuel-fired central forced-air heating determines furnace fan

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[1] *Association of Home Appliances Manufacturers, ``Refrigerators: Energy Efficiency and Consumption Trends,'' Washington, DC, May 23, 2003.*

fan energy consumption. The relative size of heating and cooling degree-days also affects the amount of energy used for this service.

Ceiling Fans, Microwave Ovens, Spas, DVD/VCR, Security Systems, Coffee Makers, Home Audio, and Rechargeable Electronics

The forecast for energy consumption for these uses is based on future saturation rates and Unit Energy Consumption (UEC) estimates found in "*Commercial and Residential Sector Miscellaneous Electricity Consumption: Y2005 and Projections to 2030*," TIAX LLC, Reference Number D0366, September 22, 2006.

Other Appliances

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

Secondary Heating

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

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.

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 six logical components: housing stock projection, technology choice, appliance stock projection, building shell integrity, distributed generation, and energy consumption.

Housing Stock Projection

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:

1. Single-Family Homes
2. Multifamily Homes
3. Mobile Homes

Equipment Technology Choice

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

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 listed in Table 1. The

technologies are distinguished by the service demand that they satisfy, by the fuel that they consume, and by their efficiency.

Table 1. Services and Equipment in NEMS Residential Demand Module

Space Heating Equipment

| Electric Furnace |
| Electric Air-Source Heat Pump |
| Natural Gas Furnace |
| Natural Gas Other (Hydronic) |
| Kerosene Furnace |
| LPG Furnace |
| Distillate Furnace |
| Distillate Other (Hydronic) |
| Wood Stove |
| Electric Ground-Source Heat Pump |
| Natural Gas Heat Pump |

Space Cooling Equipment

| Electric Room Air Conditioner |
| Central Air Conditioner |
| Electric Air-Source Heat Pump |
| Electric Ground-Source Heat Pump |
| Natural Gas Heat Pump |

Water Heaters

| Natural Gas |
| Electric Resistance / Heat Pump |
| Distillate |
| LPG |
| Solar Thermal |

Televisons

| LCD |
| Plasma |
| CRT |
| Projection |

Cookstoves

| Natural Gas |
| LPG |
| Electric |

Clothes Dryers

| Natural Gas |
| Electric |

Refrigerators

| 18 cubic-foot Top Mounted Freezer |
| 24 cubic-foot Side-by-Side with Through-the-Door Features |

Freezers

| Chest Manual Defrost |
| Upright Manual Defrost |

Clothes Washers

| Vertical Axis |
| Horizontal Axis |

Lighting

| Incandescent |
| Compact Fluorescent (CFL) |
| Tubular Fluorescent |
| Solid State/LED |
| Tochiere (halogen, incandescent, CFL) |
| Reflector |

Distributed Generation

| Fuel Cells |
| Solar Photovoltaic |

Appliance Stock Projection

The Appliance Stock Component projects 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	Space Cooling	Dishwashers	Water Heating	Cooking
Clothes Drying	Refrigeration	Freezers	Clothes Washers	Lighting

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 housing is a function of capital and operating costs for several levels of total system efficiency. These include homes that meet the 2006 International Energy Conservation Code (IECC), Energy Star Homes, and homes that include the most efficient building shell components.

Distributed Generation Component

The Distributed Generation Component allows fuel cells, solar photovoltaic and distributed wind turbine systems to 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 projections are constructed as the product of the number of units in the equipment stock and the average technology UEC. The average UEC changes as the composition of the equipment stock changes over time. In each year of the projection the following steps are performed to develop the projection of energy consumption:

1. A projection 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-2006 vintage equipment stock is estimated, accounting for housing demolitions and additions.

Figure 2 Residential Module Structure

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

4. The previous year's equipment additions and replacements for both pre-2006 and post-2005 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, personal disposable income, and household size, if applicable).

Figure 2 Residential Module Structure
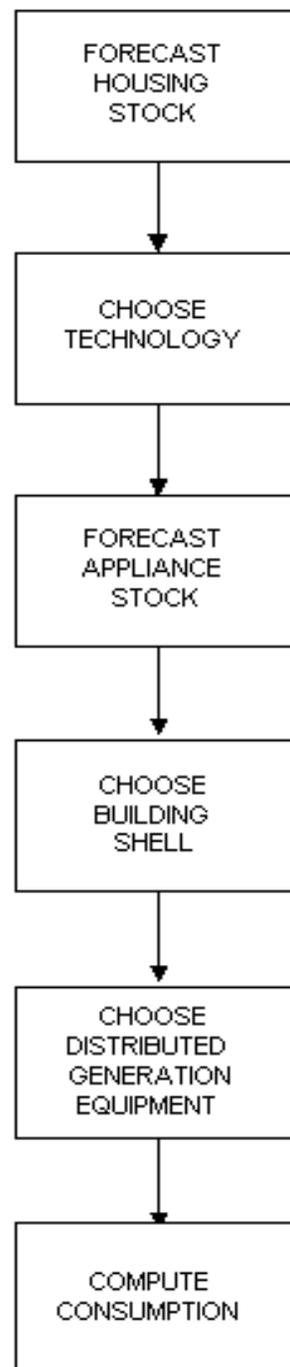
FORTRAN Subroutine Descriptions

The NEMS Residential Sector Demand Module FORTRAN source code consists of more than 50 subroutines sequentially called during the execution of the module. Table 2 lists the major subroutines and their corresponding descriptions. The subroutines can be grouped into the following 13 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 Subroutine

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   projects pre-2006 (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.
2. The base year equipment stock or the pre-2006 vintage stock is the product of the share and the amount of existing housing.

3. Project surviving equipment of the pre-2006 vintage using the equipment survival rate and the housing decay rate for every year in the projection.

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 (2)

The model includes a subroutine identified as **SQFTCALC** to calculate average home floor areas for new and existing houses and compute size and volume effects for new construction, which are estimated by the use of a building simulation model (REM-Design). The subroutine **PITC** calculates the amount of price induced technology change based on fuel prices.

Technology Choice - TEC Subroutines (10)

The code includes ten 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. Calculate efficiencies for new and replacement equipment types weighted by their respective market shares. These subroutines are as follows:

RSHVAC	**RCLTEC**	**RSTVTEC**
RHTRTEC	**RWHTEC**	**RDRYTEC**

RREFTEC	**RFRZTEC**	
	RCWTEC	
	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 eight 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-2005 vintage equipment additions are determined by the share of new (post-2005) houses from the MAM that demand that service.
2. Compute the surviving post-2005 vintage equipment in pre-2006 vintage houses.
3. Compute total equipment required for pre-2006 vintage houses.
4. Compute the equipment replacements in pre-2006 vintage houses by subtracting the sum of surviving pre-2006 vintage equipment and surviving post-2005 vintage equipment in pre-2006 vintage houses from the total equipment demanded for pre-2006 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-2005 vintage equipment that was purchased as either additions or replacements for post-2005 houses.
6. Calculate the current year's replacements of post-2005 vintage equipment in post-2005 houses by subtracting the surviving replacements and equipment additions in post-2005 houses from the stock of surviving post-2005 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:

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

End-use Consumption - CON/CNS Subroutines (15)

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 2005 consumption

    RSBENCH   calibrate consumption to 2005-2009 SEDS/STEO consumption.

Report Subroutines (2)

The following subroutines produce the output reports:

    RESDRP, RESDRP2

Table 2. 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
RDHTRTEC	PROJECT 2005 VINTAGE FOR ALL SERVICES
RDUECS	INITIALIZE EQUIPMENT UECS (SERVICE AGGREGATES)
RCONSFL	RATIONALIZE FUEL NUMBERING AMONG EQUIPMENT TYPES
EXCONS	CALCULATE 2005 CONSUMPTION
RDISTGEN	PROJECT DISTRIBUTED GENERATION PENETRATION
NEWHSE	CALCULATE NEW HOUSING.
SQFTCALC	CALCULATE AVERAGE FLOOR AREA OF HOUSING
RDEFF	READ IN EFFICIENCY OF RETIRING EQUIPMENT FROM 2005 STOCK
RDRET	READ IN PROPORTION OF RETIRING EQUIPMENT FROM 2005 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
RSHVAC	CHOOSE HVAC EQUIPMENT AND SHELL CHARACTERISTICS FOR NEW HOMES
RHTRTEC	CHOOSE HEATING EQUIPMENT AND COMPUTE AVERAGE EFFICIENCIES
RHTRADD	CALCULATE NEW AND REPLACEMENT HEATING EQUIPMENT
RHTRCON	CALCULATE HEATING CONSUMPTION
RCLTEC	CHOOSE AIR-CONDITIONING EQUIPMENT
RCLADD	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 STOCK, EFFICIENCY, AND 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

Appendix A: Model Abstract

Model Name:

NEMS Residential Sector Demand Module

Model Acronym:

RDM (Residential Demand Module)

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 2005 through 2030. The model facilitates policy analysis of energy markets, technological development, and regulatory development.

Most Recent Model Update:

December 2008.

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 and Integration Branch
(202) 586-4815

Documentation:

Model Documentation Report: Residential Sector Demand Model of the National Energy Modeling System, May 2009.

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 2009 (AEO2009).

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, 2005 through 2030 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, color televisions, furnace fans, personal computers, ceiling fans, microwave ovens, spas, DVDs/VCRs, security systems, coffee makers, rechargeable electronics, home audio, 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 distributed generation.
- 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: 2007," 2008.

- New housing characteristics and base year market shares for some services and equipment types.

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 F 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, *Residential Energy Consumption Survey 2005.*

- Base year market shares for services and equipment types.
- Base year housing stock.
- Base year unit energy consumption (UEC).

TIAX LLC, *Commercial and Residential Sector Miscellaneous Electricity Consumption: Y2005 and Projections to 2030*, Prepared for EIA, September 2006.

- Stock and UEC estimates for several miscellaneous electric appliances through 2030.

Navigant Consulting, *EIA – Technology Forecast Updates – Residential and Commercial Buildings Technologies*, Prepared for EIA, September 2007.

- Cost and performance for major appliances through 2030.

Navigant Consulting, *EIA – Technology Forecast Updates – Residential and Commercial Buildings Technologies – Residential and Commercial Lighting, Commercial Refrigeration, and Commercial Ventilation Technologies*, Prepared for EIA, September 2008.

- Cost and performance for lighting through 2030.

The major data input sources are discussed in this Appendix. Appendix F provides additional bibliographic citations of data sources used in the Residential Sector Demand Module.

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. Comprehensive reviews of the model documentation were completed by Robert Trost and Inderjit Kundra, Office of Statistical Methods, in February 2003 and by Robert Trost, Michael Ye, Ramesh Dandekar, and Inderjit Kundra, Office of Statistical Methods, in October 2008.

Status of Evaluation Efforts by Sponsor:

None.

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

- The subscript "y" in the documentation refers to the year represented as 1990 through 2030. In the FORTRAN code, the subscript CURIYR represents array dimensions starting with an index of 1 to represent 1990, and CURCALYR in the calendar year.

- 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 2030.

Table B-1. Definition of Subscripts

Subscript in Documentation	Subscript in the FORTRAN Code	Brief Description
r	r or d	Census Division
t	y or t	Calendar year index
f	f	Fuel types
b	b	Housing type
y	curiyr or curcalyr	the annual index
y-1	curiyr-1 or curcalyr-1	Previous year
eg	eqc, reccl	General equipment class within an end use (e.g., 1 to 11 for heat)
egsw	eqcsw	Equipment class within an end use available to switch to another equipment class
es	eqt	Specific equipment type within an end use
v	v	Vintage of equipment

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
6. Cooking
7. Clothes Drying
8. Food Refrigeration
9. Food Freezing
10. Lighting
11. Furnace Fans
12. Color Televisions
13. Personal Computers
14. Coffee Makers
15. Ceiling Fans
16. Home Audio
17. Security Systems
18. Spas
19. Rechargeable Devices
20. Secondary Heating
21. DVDs/VCRs

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 nine 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 gas cooking equipment). The file RTEKCL (Residential Technology Classes), which is outlined below, defines 31 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 contains 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.TXT: Technology Classes

Within the present structure of the Residential Demand Module, there are 30 defined technology classes. These are listed in Table B-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 nine 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.

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

Table B-2 Major End-Uses and General Equipment Classes

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. Matches *RTTYENDU$_{es}$* in the RTEKTY.TXT file.

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

RTCLEQCL$_{eg}$:   Equipment class number. Appears on all records. Matches *RTTYEQCL*$_{es}$ in the RTEKTY.TXT (technology type) file for one or more equipment types: there are one or more equipment types in RTEKTY.TXT for each class in RTEKCL.TXT.

RTCLTYPT$_{eg}$:   Required pointer from equipment class to a representative equipment type. This is the only pointer from RTEKCL.TXT to RTEKTY.TXT. 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.TXT of the representative equipment.

RTCLPNTR$_{eg}$:   Class pointer. Required for end uses 1, 2, and 5; 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 = 5: 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 5 below; only natural gas water heaters may point to 2 types of cookstoves.

RTCLREPL$_{eg}$:   Replacement class. Required for end use 5; zero otherwise.
   If end use = 5: 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: intensity 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 . 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 . 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.TXT 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.TXT 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.TXT 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. Twenty-one variables, described below, are read from the RTEKTY.TXT file:

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

$RTTYEQCL_{es}$:   Equipment class for this equipment type. MUST match a class number, $RTCLEQCL_{eg}$, in the RTEKCL.TXT 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.TXT 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 first year equipment is purchased (2006); 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 (2030).

RTCENDIV   Pointer to identify the appropriate Census division for the data record.

HVACPT   Pointer to identify the line number from RTEKTY.TXT to RTEKTYC.TXT.

$RTTYPNTR_{es}$:   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 2005

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 capital cost in 2007$ per unit for.

RTRECOST$_{es}$: Retail capital cost in 2007$ per unit (RTEQCOST less installation).

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 $_1$, weights capital cost.

RTECBTA2$_{es}$: Efficiency choice model log-linear parameter $_2$, weights fuel cost.

RTECBTA3$_{es}$: Efficiency choice model log-linear parameter $_3$, 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:

$$SVRTE_{t,L_{min},L_{max}} = 1 \text{ ,if } t < L_{min}$$
$$SVRTE_{t,L_{min},L_{max}} = 0 \text{ ,if } t > L_{max}$$
$$SVRTE_{t,L_{min},L_{max}} = 1 - \frac{t - L_{min}}{L_{max} - L_{min}} \text{ ,otherwise}$$

(B-1)

where,

$SVRTE_{y\text{-}t,L_{min},L_{max}}$ 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.
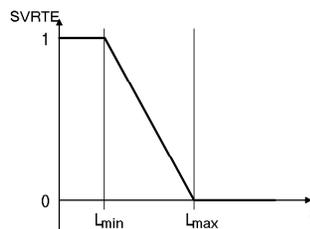
Note that function calls to SVRTE in the FORTRAN code include a "place holder" as the first parameter. However, the first parameter is currently not used in the calculations. Since it is not used

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: $HDR_2 = 0.999$

Mobile Homes: $HDR_3 = 0.976$

The surviving pre-2006 housing stock is defined by:

$$
EH_{y,b,r} = RECS\ data\ ,if\ y = 2005
$$
$$
EH_{y,b,r} = EH_{y-1,b,r} * HDR_b\ ,if\ y > 2005
$$

(B-2)

where,

$EH_{y,b,r}$ is the pre-2006 housing stock surviving in year y,

HDR_b is the housing demolition rate, from the RMISC.TXT 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:

$$
NH_{y,r} = MC\_HUSPS1_{y,r} + MC\_HUSPS2A_{y,r}
$$
$$
+ MC\_HUSMFG_{y,r}
$$

(B-3)

where,

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

$MC\_HUSPS1_{y,r}$ is single-family housing added by year and Census Division,

$MC\_HUSPS2A_{y,r}$ is multifamily housing added by year and Census Division,

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

RDSQFT (Read Floor Areas)

Read the historical and forecast data for average household area, SQRFOOT$_{y,b,r}$ from the RSSQRFT.TXT file, and calculate the ratios, SQFTADJ$_{y,b,r}$, between each area and the base year area, SQRFOOT$_{2005,b,r}$.

SQFTCALC (Calculate Average Floor Area Component)

First aggregate the housing stock to the national level,

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

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

where,

OLDHSES$_y$ is the national total of remaining pre-2006 housing.

NEWHSES$_y$ is the national total of remaining post-2005 housing additions.

SQFTCALC (Calculate Average Floor Area Component)

To calculate the average floor areas of homes in a given year,

$$SQFTAVG_{2005} = \frac{\sum_{b,r} \left(SQRFOOT_{2005,b,r} * EH_{2005,b,r} \right)}{OLDHSES_{2005}} \tag{B-6}$$

$$SQFTAVG_y =$$

$$\frac{\sum_{b,r}\left(SQRFOOT_{2005,b,r} * EH_{2005,b,r} + SQRFOOT_{y,b,r} * NH_{y,b,r}\right)}{OLDHSES_{2005} + NWHSES_y} \qquad \text{(B-7)}$$

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.TXT file, by year, housing type and Census Division.

RDHTREQC (Project 2005 Vintage Equipment for all End-Use Services)

This routine reads in the 2005 equipment stock for all services from external files, and then calculates surviving equipment in the pre-2006 housing stock for 2006 through the end of the forecast.

For y > 2005,

$$EQCESE_{y,eg,b,r} = EQCESE_{2005,eg,b,r} * HDR_b{}^{y-2005} * EQCRET_{y,eg} \qquad \text{(B-8)}$$

where,

$EQCESE_{y,eg,b,r}$ is the amount of surviving pre-2006 vintage equipment in pre-2006 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.TXT.

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 ten 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, home audio, furnace fans, ceiling fans, coffee makers, microwave ovens, spas, security systems, and rechargeable devices are modeled differently from the major services listed above.

New equipment operating costs are computed by the expression,

$$OPCOST_{y,es,b,r,v} = PRICES_{f,r,y} * EQCUEC_{y,eg,b} * HDDFACT_{r,y}$$
$$* RTEFFAC_{eg,v} * HSHELL_{y-1,r,v}$$

(B-9)

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 price 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,

$RTEFFAC_{eg,v}$ is the efficiency adjustment for the general equipment class and vintage, and,

$HSHELL_{y-1,r,v}$ is the shell efficiency adjustment to account for building shell improvements over time (which reduce heating loads).

For newly constructed homes, operating cost is a function of both the heating and cooling operating costs, with the shell efficiency also accounted for as shown:

$$
\begin{aligned}
OPCOST_{y,es,b,r,hvac} &= PRICES_{f,r,y} * EQCUEC_{y,heating,b} * HDDFACT_{r,y} \\
&* RTEFFAC_{heating,v} * HTSHELL_{eg,r,b} + PRICES_{f,r,y} * EQCUEC_{y,cooling,b} \\
&* CDDFACT_{r,y} * RTEFFAC_{cooling,v} * CLSHELL_{eg,r,b}
\end{aligned}
$$
(B-10)

where,

$HTSHELL_{eg,r,b}$ is the heating shell efficiency factor for the HVAC system,

$CDDFACT_{r,y}$ is the cooling degree-day adjustment, and

$CLSHELL_{eg,r,b}$ is the cooling shell efficiency factor for the HVAC system.

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:

$$
\begin{aligned}
EQCOST_{es,y,CAP} &= RTEQCOST_{es} \text{ , if } RTMATURE_{es} = MATURE \\
EQCOST_{es,y,RET} &= RTRECOST_{es} \text{ , if } RTMATURE_{es} = MATURE
\end{aligned}
$$
(B-11)

$$EQCOST_{es,y,CAP} = \frac{RTEQCOST_{es} * 2 * d}{1 + \left(\dfrac{y - y_1}{y_0 - y_1}\right)^y} + (1 - d) * RTEQCOST_{es},$$

$$if\ RTMATURE_{es} = ADOLESCENT$$

$$EQCOST_{es,y,RET} = \frac{RTRECOST_{es} * 2 * d}{1 + \left(\dfrac{y - y_1}{y_0 - y_1}\right)^y} + (1 - d) * RTRECOST_{es},$$

$$if\ RTMATURE_{es} = ADOLESCENT$$

(B-12)

$$EQCOST_{es,y,CAP} = \frac{RTEQCOST_{es} * d}{1 + \left(\dfrac{y - y_1}{y_0 - y_1}\right)^y} + (1 - d) * RTEQCOST_{es},$$

$$if\ RTMATURE_{es} = INFANT$$

$$EQCOST_{es,y,RET} = \frac{RTRECOST_{es} * d}{1 + \left(\dfrac{y - y_1}{y_0 - y_1}\right)^y} + (1 - d) * RTRECOST_{es},$$

$$if\ RTMATURE_{es} = INFANT$$

(B-13)

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 2007$ per unit for new homes, remains constant for MATURE technologies only (used when ctype = CAP),

RTRECOST$_{es}$ Retail capital cost in 2007$ 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,

is the logistic curve shape parameter, RTCOSTP2$_{es}$.

For newly constructed homes, the costs shown above also include the cooling system and shell efficiency measures.

The concept of price induced technology change is also 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 2005:

$$PRICE\Delta_{y,f} = \frac{.334 * \left(PRICE_{y,f} + PRICE_{y-1,f} + PRICE_{y-2,f}\right)}{PRICE_{2005}}$$ (B-14)

Under a "persistent" doubling of energy prices (defined in the models as three consecutive years, as noted in (B-14) 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 2006). Shifts from 0 to 10 years are allowed in the current model formulations. For nearer term technologies

technologies (e.g., 2005 projections) shifts are limited to a lesser 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:

$$SHIFTYEARS_t = \frac{\left(PRICE\Delta_{y,f} - 1.0\right)}{0.10}$$ (B-15)

subject to the constraints listed above. The technology data presented in equations (B-11) to (B-13) are adjusted according to the results obtained in equation (B-14).

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

$$LFCY_{y,es,b,r,v} = CAPITAL_{es} + OPCOST_{y,es,b,r,v}$$
$$* \left(\frac{1 - \left(1 + DISRT\right)^{-HORIZON}}{DISRT}\right)$$ (B-16)

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,

$$HEATSYS_{y,eg,b,r} = (1 - LAGFACTOR) * HEATSYS_{y-1,eg,b,r} +$$
$$LAGFACTOR * EXP^{(RFTBIAS_{y,eg} + RFTCBETA_{eg} * LFCY_{y,eg,b,r,v})}$$

(B-17)

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,
$LAGFACTOR$	is the weight given to the prior year's heating system share,
$RTFCBIAS_{y,eg}$	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:

$$SYSTOT_{y,b,r} = \sum_{eg=1}^{eg=11} HEATSYS_{y,eg,b,r}$$

(B-18)

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

$$HTYSSHR_{y,eg,b,r} = \frac{HEATSYS_{y,eg,b,r}}{SYSTOT_{y,b,r}}, if \ SYSTOT_{y,b,r} > 0$$

$$HTYSSHR_{y,eg,b,r} = 0, otherwise$$

(B-19)

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,

$$EQWTN_{y,es,b,r} = EXP^{\left(RTECBTA1_{es}*CAPITAL_{es} + RTECBTA2_{es}*OPCOST_{y,es,b,r,1} \right)}$$

(B-20)

$$EQWTR_{y,es,b,r} = EXP^{\left(RTECBTA1_{es}*CAPITAL_{es} + RTECBTA2_{es}*OPCOST_{y,es,b,r,2} \right)}$$

(B-21)

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 (1=new, 2=existing)

      $RTECBTA1_{es}$,   are parameter values of the same fit.
      $RTECBTA2_{es}$

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

$$TOTEWTN_{y,eg,b,r} = \sum_{es=loweff}^{es=hieff} EQWTN_{y,es,b,r}$$

(B-22)

$$TOTEWTR_{y,eg,b,r} = \sum_{es=loweff}^{es=hieff} EQWTR_{y,es,b,r} \qquad (\text{B-23})$$

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

$$EQFSHRN_{y,es,b,r} = \frac{EQWTN_{y,es,b,r}}{TOTEWTN_{y,eg,b,r}}, if\ TOTEWTN_{y,eg,b,r} > 0$$

$$EQFSHRN_{y,es,b,r} = 0,\ otherwise \qquad (\text{B-24})$$

$$EQFSHRR_{y,es,b,r} = \frac{EQWTR_{y,es,b,r}}{TOTEWTR_{y,eg,b,r}}, if\ TOTEWTR_{y,eg,b,r} > 0$$

$$EQFSHRR_{y,es,b,r} = 0,\ otherwise \qquad (\text{B-25})$$

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,

$$NEQTSHR_{y,es,b,r} = EQFSHRN_{y,es,b,r} \qquad (\text{B-26})$$

$$REQTSHR_{y,es,b,r} = EQFSHRR_{y,es,b,r} \qquad\qquad\qquad\text{(B-27)}$$

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,

$$WTEQCEFFN_{y,eg,b,r} = \frac{\sum\limits_{es}\left[\dfrac{NEQTSHR_{y,es,b,r}}{RTEQEFF_{y,es}}\right]}{\sum\limits_{es} NEQTSHR_{y,es,b,r}}, if \sum\limits_{es} NEQTSHR_{y,es,b,r} > 0 \qquad\text{(B-28)}$$

$$WTEQCEFFN_{y,eg,b,r} = \frac{1}{RTBASEFF_{eg}}, otherwise$$

$$WTEQCEFFR_{y,eg,b,r} = \frac{\sum\limits_{es}\left[\dfrac{REQTSHR_{y,es,b,r}}{RTEQEFF_{y,es}}\right]}{\sum\limits_{es} REQTSHR_{y,es,b,r}}, if \sum\limits_{es} REQTSHR_{y,es,b,r} > 0 \qquad\text{(B-29)}$$

$$WTEQCEFFR_{y,eg,b,r} = \frac{1}{RTBASEFF_{eg}}, otherwise$$

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,

        RTEQEFF$_{y,es}$ is the efficiency of the equipment type,

        RTBASEFF$_{eg}$ is the 2005 stock-average efficiency of the equipment class, and

        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 B-3 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 2006 (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 seven categories of equipment that are tracked.

Table B-3. Heating Equipment, UEC and Housing Shell Accounting Scheme

Housing Units that Existed in 2005			Housing Units Added From 2006 through 2030		
Equipment	UEC	Shell	Equipment	UEC	Shell
EQCRP90RP	EQCNUEC	EHSHELL			
EQCRP90	EQCRUEC	EHSHELL			
EQCSR90	EQCAUEC	EHSHELL			
			EQCADD	EQCHVUEC	NHSHELL
			EQCREP	EQCNUEC	AHSHELL
EQCESE	EQCSUEC	EHSHELL	EQCSUR	EQCAUEC	AHSHELL

The equipment categories for pre-2006 housing units are:

EQCESE denotes the surviving pre-2006 equipment stock in pre-2006 homes,

EQCSR90 represents equipment stock in pre-2006 homes that has been replaced after 2005
and that still survives, and

EQCRP90 is current-year replacement equipment for pre-2006 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-2005 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 2005 equipment in housing units that existed in 2005,

EQCSUEC is the average UEC for surviving equipment in pre-2006 housing units,

EQCAUEC is the average UEC for surviving equipment in post-2006 housing units,

EQCHVUEC is the UEC for heating and cooling equipment in new construction,

EQCRUEC is the UEC for all equipment added in the current year to replace pre-2006 equipment, and

EQCNUEC is the UEC for all equipment added in the current year to replace post-2005 equipment.

Shell indices are modeled for three categories of housing units:

EHSHELL is the shell index applicable to pre-2006 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-2006 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-2006 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,

$$
\begin{aligned}
SVRTE_{y-t,L_{min},L_{max}} &= 1.0 \\
SVRTE_{y-t,L_{min},L_{max}} &= \frac{L_{max}-(y-t)}{L_{max}-L_{min}}, if\ L_{min} < y-t < L_{max} \\
SVRTE_{y-t,L_{min},L_{max}} &= 0.0, if\ y-t \geq L_{max}
\end{aligned}
\tag{B-30}
$$

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-2005 (new) houses is the product of the number of new houses and the market share of each equipment class. This is expressed as,

$$
EQCADD_{y,t,eg,b,r} = HSEADD_{y,b,r} * SHARESN_{y,eg,b,r}
\tag{B-31}
$$

where,

$EQCADD_{y,t,eg,b,r}$	is the number of post-2005 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-2005 equipment units in post-2005 houses is calculated

calculated as:

$$EQCREP_{y,t,eg,b,r} = \sum_{t=2006}^{t=y-1}\left(EQCADD_{t,eg,b,r} * HDR_b{}^{y-t} * \left(1 - SVRTE_{eg}\right)\right) \qquad \text{(B-32)}$$

where,

    $EQCREP_{y,t,eg,b,r}$ is the number of equipment replacements of post-2005 equipment in post-2005 houses,

    HDR_b is the housing survival rate by housing type, and

    y-t   represents the age of the equipment.

Post-2005 replacement units required for pre-2006 houses in the current year are calculated as,

$$EQCRP90_{y,t,eg,b,r} = EQCESE_{2005,eg,b,r} * EQCRET_{y,eg} * HDR_b \qquad \text{(B-33)}$$

where,

    $EQCRP90_{y,t,eg,b,r}$ is the number of replacement units required for pre-2006 homes in year *y*, vintaged to year *t* by housing type and Census Division,

    $EQCRET_{y,eg}$ is the equipment retirement rate for pre-2006 houses by forecast year,

    $EQCESE_{2005,eg,b,r}$ is the pre-2006 vintage stock of equipment in pre-2006 vintage houses in 2005 by housing type and Census Division.

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

$$EQCRP90RP_{y,t,eg,b,r} = \sum_{t=2006}^{t=y-1}\left(EQCRP90_{t,eg,b,r} + EQCRP90RP_{y,t,eg,b,r}\right) \\ * \left(1 - SVRTE_{eg}\right) \qquad \text{(B-34)}$$

where,

    $EQCRP90RP_{y,t,eg,b,r}$ is the number of replacement units required to replace post-2005

equipment in pre-2006 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).

$$ELIGIBLE_{y,eg,b,r} = \sum_{eg} \left(\begin{array}{c} EQCRP90_{y,t,eg,b,r} + EQCRP90RP_{y,t,eg,b,r} \\ + EQCREP_{y,t,eg,b,r} \end{array} \right) * \left(SWFACT_{eg} \right) \quad \text{(B-35)}$$

where,

$ELIGIBLE_{y,eg,b,r}$ is the number of replacements eligible to switch technology types by housing type and Census Division, and

$SWFACT_{eg}$ is the fraction who may switch from equipment class eg.

The "switching" weight for each equipment type is calculated as,

$$RPWEIGHT_{y,egsw,b,r} =$$
$$EXP^{\left(RTSWBIAS_{egsw} + RTSWBETA_{egsw} * \left(LFCY_{y,eqsw,b,r,v} + RPINSCOST_{eg,egsw} \right) \right)} \quad \text{(B-36)}$$

Summing over all equipment types,

$$TOTSH_{y,b,r} = \sum_{egsw=1}^{egsw=11} RPWEIGHT_{y,egsw,b,r} \quad \text{(B-37)}$$

allows for shares summing to 100 percent.

$$RPSHARE_{y,egsw,b,r} = \frac{RPWEIGHT_{y,egsw,b,r}}{TOTSH_{y,b,r}}, if \ TOTSH_{y,b,r} > 0$$

$$RPSHARE_{y,egsw,b,r} = 0, otherwise$$

(B-38)

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 weights.

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

The surviving post-2005 vintage equipment in pre-2006 houses is computed as,

$$EQCSR90_{y,t,eg,b,r} = \sum_{t=2006}^{t=y-1} \begin{pmatrix} \left(EQCRP90_{t,y,eg,b,r} + EQCRP90RP_{t,y,eg,b,r} \right) \\ * SVRTE_{eg,y-t,L_{min},L_{max}} * HDR_b^{y-t} \end{pmatrix}$$

(B-39)

where,

$EQCSR90_{y,eg,b,r}$	is the equipment stock in pre-2006 homes that has been replaced after 2005 and still survives by housing type and Census Division,
$EQCRP90_{t,y,eg,b,r}$	is the number of replacement (post-2005 vintage) equipment units demanded each year in pre-2006 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$_{eg,y-t,Lmin,Lmax}$ 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-2005 equipment, originally purchased as additions or replacements in post-2005 houses, is calculated as,

$$EQCSUR_{y,eg,b,r} = \sum_{t=2006}^{t=y-1} \left(\frac{(EQCADD_{t,eg,b,r} + EQCREP_{t,eg,b,r})}{* SVRTE_{eg,y-t,L_{min},L_{max}} * HDR_b^{y-t}} \right)$$

(B-40)

where,

EQCSUR$_{y,eg,b,r}$ is the surviving post-2005 equipment purchased as additions or replacements in post-2005 houses by housing type and Census Division,

EQCADD$_{t,eg,b,r}$ is the quantity of post-2005 vintage equipment added to post-2005 houses by forecast year, housing type and Census Division,

SVRTE$_{eg,y-t,Lmin,Lmax}$ is the equipment survival function,

EQCREP$_{t,eg,b,r}$ is the number of equipment replacements of post-2005 equipment in post-2005 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-2006 housing stock, and two indices correspond to the post-2005 stock, one for housing constructed in the current year and the other for the average post-2005 stock. The existing shell index is adjusted each year to account for fuel price increases (decreases have no effect on shell integrity, i.e., shell efficiency

efficiency increases as price increases) and technology improvements. The shell index for newly-constructed homes is based on the choice of HVAC system, which includes the shell characteristics represented as an index, incorporating the size of the structure into the index as well. As the physical size of structures increases, the index will increase in value, while an increase in energy efficiency decreases the value of the index.

The existing housing heating shell index is calculated as,

$$
\begin{aligned}
& EHSHELL_{y,f,r,b} = EHSHELL_{y-1,f,r,b}, if\ EHSHELL_{y,f,r,b} > EHSHELL_{y-1,f,r,b} \\
& EHSHELL_{y,f,r,b} = LIMIT, if\ EHSHELL_{y,f,r,b} > LIMIT \\
& EHSHELL_{y,f,r,b} = EHSHELL_{RECSYEAR f,r,b} * RSELAST_{y,f,r,alpha2,ef1,ef2,ef3,RECSYEAR} \\
& * TECHG_{e,r,b}, otherwise
\end{aligned}
\tag{B-41}
$$

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

 TECHG$_{1,d,b}$ is a parameter that represents the annual increase in existing shell integrity due to technology improvements, and

 RSELAST   is the short-term price elasticity function with distributed lag weights EF1, EF2, and EF3, and , the total short-term price elasticity.

The new housing heating shell index is calculated as,

$$
NHSHELL_{y,f,r,b} = \sum_{t=2006}^{t=y-1} \left(EQFSHRN_{y,es,b,r} * SHELLEFF_{y,es,b,r} \right)
\tag{B-42}
$$

where,

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

SHELLEFF$_{y,es,b,r}$ is the shell integrity factor associated with each HVAC package available.

The average post-2005 housing heating shell index is calculated as,

$$AHSHELL_{y,f,r,b} = \frac{\sum_{eg}\left[\begin{array}{c} NHSHELL_{y,r,r,b} * EQCADD_{y,eg,b,r} + AHSHELL_{y-1,f,r,b} \\ * \left(EQCREP_{y,eg,b,r} + EQCSUR_{y,eg,b,r}\right) \end{array}\right]}{\sum_{eg}\left[EQCADD_{y,eg,b,r} + EQCREP_{y,eg,b,r} + EQCSUR_{y,eg,b,r}\right]} \quad \text{(B-43)}$$

where,

AHSHELL$_{y,f,r,b}$ is the average post-2005 heating shell index by year, fuel, Census Division, and building type, equal to NHSHELL in 2006,

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-2005 equipment in post-2005 houses, and

EQCSUR$_{y,eg,b,r}$ is the surviving post-2005 equipment purchased as additions or replacement in post-2005 houses by forecast year, housing type and Census Division.

In addition to the calculation shown above, the module places two additional restrictions upon AHSHELL$_{y,f,r,b}$: it may never increase, and it must not fall below LIMIT. If ever AHSHELL$_{y,r,r,b}$ 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

equipment UEC values are calculated as:

$$EQCNUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * WTEQCEFFN_{y,eg,b,r}$$
$$* RTBASEFF_{2005,eg} * HDDFACT_{y,r} * SQFTADJ_{y,b,r}$$

(B-44)

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,
$RTBASEFF_{2005,eg}$	is the 2005 stock-average efficiency of the equipment class,
$EQCUEC_{r,eg,b}$	is unit energy consumption for original 2005 stock of the equipment class by Census Division and housing type,
$HDDFACT_{y,r}$	is the heating degree day adjustment factor by Census Division to correct to normal weather relative to 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:

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * WTEQCEFFR_{y,eg,b,r}$$
$$* RTBASEFF_{2005,eg} * HDDFACT_{y,r}$$

(B-45)

where,

$EQCRUEC_{y,eg,b,r}$	is the unit energy consumption for replacement equipment by housing type and Census Division,
$RTBASEFF_{2005,eg}$	is the efficiency of the weighted average of retiring units from the 2005 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:

$$EQCSUEC_{r,eg,b,r} = EQCUEC_{r,eg,b} * HDDFACT_{y,r} * \frac{RTBASEFF_{2005,eg}}{RTBASEFF_{y,eg}}$$ (B-46)

where,

$EQCSUEC_{y,eg,b,r}$ is the average unit energy consumption of the original 2005 equipment stock that remains after the replacements have taken place.

The average UEC for all equipment is calculated as:

$$EQCAUEC_{y,eg,b,r} = EQCNUEC_{y,eg,b,r}, \text{ if } y = 2006$$

$$EQCAUEC_{y,eg,b,r} = \frac{\begin{pmatrix} (EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + \\ EQCRP90RP_{y,eg,b,r}) * EQCNUEC_{y,eg,b,r} \\ + (EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r}) \\ * EQCAUEC_{y-1,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \end{pmatrix}}{\begin{pmatrix} EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} + EQCSR90_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} + EQCRP90_{y,eg,b,r} \end{pmatrix}},$$ (B-47)

     otherwise

where:

$EQCAUEC_{y,eg,b,r}$ is the average unit energy consumption for all post-2005 equipment
categories.

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,

$$HTRCON_{y=2006,f,r} =$$

$$\sum_b \sum_{eg} \left[\begin{pmatrix} EQCESE_{y,eg,b,r} * ECQCUEC_{eg,b,r} * EHSHELL_{y,f,r,b} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * NHSHELL_{y,f,r,b} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} * EHSHELL_{y,f,r,b} \end{pmatrix} \\ * RSELAST(f,r,\alpha,EF1,EF2,EF3,2005) \right]$$

(B-48)

and subsequent consumption as,

$$HTRCON_{y,f,r} =$$

$$\sum_b \sum_{eg} \left[\begin{pmatrix} EQCESE_{y,eg,b,r} * ECQCUEC_{eg,b,r} * EHSHELL_{y,f,r,b} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * NHSHELL_{y,f,r,b} * RBN_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} * EHSHELL_{y,f,r,b} * RBR_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * EHSHELL_{y,f,r,b} * RBN_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} * EHSHELL_{y,f,r,b} * RBA_{y,eg,b,r} \\ + EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * AHSHELL_{y,f,r,b} * RBN_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} * AHSHELL_{y,f,r,b} * RBA_{y,eg,b,r} \end{pmatrix} \\ * RSELAST(f,r,\alpha,EF1,EF2,EF3,2005) \right]$$

(B-49)

where,

HTRCON$_{y,f,r}$ is heating energy consumption by year, fuel type, and region,

RSELAST is the short-term price elasticity function with distributed lag weights EF1, EF2, and EF3, and , the total short-term price elasticity, and

the "rebound effect" associated with increasing equipment efficiency for a particular equipment class causes a corresponding change in the price elasticity for the class are represented as:

$$RBN_{r,eg,b,r} = WTEQCEFFN_{y,eg,b,r} * RTBASEFF_{2005,eg}^{\alpha_1} \qquad \text{(B-50)}$$

$$RBR_{r,eg,b,r} = WTEQCEFFR_{y,eg,b,r} * RTBASEFF_{2005,eg}^{\alpha_1} \qquad \text{(B-51)}$$

$$RBA_{r,eg,b,r} = WTEQCEFFA_{y,eg,b,r} * RTBASEFF_{2005,eg}^{\alpha_1} \qquad \text{(B-52)}$$

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.

$_1$ is the rebound effect elasticity, presently valued at -0.15.

Consumption by furnace fans and boiler pumps, 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,

$$CDDFACT_r = \left(\frac{CDDADJ_{y,r}}{CDDADJ_{2005,r}} \right)^{1.75} \tag{B-53}$$

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 from the RMISC file.

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

$$OPCOST_{y,es,b,r,v} = PRICES_{f,r,y} * EQCUEC_{y,eg,b} * $$
$$CDDFACT_{r,y} * RTEFFAC_{eg,v} * CSHELL_{y-1,r,v} \tag{B-54}$$

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 2005 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 (B-16) 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 (B-20) 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 (B-21) above.

$TOTEWTN_{y,eg,b,r}$ is the sum of equipment types' weights for the new equipment class. It is computed as in (B-22) above.

$TOTEWTR_{y,eg,b,r}$ is the sum of equipment types' weights for the replacement equipment class. It is computed as in (B-23) 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,

$$NEQTSHR_{y,es,b,r} = NEQTSHR_{y,RTTYPNTR_{es},b,r}$$
$$REQTSHR_{y,es,b,r} = REQTSHR_{y,RTTYPNTR_{es},b,r}$$

(B-55)

and for other cooling equipment,

$$NEQTSHR_{y,es,b,r} = \frac{EQWTN_{y,es,b,r}}{TOTEWTN_{y,eg,b,r}}$$

(B-56)

$$REQTSHR_{y,es,b,r} = \frac{EQWTR_{y,es,b,r}}{TOTEWTR_{y,eg,b,r}}$$

(B-57)

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 (B-28).

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

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:

$$EQCADD_{y,t,CAC,b,r} = HSEADD_{y,b,r} * CACSAT_{b,r} \qquad \text{(B-58)}$$

where,

$EQCADD_{y,t,CAC,b,r}$ is the number of central air conditioners added to new (post-2005) 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:

$$EQCADD_{y,t,RAC,b,r} = HSEADD_{y,b,r} * RACSAT_{b,r} \qquad \text{(B-59)}$$

where,

$EQCADD_{y,t,RAC,b,r}$ is the number of room air conditioners added to new (post-2005) 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:

$$EQCADD_{y,t,HP,b,r} = EQCADD_{y,t,RTCLPNTR_{eg}b,r} \qquad \text{(B-60)}$$

where,

$EQCADD_{y,t,eg,b,r}$ is the number of heat pumps used for space cooling added to new (post-2005) 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 (60) 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:

$$EQCADD_{y,t,CAC,b,r} = EQCADD_{y,t,CAC,b,r} - EQCADD_{y,e,HP,b,r} \qquad \text{(B-61)}$$

where,

    $EQCADD_{y,t,eg,b,r}$ is the number of central air conditioners in each equipment class added to new (post-2005) housing units by year, housing type and Census Division,

    eg   is the space cooling equipment class where the RTEKCL file defines that 1=Room air conditioner, 2=Central air conditioner, 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 (B-39) above. For heat pumps, the stock is equated to that calculated in the space heating subroutines:

$$EQCSR90_{y,eg,b,r} = EQCSR90_{y,RTCLPNTR\ eg,b,r} \qquad \text{(B-62)}$$

where,

    $EQCSR90_{y,eg,b,r}$ is the surviving post-2005 cooling equipment in pre-2006 housing units by year, housing type and Census Division, equated to the stock calculated in the space heating subroutines, and

    RTCLPNTR   is a FORTRAN pointer that maps the heat pump stock from the heating subroutine into the correct heat pump stock in the cooling subroutine.

For centrally air-conditioned single-family houses, there is a penetration rate that describes new units added in pre-2006 houses:

$$EQCND90_{y,eg,b,r} = EQCND90_{y,eg,b,r} * CACPR_r * HDR_b \qquad \text{(B-63)}$$

where,

    $EQCND90_{y,eg,b,r}$ is the number of air conditioning units needed in pre-2006 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, EQCREP, EQCRP90, and EQCRP90RP are computed as in (B-34), (B-35), and (B-334) respectively. The surviving new additions, EQCSUR is computed as in (B-40) above.

Since replacements for heat pumps in the cooling end use equal replacements for heat pumps in the heating end use, and switching was allowed on replacement of heat pump furnaces, switching on replacement of heat pumps in the cooling end use 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 (B-54) above.

Unit energy consumption is calculated for each of the vintages of homes. For surviving equipment in pre-2006 vintage homes,

$$EQCSUEC_{r,eg,b,r} = EQCUEC_{r,eg,b} * CDDFACT_{y,r} * \frac{RTBASEFF_{2005,eg}}{RTBASEFF_{y,eg}} \qquad \text{(B-64)}$$

where,

$EQCSUEC_{y,eg,b,r}$ is the unit energy efficiency of surviving equipment in pre-2006 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 2005, 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:

$$EQCNUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * WTEQCEFFN_{y,eg,b,r}$$
$$* RTBASEFF_{2005,eg} * CDDFACT_{y,r} * SQFTADJ_{y,b,r} \qquad \text{(B-65)}$$

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 2005 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:

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * WTEQCEFFR_{y,eg,b,r}$$
$$* RTBASEFF_{2005,eg} * CDDFACT_{y,r} \qquad \text{(B-66)}$$

where,

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

$RTBASEFF_{2005,eg}$ is the efficiency of the weighted average of retiring units from the 2005

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 (B-48) above.

Cooling shell efficiency is calculated similarly to heating shell efficiency computed in equations (B-41) through (B-44).

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,

$$COOLCN_{y=2006,f,r} =$$

$$\sum_{b}\sum_{eg}\left[\begin{pmatrix} EQCESE_{y,eg,b,r} * ECQCUEC_{eg,b,r} * ECSHELL_{y,r,b} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * NCSHELL_{y,r,b} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} * ECSHELL_{y,r,b} \end{pmatrix} \\ * RSELAST(f,r,\alpha,EF1,EF2,EF3,2005) \right] \qquad \text{(B-67)}$$

and subsequent consumption as,

$$COOLCN_{y,f,r} =$$

$$\sum_{b}\sum_{eg}\left[\begin{pmatrix} EQCESE_{y,eg,b,r} * ECQCUEC_{eg,b,r} * ECSHELL_{y,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * NCSHELL_{y,r,b} * RBN_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} * ECSHELL_{y,r,b} * RBR_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * ECSHELL_{y,r,b} * RBN_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} * ECSHELL_{y,r,b} * RBA_{y,eg,b,r} \\ + EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * ACSHELL_{y,r,b} * RBN_{y,eg,b,r} \\ + EQCSUR\cdot\cdot_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} * ACSHELL_{y,r,b} * RBA_{y,eg,b,r} \end{pmatrix} \\ * RSELAST(f,r,\alpha,EF1,EF2,EF3,2005) \right] \qquad \text{(B-68)}$$

where,

RSELAST   is the short-term price elasticity function with distributed lag weights EF1, EF2, and EF3, and   , the total short-term price elasticity.

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 (B-51) through (B-53).

Clothes Washers

RCWTEC (Clothes Washer Technology Choice Component)
Compute current year operating costs,

$$OPCOST_{y,es,b,r,v} = PRICES_{f,r,y} * EQCUEC_{y,eg,b} * \frac{RTBASEFF_{2005,eg}}{RTEQCEFF_{es}} \qquad \text{(B-69)}$$

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,

$RTBASEFF_{2005,eg}$ is the 2005 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 (B-16) 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 (B-20) 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 (B-21) above.

$TOTEWTN_{y,eg,b,r}$ is the sum of equipment weights for the new equipment class. It is computed as in (B-22) above.

$TOTEWTR_{y,eg,b,r}$ is the sum of equipment weights for the replacement equipment class. It is computed as in (B-23) above.

Market shares for new and replacement clothes washers are next:

$$NEQTSHR_{y,es,b,r} = \frac{EQWT_{y,es,b,r}}{TOTEWT_{y,eg,b,r}} \qquad \text{(B-70)}$$

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:

$$TEMP = \sum_{es} EQWT_{y,es,b,r}$$

$$NCWLOAD_{y,eg,b,r} = \frac{\sum_{es} \left(EQWT_{y,es,b,r} * LOADADJ_{es} \right)}{TEMP}, \quad if\ TEMP > 0 \qquad \text{(B-71)}$$

$$NCWLOAD_{y,eg,b,r} = NCWLOAD_{y-1,eg,b,r}\ , otherwise$$

where,

$NCWLOAD_{y,eg,b,r}$ 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,

$EQWT_{y,es,b,r}$ 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

$$EQCADD_{y,t,eg,b,r} = HSEADD_{y,b,r} * \frac{WASHNEW_{b,r}}{100} \qquad \text{(B-72)}$$

where,

$EQCADD_{y,t,eg,b,r}$ is the amount of new (post-2005 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

$WASHNEW_{b,r}$ 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 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-2005 vintage equipment in pre-2006 housing units in the current year by housing type and Census Division. It is computed as in (B-39) above.

$EQCSUR_{y,eg,b,r}$ is the surviving new (post-2005 vintage) equipment in the current year by housing type and Census Division. It is computed as in (B-40) above.

$EQCREP_{y,t,eg,b,r}$ is the number of replacement units (post-2005 vintage) equipment demanded in post-2005 vintage housing units by housing type and Census Division. It is computed as in (B-33) above.

$EQCRP90_{y,t,eg,b,r}$ is the number of replacement units demanded in pre-2006 housing units each year by housing type and Census Division. It is computed as in (B-34) 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 (B-35) 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 (B-45) through (B-48). Namely,

$EQCSUEC_{y,eg,b,r}$ is the UEC for surviving 2005 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:

$$CSWCON_{y=2006,r} = \sum_{b,eg} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \end{pmatrix}$$ (B-73)

$$CSWCON_{y,r} =$$

$$\sum_{b,eg} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \\ + EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \end{pmatrix}, \quad if \ y > 2006$$ (B-74)

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 (B-69) 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 (B-16) 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 (B-20) 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 (B-21) above.

$TOTEWTN_{y,eg,b,r}$ is the sum of equipment weights for the new equipment class. It is computed as in (B-22) above.

$TOTEWTR_{y,eg,b,r}$ is the sum of equipment weights for the replacement equipment class. It is computed as in (B-23) above.

Market shares for new and replacement dishwashers are next:
where,

$$NEQTSHR_{y,es,b,r} = \frac{EQTWT_{y,es,b,r}}{TOTEWT_{y,eg,b,r}} \tag{B-75}$$

$NEQTSHR_{y,es,b,r}$ 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

$$EQCADD_{y,t,eg,b,r} = HSEADD_{y,b,r} * DISHNEW_{b,r} \qquad \text{(B-76)}$$

where,

$EQCADD_{y,t,eg,b,r}$ is the amount of new (post-2005 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

$DISHNEW_{b,r}$ is the share of dishwashers 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-2005 vintage equipment in pre-2006 housing units in the current year by housing type and Census Division. It is computed as in (B-39) above.

$EQCSUR_{y,eg,b,r}$ is the surviving new (post-2005 vintage) equipment in the current year by housing type and Census Division. It is computed as in (B-40) above.

$EQCREP_{y,t,eg,b,r}$ is the number of replacement units (post-2005 vintage) equipment demanded in post-2005 vintage housing units by housing type and Census Division. It is computed as in (B-33) above.

$EQCRP90_{y,t,eg,b,r}$ is the number of replacement units demanded in pre-2006 housing units each year by housing type and Census Division. It is computed as in (B-34) 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 (B-35) 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 (B-45) through (B-48). Namely,

$EQCSUEC_{y,eg,b,r}$ is the UEC for surviving 2005 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:

$$DSWCON_{y=2002,r} =$$
$$\sum_{b,eg} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \end{pmatrix}, \quad if \ y = 2006 \qquad \text{(B-77)}$$

$$DSWCON_{y,r} =$$

$$\sum_{b,eg} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \\ + EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \end{pmatrix}, \quad if \ y > 2006 \qquad \text{(B-78)}$$

Water Heating

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,

$$TOTN_{b,r} = \sum_{eg} HSYSSHR_{y,eg,b,r} \qquad \text{(B-79)}$$

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,

$$NH2OSH_{y,b,r} = \frac{\sum_{eg} HSYSSHR_{y,RTCLEQCLI_{SH}=RTCLPNTR_{WH},b,r}}{TOTN_{b,r}} \qquad (B-80)$$

where,

$NH2OSH_{y,b,r}$ 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 (B-69) 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 (B-16) 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 (B-20) 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 (B-21) above.

$TOTEWTN_{y,eg,b,r}$ is the sum of the equipment types' weights for the new equipment class. It is computed as in (B-22) above.

$TOTEWTR_{y,eg,b,r}$ is the sum of the equipment types' weights for the replacement equipment class. It is computed as in (B-23) 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 (B-24) 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 (B-25) above.

The fuel shares are stored into their final places:

$$NEQTSHR_{y,f,b,r} = EQFSHRN_{y,es,b,r}$$ (B-81)

$$REQTSHR_{y,f,b,r} = EQFSHRR_{y,es,b,r}$$ (B-82)

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 (B-28) and (B-29):

$WTEQCEFFN_{y,eg,b,r}$ 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.

The first operation is to calculate the total equipment in pre-2006 housing,

$$EQCND90_{y,eg,b,r} = EQCESE_{2005,eg,b,r} * HDR_b \quad , if \ y = 2006$$
$$EQCND90_{y,eg,b,r} = EQCESE_{y-1,eg,b,r} * HDR_b \quad , if \ y > 2006$$

(B-83)

where,

$EQCND90_{y,eg,b,r}$ is the total equipment in pre-2006 housing each year by housing type and Census Division,

$EQCESE_{2005,eg,b,r}$ is the pre-2006 equipment stock in pre-2006 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,

$$EQCADD_{y,t,eg,b,r} = HSEADD_{y,b,r} * SHARE$$

(B-84)

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-2005 vintage equipment in pre-2006 housing units by year, housing type and Census Division. It is calculated as in (B-39) above.

$EQCSUR_{y,eg,b,r}$ is the surviving post-2005 vintage equipment in post-2005 housing by year,

housing type and Census Division. It is computed as in (B-40) above.

$EQCREP_{y,t,eg,b,r}$ is the number of equipment replacements of post-2005 equipment in post-2005 housing units by year, housing type and Census Division. It is computed as in (B-33) above.

$EQCRP90_{y,t,eg,b,r}$ is the number of replacement units demanded in pre-2006 housing units by year, housing type and Census Division. It is computed as in (B-34) 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 (B-35) above.

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 are 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,

$$HHSIZE_{y,r} = \frac{MC\_NP16A_{r,y}}{\sum\limits_{b}\left(EH_{y,b,r} + NH_{y,b,r}\right)}$$

(B-85)

where,

$HHSIZE_{y,r}$ is the average number of persons over age 16 per household by year and region,

$MC\_NP16A_{r,y}$ 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-2006 vintage homes existing in year y, from the RMISC.TXT file, and

$NH_{y,b,r}$ is the number of post-2005 vintage homes remaining in year y, from the NEMS Macroeconomic Module, as shown in equation (B-3).

Unit energy consumption is calculated for the usual vintages. First, the surviving base-year homes,

$$EQCSUEC_{r,eg,b,r} =$$

$$EQCUEC_{r,eg,b} * \left(\frac{HHSIZE_{y,r}}{HHSIZE_{2005,r}} \right)^{HHSELAS} * \frac{RTBASEFF_{2005,eg}}{RTBASEFF_{y,eg}} \quad \text{(B-86)}$$

where,

$EQCSUEC_{y,eg,b,r}$ is the unit energy efficiency of surviving water heating equipment in pre-2006 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 2005, 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,

$$EQCNUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * WTEQCEFFN_{y,eg,b,r}$$

$$* RTBASEFF_{2005,eg} * \left(\frac{HHSIZE_{y,r}}{HHSIZE_{2005,r}} \right)^{HHSELAS} \quad \text{(B-87)}$$

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,

$HHSIZE_{y,r}$ 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 all years,

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * WTEQCEFFR_{y,eg,b,r}$$
$$* RTBASEFF_{2005,eg} * \left(\frac{HHSIZE_{y,r}}{HHSIZE_{2005,r}} \right)^{HHSELAS} \tag{B-888}$$

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 2005 stock by year.

The average UEC for all equipment is calculated as:

$$EQCAUEC_{y,eg,b,r} = EQCNUEC_{y,eg,b,r}, if \ y = 2006$$

$$EQCAUEC_{y,eg,b,r} =$$
$$\frac{\left(\begin{array}{l} (EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP90RP_{y,eg,b,r}) \\ * EQCNUEC_{y,eg,b,r} \\ + (EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r})* EQCAUEC_{y-1,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \end{array} \right)}{\left(\begin{array}{l} EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP90RP_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r} + EQCRP90_{y,eg,b,r} \end{array} \right)}, \tag{B-889}$$
$$if \ y > 2006$$

where,

EQCAUEC$_{y,eg,b,r}$ is the average unit energy consumption for all post-2005 equipment.

Water heater efficiency is calculated next. If y = 2006,

$$WTEQCEFFA_{y=2006,eg,b,r} = WTEQCEFFN_{y=2006,eg,b}$$

(B-900)

If y > 2006,

$$WTEQCEFFA_{y,eg,b,r} = \frac{\left(\begin{array}{l} (EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP\,90\,RP_{y,eg,b,r}) \\ * WTEQCEFFN_{y,eg,b,r} \\ + (EQCSR\,90_{y,eg,b,r} + EQCSUR_{y,eg,b,r}) * WTEQCEFFA_{y-1,eg,b,r} \\ + EQCRP\,90_{y,eg,b,r} * WTEQCEFFR_{y,eg,b,r} \end{array} \right)}{\left(\begin{array}{l} EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP\,90\,RP_{y,eg,b,r} \\ + EQCSR\,90_{y,eg,b,r} + EQCSUR_{y,eg,b,r} + EQCRP\,90_{y,eg,b,r} \end{array} \right)}$$

(B-911)

where,

$WTEQCEFFA_{y,eg,b,r}$ 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,

$$H2OSHRCW_{y,f,b,r,v} = H2OSHR_{y,f,b,r,v} * NUMCW_{y,b,r,v}$$

(B-922)

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,

$NUMCW_{y,b,r,v}$ 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:

$$H2OCONCW_{y,f,b,r,v} = H2OSHRCW_{y,f,b,r,v} * H2OUEC_{y,f,b,r,v} * LDADJCW_{y,b,r} \quad \text{(B-933)}$$

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, and

$LDADJCW_{y,b,r}$ 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.

Finally, energy consumption by fuel can be summed over the different housing types. If y = 2006,

$$H2OCON_{y=2006,f,r} =$$

$$\sum_{b} \left(\left(\left(\begin{array}{l} EQCESE_{y,eg,b,r} * EQCSUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \end{array} \right) + H2OCONCW_{y,f,b,r,v} \right) \\ * RSELAST(f,r,\alpha,EF1,EF2,EF3,2005) \right) \qquad \text{(B-944)}$$

If y > 2006,

$$H2OCON_{y,r} =$$

$$\sum_{b} \left(\left(\left(\begin{array}{l} EQCESE_{y,eg,b,r} * EQCSUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \\ + EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \end{array} \right) + H2OCONCW_{y,f,b,r,v} \right) \\ * RSELAST(f,r,\alpha,EF1,EF2,EF3,2005) \right) \qquad \text{(B-955)}$$

where,

$H2OCON_{y,f,r}$ is consumption for water heating by fuel, and

RSELAST   is the short-term price elasticity function with distributed lag weights EF1, EF2, and EF3, and , the total short-term price elasticity.

Cooking Equipment

RSTVTEC (Choose Cooking Equipment Component)

The existing cooking equipment distribution is associated with the choice of 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:

$$NCKSHR_{y,eg,b,r} = NH2OSH_{y,eg,b,r} * NGNGFACT \quad , if \ eg \ = gas \ stove$$

$$NCKSHR_{y,eg,b,r} = NH2OSHR_{y,eg,b,r} \quad , if \ eg \ = LPG \ stove$$

$$NCKSHR_{y,eg,b,r} =$$
$$\sum \left(NH2OSH_{y,eg,b,r} \right) + NH2OSH_{y,ng,b,r} * \left(1. - NGNGFACT \right),$$

$$if \ eg \ = electric \ stove$$

(B-96)

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.TXT 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 cooking equipment type by housing type, Census

	Division, vintage, and year. It is computed as in (B-69) above.
$LFCY_{y,es,b,r,v}$	is the cooking equipment's life cycle cost by year, housing type Census Division, and vintage. It is computed as in (B-16) 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 (B-20) 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 (B-21) above.
$TOTEWTN_{y,eg,b,r}$	is the sum of the equipment types' weights for the new equipment class. It is computed as in (B-22) above.
$TOTEWTR_{y,eg,b,r}$	is the sum of the equipment types' weights for the replacement equipment class. It is computed as in (B-23) 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 (B-24) 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 (B-25) above.

The final shares for the equipment types are the products of the market shares and the equipment type shares,

$$NEQTSHRD_{y,eg,b,r} = NCKSH_{y,eg,b,r} * EQFSHRN_{y,es,b,r}$$
$$REQTSHRD_{y,eg,b,r} = NCKSH_{y,eg,b,r} * EQFSHRR_{y,es,b,r}$$

$$(B-97)$$

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:

$$WTEQCEFFA_{y,eg,b,r} = \frac{\sum_{es} \left(NEQTSHR_{y,es,b,r} * RTEQEFF_{es} \right)}{\sum_{es} NEQTSHR_{y,es,b,r}}$$ (B-98)

where,

$WTEQCEFFA_{y,eg,b,r}$ is the weighted average cooking equipment usage in the current year by housing type and Census Division, and

$RTBASEFF_{2005,eg}$ is the 2005 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,

$$EQCSUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * \frac{RTBASEFF_{2005,eg}}{RTBASEFF_{y,eg}}$$ (B-99)

where,

$EQCSUEC_{y,eg,b,r}$ 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,

$$EQCNUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * \frac{WTEQCEFFN_{y,eg,b,r}}{RTBASEFF_{2005,eg}}$$ (B-100)

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

$RTBASEFF_{2005,eg}$ is the 2005 efficiency of the cooking equipment class.

For replacement equipment,

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * \frac{WTEQCEFFR_{y,eg,b,r}}{RTBASEFF_{2005,eg}}$$ (B-101)

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

$RTBASEFF_{2005,eg}$ is the 2005 efficiency of the cooking equipment class.

For the average efficiency, the initial year level is set to the new equipment efficiency:

If y = 2006,

$$EQCAUEC_{y,eg,b,r} = EQCNUEC_{r,eg,b} \qquad \text{(B-102)}$$

If y > 2006,

$$EQCAUEC_{y,eg,b,r} = \frac{\left(\begin{array}{l} (EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP\,90\,RP_{y,eg,b,r}) \\ * EQCNUEC_{y,eg,b,r} \\ + (EQCSR\,90_{y,eg,b,r} + EQCSUR_{y,eg,b,r}) * EQCAUEC_{y-1,eg,b,r} \\ + EQCRP\,90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \end{array} \right)}{\left(\begin{array}{l} EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP\,90\,RP_{y,eg,b,r} \\ + EQCSR\,90_{y,eg,b,r} + EQCSUR_{y,eg,b,r} + EQCRP\,90_{y,eg,b,r} \end{array} \right)} \qquad \text{(B-103)}$$

And energy consumption is defined as:

$$CKCON_{y=2006,r} = \sum_{b} \left(\begin{array}{l} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \end{array} \right), \quad if \ \ y = 2006 \qquad \text{(B-104)}$$

$$CKCON_{y,r} = \sum_{b} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \\ + EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \end{pmatrix}, \quad if\ y > 2006$$

(B-105)

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 (B-69) above.

$LFCY_{y,es,b,r,v}$ is the clothes dryer's life cycle cost by year, housing type Census Division, and vintage. It is computed as in (B-16) 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 (B-20) 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 (B-21) above.

$TOTEWTN_{y,eg,b,r}$ is the sum of equipment weights for the new equipment class. It is computed as in (B-22) above.

$TOTEWTR_{y,eg,b,r}$ is the sum of equipment weights for the replacement equipment class. It is computed as in (B-23) above.

Market shares for new and replacement dryers are next:

$$NEQTSHR_{y,es,b,r} = \frac{EQWT_{y,es,b,r}}{TOTEWT_{y,eg,b,r}}$$ (B-106)

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:

$$TEMP = \sum_{es} EQWT_{y,es,b,r}$$

$$WTEQCEFFA_{y,eg,b,r} = \frac{\sum_{es}\left(EQWT_{y,es,b,r} \middle/ RTEQEFF_{es} \right)}{TEMP}, \text{ if } TEMP > 0$$ (B-107)

$$WTEQCEFFA_{y,eg,b,r} = \frac{1}{RTBASEFF_{2005,eg}}, \text{ otherwise}$$

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

$$EQCADD_{y,eg,b,r} =$$
$$\sum_{es}\left(HSEADD_{y,b,r} * NEQTSHR_{y,es,b,r} * \frac{NEWDRYSAT_{b,r}}{100} \right)$$ (B-108)

where,

$EQCADD_{y,eg,b,r}$ is the amount of new (post-2005 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,

$NEQTSHR_{y,es,b,r}$ 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.TXT 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-2005 vintage equipment in pre-2006 housing units in the current year by housing type and Census Division. It is computed as in (B-39) above.

$EQCSUR_{y,eg,b,r}$ is the surviving new (post-2005 vintage) equipment in the current year by housing type and Census Division. It is computed as in (B-40) above.

$EQCREP_{y,eg,b,r}$ is the number of replacement units (post-2005 vintage) equipment demanded in multi-family or mobile post-2005 vintage housing units by housing type and Census Division, computed as in (B-33).

$EQCRP90_{y,eg,b,r}$ is the number of replacement units demanded in pre-2006 housing units each year by housing type and Census Division. It is computed as in (B-34) above.

$EQCRP90RP_{y,eg,b,r}$ 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 (B-35) above.

RDRYCON (Clothes Dryer Energy Consumption Component)

The unit energy consumption for surviving equipment is calculated as,

$$EQCSUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * \frac{RTBASEFF_{2005,eg}}{RTBASEFF_{y,eg}}$$

(B-109)

where,

    $EQCSUEC_{y,eg,b,r}$ is the UEC for surviving 2005 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,

$$EQCNUEC_{y,eg,b,r} =$$
$$EQCUEC_{r,eg,b} * WTEQCEFFN_{y,eg,b,r} * RTBASEFF_{y,eg,b,r}$$

(B-110)

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 2005 housing by Census Division, equipment class and housing type.

For replacement equipment,

$$EQCRUEC_{y,eg,b,r} =$$
$$EQCUEC_{r,eg,b} * WTEQCEFFR_{y,eg,b,r} * RTBASEFF_{y,eg,b,r}$$

(B-111)

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 2005 housing by Census Division, equipment class and housing type.

The average of the two unit energy consumption variables is,

If y = 2006,

$$EQCAUEC_{y,eg,b,r} = EQCNUEC_{r,eg,b} \qquad \text{(B-112)}$$

If y > 2006,

$$EQCAUEC_{y,eg,b,r} = \frac{\begin{pmatrix} (EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP\,90\,RP_{y,eg,b,r}) \\ * EQCNUEC_{y,eg,b,r} \\ + (EQCSR\,90_{y,eg,b,r} + EQCSUR_{y,eg,b,r})* EQCAUEC_{y-1,eg,b,r} \\ + EQCRP\,90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \end{pmatrix}}{\begin{pmatrix} EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP\,90\,RP_{y,eg,b,r} \\ + EQCSR\,90_{y,eg,b,r} + EQCSUR_{y,eg,b,r} + EQCRP\,90_{y,eg,b,r} \end{pmatrix}} \qquad \text{(B-113)}$$

And energy consumption is defined as:

$$DRYCON_{y=2006,r} = \sum_{b,eg} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \end{pmatrix}, \quad if \ y = 2006 \qquad \text{(B-114)}$$

$$DRYCON_{y,r} =$$

$$\sum_{b,eg} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \\ + EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \end{pmatrix}, \quad if \ y > 2006 \qquad \text{(B-115)}$$

Refrigeration

RREFTEC (Refrigerator Technology Choice Component)

Equipment operating cost for refrigerators is,

$$OPCOST_{y,es,b,r,v} = PRICES_{f,r,y} * RTEQEFF_{eg} * FACTOR \qquad \text{(B-116)}$$

where,

$OPCOST_{y,es,b,r,v}$ 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 (B-16) above.

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

Division. It is computed as in (B-20) above.

$EQWTR_{es,b,r}$ is the equipment weight for replacement equipment by housing type and Census Division. It is computed as in (B-21) 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 (B-22) 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 (B-23) above.

The two available classes of refrigerators, through-the-door and others, have market shares, distinguished by *TTDSHR*. For through-the-door refrigerators,

$$NEQTSHR_{y,es,b,r} = TTDSHR$$
$$REQTSHR_{y,es,b,r} = TTDSHR$$

(B-117)

And for all others,

$$NEQTSHR_{y,es,b,r} = \frac{EQWTN_{es,b,r}}{TOTEWTN_{b,r}} * (1 - TTDSHR)$$

(B-118)

$$REQTSHR_{y,es,b,r} = \frac{EQWTR_{es,b,r}}{TOTEWTR_{b,r}} * (1 - TTDSHR)$$

(B-119)

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.

$$WTEQCEFFN_{y,eg,b,r} = \frac{\sum\limits_{es} \left(NEQTSHR_{y,es,b,r} * RTEQEFF_{es} \right)}{\sum\limits_{es} NEQTSHR_{y,es,b,r}} \qquad \text{(B-120)}$$

$$WTEQCEFFR_{y,eg,b,r} = \frac{\sum\limits_{es} \left(REQTSHR_{y,es,b,r} * RTEQEFF_{es} \right)}{\sum\limits_{es} REQTSHR_{y,es,b,r}} \qquad \text{(B-121)}$$

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.TXT 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 2005. The additions are calculated as:

$$EQCADD_{y,eg,b,r} = HSEADD_{y,b,r} * RFADDFAC \quad, if \ b = 1$$
$$EQCADD_{y,eg,b,r} = HSEADD_{y,b,r}, otherwise \qquad \text{(B-122)}$$

where,

$EQCADD_{y,eg,b,r}$ is the amount of new (post-2005 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

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:

$EQCSR90_{y,eg,b,r}$ is the surviving new (post-2005 vintage) equipment in old (pre-2006 vintage) housing units by housing type and Census Division. It is computed as in (B-39) above.

$EQCRP90_{y,eg,b,r}$ is the number of replacement (post-2005 vintage) equipment in pre-2006 housing units in the current year by housing type and Census Division. It is computed as in (B-34) above.

$EQCRP90RP_{y,eg,b,r}$ 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 (B-35) above.

$EQCSUR_{y,eg,b,r}$ is the surviving new (post-2005 vintage) equipment in the current year by housing type and Census Division. It is computed as in (B-40) above.

$EQCREP_{y,eg,b,r}$ is the number of replacement units (post-2005 vintage) equipment demanded in new (post-2005 vintage) housing units by housing type and Census Division. It is computed as in (B-33) above.

RREFCON (Refrigerator Energy Consumption Component)

The unit energy consumption calculations for surviving, new, and replacement equipment, and their averages. are calculated as:

$$EQCSUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * \frac{RTBASEFF_{y,eg}}{RTBASEFF_{2005,eg}} \tag{B-123}$$

where,

$EQCSUEC_{y,eg,b,r}$ is the UEC for surviving 2005 equipment in each equipment class, by housing type and Census Division, and

$EQCUEC_{r,eg,b}$ is the UEC for the original 2005 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,

$$EQCNUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * \frac{WTEQCEFFN_{y,eg,b,r}}{RTBASEFF_{2005,eg}}$$ (B-124)

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 2005 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

$RTBASEFF_{2005,eg}$ is the 2005 stock-average efficiency of refrigerators.

For replacement refrigerators,

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * \frac{WTEQCEFFR_{y,eg,b,r}}{RTBASEFF_{2005,eg}}$$ (B-125)

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,

$RTBASEFF_{2005,eg}$ is the 2005 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 2005

2005 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. If y = 2006,

$$EQCAUEC_{y,eg,b,r} = EQCNUEC_{y,eg,b,r} \qquad \text{(B-126)}$$

If y > 2006,

$$
\begin{aligned}
&EQCAUEC_{y,eg,b,r} = \\
&\frac{\begin{pmatrix} (EQCREP_{y,t,eg,b,r} + EQCADD_{y,t,eg,b,r} * 0.9 + EQCRP\ 90\ RP_{y,t,eg,b,r}) \\ * EQCNUEC_{y,eg,b,r} \\ + (EQCSR\ 90_{y,t,eg,b,r} + EQCSUR_{y,t,eg,b,r}) * EQCAUEC_{y-1,eg,b,r} \\ + EQCRP\ 90_{y,t,eg,b,r} * EQCRUEC_{y,t,eg,b,r} + EQCADD_{y,t,eg,b,r} * 0.1 \\ * EQCUEC_{r,eg,b} \end{pmatrix}}{\begin{pmatrix} EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP\ 90\ RP_{y,eg,b,r} \\ + EQCSR\ 90_{y,eg,b,r} + EQCSUR_{y,eg,b,r} + EQCRP\ 90_{y,eg,b,r} \end{pmatrix}} \qquad \text{(B-127)}
\end{aligned}
$$

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.

$$WTEQCEFFA_{y,eg,b,r} = WTREFFN_{y,b,r}, if \ y = 2006$$

$$WTEQCEFFA_{y,eg,b,r} =$$

$$\frac{\left(\begin{array}{l} (EQCREP_{y,t,eg,b,r} + EQCADD_{y,t,eg,b,r} * 0.9 + EQCRP \ 90 \ RP_{y,t,eg,b,r}) * \\ WTEQCEFFN_{y,eg,b,r} \\ + (EQCSR \ 90_{y,t,eg,b,r} + EQCSUR_{y,t,eg,b,r}) * WTEQCEFFA_{y-1,eg,b,r} \\ + EQCRP \ 90_{y,t,eg,b,r} * WTEQCEFFR_{y,eg,b,r} + EQCADD_{y,t,eg,b,r} * 0.1 * \\ RTBASEFF_{2005,eg} \end{array} \right)}{\left(\begin{array}{l} EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP \ 90 \ RP_{y,eg,b,r} \\ + EQCSR \ 90_{y,eg,b,r} + EQCSUR_{y,eg,b,r} + EQCRP \ 90_{y,eg,b,r} \end{array} \right)}$$

(B-128)

$$, otherwise$$

And energy consumption is defined as:

$$REFCON_{y=2006,r} =$$

$$\sum_{b,eg} \left(\begin{array}{l} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * 0.9 * EQCNUEC_{y,eg,b,r} \\ + EQCADD_{y,eg,b,r} * 0.1 * EQCUEC_{eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \end{array} \right), \quad if \ y = 2006$$

(B-129)

$$REFCON_{y,r} =$$

$$\sum_{b,eg} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * 0.9 * EQCNUEC_{y,eg,b,r} \\ + EQCADD_{y,eg,b,r} * 0.1 * EQCUEC_{eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \\ + EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \end{pmatrix}, \quad if \ y > 2006 \qquad \text{(B-130)}$$

where,

$REFCON_{y,r}$ is energy consumption for refrigeration,

$EQCESE_{y,b,r}$ is the surviving old (pre-2006 vintage) equipment in old (pre-2006 vintage) housing units in the current year by housing type and Census Division,

$EQCADD_{y,b,r}$ is the amount of new (post-2005 vintage) refrigerators added in new housing units in the current year by housing type and Census Division,

$EQCRP90_{y,b,r}$ is the number of replacement (post-2005 vintage) equipment in pre-2006 housing units in the current year by housing type and Census Division,

$EQCRP90RP_{y,b,r}$ 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:

$OPCOST_{y,es,b,r,v}$ is the operating cost of freezers by housing type and Census Division in the current year. It is computed as for refrigerators in (B-115) above.

$LFCY_{es,r,v}$ is the life cycle cost for the type of equipment by Census Division. It is computed as in (B-16) above.

$EQWTN_{es,b,r}$ is the equipment weight for new equipment types by housing type and Census Division. It is computed as in (B-20) above.

$EQWTR_{es,b,r}$ is the equipment weight for replacement equipment by housing type and Census Division. It is computed as in (B-21) 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 (B-22) 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 (B-23) above.

Shares for equipment types, in normalized form, are calculated somewhat as usual:

$$NEQTSHR_{y,es,b,r} = UPSHR \text{ , } if \text{ } es = upright \text{ } freezer$$

$$NEQTSHR_{y,es,b,r} = \frac{EQWTN_{es,b,r}}{TOTEWTN_{b,r}} * (1 - UPSHR), otherwise \tag{B-131}$$

$$REQTSHR_{y,es,b,r} = UPSHR \text{ , } if \text{ } es = upright \text{ } freezer$$

$$REQTSHR_{y,es,b,r} = \frac{EQWTR_{es,b,r}}{TOTEWTR_{b,r}} * (1 - UPSHR), otherwise \tag{B-132}$$

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:

$$WTEQCEFFN_{y,eg,b,r} = \frac{\sum\limits_{es} \left(NEQTSHR_{y,es,b,r} * RTEQEFF_{es} \right)}{\sum\limits_{es} NEQTSHR_{y,es,b,r}}$$ (B-133)

$$WTEQCEFFR_{y,eg,b,r} = \frac{\sum\limits_{es} \left(REQTSHR_{y,es,b,r} * RTEQEFF_{es} \right)}{\sum\limits_{es} REQTSHR_{y,es,b,r}}$$ (B-134)

where,

$WTEQCEFFN_{y,eg,b,r}$ is the market share-weighted usage of new freezers in the current year by housing type and Census Division,

$WTEQCEFFR_{y,eg,b,r}$ is the market share-weighted usage of replacement freezers 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-2006:

$$EQCADD_{y,eg,b,r} = HSEADD_{y,b,r} * \left(\frac{FRZSAT_{b,r}}{100} \right)$$ (B-135)

where,

$EQCADD_{y,eg,b,r}$ is the amount of new (post-2005 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.TXT file, expressed as percents.

The following variables are computed as in the equations indicated:

$EQCSR90_{y,b,r}$ is the surviving new (post-2005 vintage) equipment in old (pre-2006 vintage) housing units by housing type and Census Division. It is computed as in (B-39) above.

$EQCRP90_{y,t,eg,b,r}$ is the number of replacement (post-2005 vintage) equipment in pre-2006 housing units in the current year by housing type and Census Division. It is computed as in (B-34) above.

$EQCSUR_{y,b,r}$ is the amount of surviving new (post-2005 vintage) equipment in new (post-2005 vintage) housing units in the current year by housing type and Census Division. It is computed as in (B-40) above.

$EQCREP_{y,b,r}$ is the number of replacements for the current year in new (post-2005 vintage) housing units by housing type and Census Division. It is computed as in (B-33) 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 (B-34) above.

FRZCON (Freezer Energy Consumption Component)

The detailed unit energy consumption variables are computed exactly as for freezers:

$EQCSUEC_{y,eg,b,r}$ is the UEC for surviving 2005 equipment in each equipment class, by housing type and Census Division, calculated as in equation (B-123),

$EQCNUEC_{y,eg,b,r}$ is the efficiency-weighted unit energy consumption for new freezers in the current year by housing type and Census Division, calculated as in equation (B-124),

$EQCRUEC_{y,eg,b,r}$ is the efficiency weighted unit energy consumption for replacement refrigerators in the current year by housing type and Census Division, calculated as in equation (B-125).

Average UEC's are different in that they do not include the offset for second refrigerators found in equation (B-127).

Weighted average usages are then calculated,

$$
\begin{aligned}
WTEQCEFFA_{y,eg,b,r} &= WTREFFN_{y,b,r} \text{, } if \ y = 2006 \\
WTEQCEFFA_{y,eg,b,r} &= \\
&\frac{\left(\begin{array}{l} (EQCREP_{y,t,eg,b,r} + EQCADD_{y,t,eg,b,r} + EQCRP\ 90\ RP_{y,t,eg,b,r}) \\ * WTEQCEFFN_{y,eg,b,r} \\ + (EQCSR\ 90_{y,t,eg,b,r} + EQCSUR_{y,t,eg,b,r}) * WTEQCEFFA_{y-1,eg,b,r} \\ + EQCRP\ 90_{y,t,eg,b,r} * WTEQCEFFR_{y,eg,b,r} \end{array}\right)}{\left(\begin{array}{l} EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP\ 90\ RP_{y,eg,b,r} \\ + EQCSR\ 90_{y,eg,b,r} + EQCSUR_{y,eg,b,r} + EQCRP\ 90_{y,eg,b,r} \end{array}\right)},
\end{aligned}
$$

otherwise

(B-136)

And energy consumption is defined as:

$$
FRZCON_{y=2006,r} = \sum_{b,eg}\left(\begin{array}{l} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \end{array}\right), \quad if \ y = 2006
$$

(B-137)

$$FRZCON_{y,r} =$$

$$\sum_{b,eg} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \\ + EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \end{pmatrix}, \quad if \ y > 2006 \qquad \text{(B-138)}$$

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:

Lighting

Lighting data is found in the RMISC.TXT file. For lighting, there is a single component, as shown in the following section.

LTCNS (Lighting Choice, Stock, and Energy Consumption Component)

The lighting end use is separated into four distinct segments: General use, general use reflector, torchiere, and tubular fluorescent. Since the general use segment is most important in terms of energy consumption in the sector, it has the most detailed accounting of the four segments. The equations below are generalized to represent the four segments of the market described above. The only difference between the four segments is that the general use category is further partitioned into hours of use bins, which affects the economics in the operating and capital costs as documented below. The capital costs included in the RMISC.TXT file account for the fact that multiple bulbs are needed to satisfy the hours of use for a particular hourly bin on an annual basis.

Operating costs for lighting are defined as:

$$OPCOST_{y,es,b,r} =$$
$$PRICES_{y,r} * WATTS_{es,y} * FACTOR * HOURS * 365 \qquad \text{(B-139)}$$

where,

$OPCOST_{y,es,b,r}$ are the operating costs for specific lighting technologies,

$PRICES_{y,r}$ are electricity prices by year and region,

$WATTS_{es,y}$ are the watts of each particular bulb type,

$FACTOR$ converts watts to Btu,

$HOURS$ are the number of hours per day of bulb use, and

365 are the number of days in a year.

Market shares for general use, general us reflector, torchiere, and tubular fluorescent lighting are computed as follows:

$$MKTSHR_{y,es,b,r} = \frac{exp^{\beta_1 * EQCOST_{y,es} + \beta_2 * OPCOST_{y,es,b,r}}}{\sum_{es} exp^{\beta_1 * EQCOST_{y,es} + \beta_2 * OPCOST_{y,es,b,r}}} \qquad \text{(B-140)}$$

where,

$MKTSHR_{y,es,b,r}$ are annual market shares for standard lighting applications and

$EQCOST_{y,es}$ are lighting equipment costs.

Next, weighted efficiency indices are computed for the three lighting classes. Namely,

$$WTLEFF_{y,b,r} = \sum_{es} \left(\frac{1}{EFF_{es}} * MKTSHR_{y,es,b,r} \right) \qquad \text{(B-141)}$$

where,

$WTLEFF_{y,b,r}$ are weighted-average usages for lighting, by year, housing type and Census

Division,

EFF_{es}   are efficiencies of the three classes of light bulbs (3 for torchiere, 2 for reflector and tubular fluorescent lamps), from the table above, and

MKTSHR_{y,es,b,r}   are annual market shares for the lighting classes, from the table above.

Stock accounting of all bulbs are separated into new and replacement units as shown in equations (B-33) to (B-40). The number of bulbs needed for each hourly bin, are annualized, meaning some bins might need more than one bulb per year, based on hourly life expectancy and annual hourly usage.

Next, the component calculates unit energy consumption for the three classes of lighting,

$$LTNUEC_{y,r,b} = LTUEC_{r,b} * WTLEFF_{y,b,d} * BASEFF \qquad \text{(B-142)}$$

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.TXT 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.

For general use lighting, the UEC is calculated over the various hourly bins, but has not been shown in equation (B-142). The final step of this component is to calculate consumption for the lighting service category. Namely,

$$LTCON_{y,r} = \sum_b \left(\begin{pmatrix} \left(LTSTOCK_{y,b,r} * SQFTLTS_{y,b,r} \right) * LTNUEC_{y,r,b} \\ + \left(TCHSTOCK_{y,b,r} \right) * TCHUEC_{y,b,r} \\ + \left(LFLSTOCK_{y,b,r} * LFLUEC_{y,b,r} \right) \\ + \left(REFSTOCK_{y,b,r} * REFUEC_{y,b,r} \right) \end{pmatrix} * RSELAST \left(f, r, \alpha, EF1, EF2, EF3, 2005 \right) \right) \quad \text{(B-143)}$$

where,

	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,
$LTSTOCK_{y,b,r}$	is the number general use bulbs in the current year by housing type and Census Division,
$TCHSTOCK_{y,b,r}$	is the number of torchiere bulbs in the current year by housing type and Census Division,
$LFLSTOCK_{y,b,r}$	is the number of standard fluorescent bulbs in the current year by housing type and Census Division,
$REFSTOCK_{y,b,r}$	is the number of general use reflector bulbs in the current year by housing type and Census Division,
$LTNUEC_{y,r,b}$	is the unit energy consumption for general use lighting by year, Census Division and housing type,
$SQFTLTS_{y,b,r}$	is the average floor area of homes, relative to 2005 floor areas, calculated from the floor areas given in the RSSQRFT.TXT file, used to adjust for increased lighted areas in future new homes,
$TCHUEC_{y,b,r}$	is the unit energy consumption for torchiere lighting by year, Census Division, and housing type,
RSELAST	is the short-term price elasticity function with distributed lag weights EF1, EF2, and EF3, and , the total short-term price elasticity,
$LFLUEC_{y,b,rt}$	is the UEC for tubular fluorescent lamps by year, Census Division and housing type, and
$REFUEC_{y,b,r}$	is the UEC for general use reflector bulbs by year, Census Division, and

housing type.

PCCNS (Personal Computer Energy Consumption Component)

This submodule is similar in nature to the television submodule documented below. For these two equipment classes, offline EXCEL spreadsheet models have been created to provide the NEMS residential module with the inputs it needs to forecast energy consumption for PCs and TVs and Set-Top Boxes. The spreadsheet model for PCs assumes certain market penetration for the different technologies over the forecast period, including desktops vs. laptops, LCD screen vs. CRT, etc. The two outputs from the spreadsheet model are a penetration rate (PCs/household) and usage trend. Specifically,

$$PCNUEC_{y,r,b} = PCUEC_{r,b} * WTPCEFF_{y,} * \left(\frac{INCOME_{y,r}}{INCOME_{2005,r}} \right)^{0.1} \qquad \text{(B-144)}$$

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,

$INCOME_{y,r}$ is personal disposable income by year and region, and

$WTPCEFF_y$ is the stock efficiency/usage index for personal computers in year y.

Next, the component calculates the number of personal computers in the stock for future years.

$$PCEQP_{y,r,b} = \left(\frac{PCSAT_{r,b}}{EH_{y=2005,r,b}} \right) * PCPEN_y * \left(EH_{y,b,r} + NH_{y,b,r} \right) \qquad \text{(B-145)}$$

where,

$PCEQP_{y,r,b}$ is the number of personal computers by year, Census Division and housing type, and

$PCPEN_y$ is the estimated penetration of personal computers for future years.

The final step of this component is to calculate consumption for personal computers. Namely,

$$PCCON_{y,r} = \sum_b \left(\frac{(PCEQP_{y,b,r} * PCNUEC_{y,b,r}) *}{RSELAST(f,r,\alpha,EF\,1,EF\,2,EF\,3,2005)} \right) \tag{B-146}$$

where,

$PCCON_{y,r}$ is the energy consumption for personal computers by year and Census Division, and

RSELAST   is the short-term price elasticity function with distributed lag weights EF1, EF2, and EF3, and , the total short-term price elasticity.

TVCNS (Color Television and Set-Top Box Energy Consumption Component)

This submodule is similar in nature to the personal computer submodule. For these two equipment classes, offline EXCEL spreadsheet models have been created to provide the NEMS residential module with the inputs it needs to forecast energy consumption for PCs and TVs and set-top boxes. The spreadsheet model for TVs and Set-Top Boxes assumes certain market penetration for the different technologies over the forecast period, including plasma vs. LCD vs. CRT, high definition vs. standard definition, cable vs. satellite, etc. The two outputs from the spreadsheet model are a penetration rate (TVs/household) and usage trend. Specifically

$$TVNUEC_{y,r,b} = TVUEC_{r,b} * WDTVEFF_y, \tag{B-147}$$

where,

$TVNUEC_{y,r,b}$ is the unit energy consumption for color televisions and set-top boxes by year, Census Division and housing type,

$TVUEC_{r,b}$ is base year unit energy consumption for color televisions and set-top boxes by Census Division and housing type, from the RSUEC10.TXT file, and

$WTDTVEFF_y$ is the stock efficiency/usage index for color televisions and set-top boxes in year y.

Next, the component calculates the number of color televisions and set-top boxes in the stock for future years.

$$TVEQP_{y,r,b} = \left(EH_{y,b,r} * NH_{y,b,r}\right) * TVPEN_{y} * CTVSAT_{2005}$$ (B-148)

where,

TVPEN$_y$ is the estimated penetration of color televisions and set-top boxes for future years,

CTVSAT$_{2005}$ is the color television and set-top box saturation rate in 2005, and

TVEQP$_{y,r,b}$ is the number of color televisions and set-top boxes by year, Census Division and housing type.

The final step of this component is to calculate consumption for color televisions and set-top boxes. Namely,

$$TVCON_{y,r} = \sum_{b} \left(\begin{array}{c} \left(TVEQP_{y,b,r} * TVNUEC_{y,b,r}\right) \\ * RSELAST\left(f,r,\alpha,EF\,1,EF\,2,EF\,2,2005\right) \end{array} \right)$$ (B-149)

where,

TVCON$_{y,r}$ is the energy consumption for color televisions and set-top boxes by year and Census Division, and

RSELAST   is the short-term price elasticity function with distributed lag weights EF1, EF2, and EF3, and , the total short-term price elasticity.

Other Electric Appliances

Beginning in the AEO 2007 version of the residential module, several new electrical uses were introduced as separate uses based on a report by TIAX, LLC (see bibliography section). These uses include: Home audio, ceiling fans, spas, microwave ovens, coffee machines, security systems, and handheld rechargeable devices. For each of these seven uses, the NEMS input from the report is similar to that found in the TVs and PCs sub-modules, namely an efficiency trend and a penetration

penetration trend. All the services follow the exact formulation found in equations (B-147) to (B-149), except for ceiling fans, which adds a regional dimension for the usage estimate based on the fact that warmer regions have higher usage rates for these devices.

The remaining electricity is captured in a catch-all category that includes miscellaneous electrical uses such as small kitchen appliances, small 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 contains a UEC on a per household basis, by housing type and Census division. Based on historical data, a growth rate is estimated and applied to the unit energy consumption to calculate future energy consumption.

APCNS (Other Electric Appliance Energy Consumption Component)

Electric appliance energy consumption is computed as follows.

$$APCON_{y,r} = \sum_{b} \begin{array}{l} \left(EAUEC_{y,r} * EAPEN_{y,r}\right) * \left(EH_{y,r,b} + NH_{y,r,b}\right) \\ \quad * RSELAST\left(f,r,\alpha,EF\,1,EF\,2,EF\,3,2005\right) \end{array} \tag{B-150}$$

where,

$APCON_{y,r}$ is other electric appliance energy consumption,

$EAUEC_{y,r}$ is other electric unit energy consumption,

$EAPEN_{y,r}$ is the growth rate in other electric unit energy consumption, and

RSELAST   is the short-term price elasticity function with distributed lag weights EF1, EF2, and EF3, and , the total short-term price elasticity.

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:

$$
\begin{aligned}
SHTCON_{y,f,r} &= \\
&\sum_b \left(
\begin{array}{l}
SHTSHR_{r,f} * EH_{y,b,r} * SHTUEC_{r,f,b} \\
* AHSHELL_{y,gas,r,b} \\
* RSELAST\left(f,r,\alpha,EF1,EF2,EF3,2005\right)
\end{array}
\right), \; if \; f = coal \\
SHTCON_{y,f,r} &= \\
&\sum_b \left(
\begin{array}{l}
SHTSHR_{r,f} * \left(NH_{y,b,r} + EH_{y,b,r}\right) * SHTUEC_{r,f,b} \\
* AHSHELL_{y,f,r,b} \\
* RSELAST\left(f,r,\alpha,EF1,EF2,EF3,2005\right)
\end{array}
\right) \; otherwise
\end{aligned}
$$

(B-151)

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-2006) housing units in the current year by housing type and Census Division,

$NH_{y,b,r}$ is the number of new (post-2005) housing units in the current year by housing type and Census Division,

$SHTUEC_{r,f,b}$ is base year unit energy consumption for secondary heating by Census Division, fuel, and housing type, from the RSUEC10.TXT file,

$AHSHELL_{y,f,r,b}$ is the average post-2005 heating shell index by year, fuel, Census Division, and building type, and

RSELAST   is the short-term price elasticity function with distributed lag weights EF1, EF2, and EF3, and , the total short-term price elasticity.

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:

$$APLCON_{y,f,r} = \sum_b \left(\frac{\left(\left(EH_{y,b,r} + NH_{y,b,r} \right) * APPUEC_{y,b,r} \right)}{* \ RSELAST \left(f, r, \alpha, EF1, EF2, EF3, 2005 \right)} \right) \quad \text{(B-152)}$$

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-2006) housing units in the current year by housing type and Census Division,

$NH_{y,b,r}$ is the number of new (post-2005) 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, and

RSELAST is the short-term price elasticity function with distributed lag weights EF1, EF2, and EF3, and , the total short-term price elasticity.

Distributed Generation Submodule

The residential model includes a submodule (subroutine rdistgen) that develops penetration estimates for distributed electric generation technologies based on explicit cost and performance assumptions. The model is structured to allow for three technologies and can be readily expanded to include more if needed. The three technologies characterized are: photovoltaics, fuel cells, and distributed wind turbines.

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 is assumed to be 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 do not necessarily have to be different from the previous version. The present practice is to characterize a "vintage" for each projection year, however for extended NEMS time frames multi-year windows beyond 2030 can be added for simplicity.
- Economic assumptions (tax rates, inflation rates for projecting results in the cashflow model, financing assumptions such as down payment percentage and loan term).
- Program driven penetrations of technologies by census division. These are viewed as non-economic, supplemental to any economic penetrations.
- Niche variables developed from RECS 2001 and solar and wind resource maps produced by the National Renewable Energy Laboratory (NREL). Each Census division includes from two to four solar insolation niches (a total of 25 solar niches across all divisions). Niches are further subdivided based on the level of electricity prices relative to the Census division average electricity price (three cases, high, average and low prices). In addition to solar insolation and electricity price relatives, the niche variables also include average

also include average wind speed, the Census division share of households within a niche, average annual kWh per single family household, average roof area per single family household and the percentage of households considered "rural" (for wind turbine modeling). In total there are 25 solar niches, when combined with three levels of electricity prices, a total of 75 niche areas are modeled separately.

Overview of the Cashflow Calculations

Distributed generation penetration is based on a cash flow simulation model. For each year in a NEMS run, a complete 30-year cash flow analysis is done for each of the three distributed generation technologies. Simulations are carried out by niche for single family homes. System characteristics, financial variables, solar insolation and program-driven systems (e.g., the California solar program) are supplied to the submodule via the rgentk.txt input file.

The "payback" concept used in the residential distributed generation submodule is the number of years required for an investment to achieve a cumulative positive cash flow. This approach is related to, but different from calculating what is commonly referred to as the "simple payback." Simple paybacks are merely the investment cost divided by estimated annual savings and do not consider the timing of savings or costs that occur irregularly. The cumulative positive cash flow approach incorporates the time distribution of costs and returns including: loan financing terms, tax credits, production credits (as under renewable portfolio standards), intermittent maintenance costs (e.g., inverter replacement for PV systems), inflationary increases in electricity rates, degradation in system output with age, and other factors that change over time. The current financing assumption is that for new construction, investments in distributed generation technologies are rolled-in with the home mortgage. The financing terms other than the mortgage rate are controlled through the distributed generation input file. The residential mortgage rates are supplied by the NEMS Macroeconomic Activity Module. By including tax credits in the input file, modeling alternative tax policies can usually be accomplished without changes to the model code.

Investments begin with a negative cumulative cash flow representing the down payment costs, assumed to be paid up front. In any subsequent year, the net of costs and returns can either be

positive or negative.   If the return is positive, then the cumulative net cashflow increases and *vice versa*. For all technologies during the first full year of operation, electricity savings are realized and loan payments, and maintenance costs are paid. For fuel cells, natural gas costs are also paid, but hot water and potentially space heating savings are also realized via the capture and utilization of waste heat. Loan interest is separately tracked and leads to a tax savings (in the year following the payment) based on home mortgage deductibility. In the second full year of operation, tax credits, if any, are also received. For example, PV receives a 30% credit up to a maximum credit of $2000 under EPACT 2005 for the years 2006 through 2008. These are modeled as one-time payments back to the consumer can have a major effect on increasing the cumulative net cash flow, since they are received near the front-end of the cash flow.

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 75% for distributed technologies if the investment "pays back" in less than one year, 30% if the investment pays back in one year, and correspondingly less for longer paybacks less. The penetration function is assumed to follow a logistic functional form and a chart of the shape under different paybacks is provided in equation (B-180). For retrofitting distributed generation into existing construction, penetration is capped by assumption at the lesser of 0.5% or the penetration rate into new construction divided by 40. The cap is in effect if penetration into new construction exceeds 20%.

In any given NEMS projection year, the total number of cash flow simulations performed equals the number of distributed technologies modeled (t=3), times the number of Census division niches (n=25), times the number of electricity price niches (l=3). An uppercase Y is used to denote years internal to the cash flow analysis in order to distinguish cash flow simulation years from NEMS model years (which are denoted with a lowercase y). The annual technology vintages will also be denoted with lowercase y, since technology vintages currently "align" with NEMS projection years. Many of the concepts do not vary by solar or rate level niches (subscripted by n and l, respectively). In cases where a concept varies by niche for only a subset of technologies, separate equations will be given for the relevant subsets, and in downstream equations the subscript will be placed in brackets to denote that it applies to only the relevant subset of technologies.

Even though the cash flow model is run by niche for each distributed generation technology and for each NEMS model year, many of the cash flow variables are only dimensioned by Y, the simulation year of the cash flow model itself and are reused for other niches or technologies for a particular

NEMS year. Such variables will be notated in the equations as though they have the appropriate dimensions, even if they are reused.

Technology capital cost adjusted for learning effects on equipment cost for emerging technologies:

$$AdjCost_{t,y} = MIN \left\langle CapCost_{t,y}, C_{0,t} \cdot CumShip_{t,y}^{-\beta_t} \right\rangle \qquad \text{(B-153)}$$

where $C_{0,t}$ and β_t are technology-specific learning cost parameters, and *CumShip*$_{t,y}$ represents cumulative shipments in megawatts for NEMS model year *y*, for both residential and commercial buildings combined (supplied via the global interface). Learning effects are modeled for both photovoltaic and fuel cell technologies.

Calculated Maximum kW for Photovoltaic Systems:

xCalcKW$_{t=1,n,l,y}$ is allowed to vary after 2014, the date that program-driven systems are no longer characterized in the rgentk.txt input file. The capacity niche dependent with the target maximum size being enough to serve the residence's annual electricity requirements, subject to maximum and minimum size constraints for the technology being evaluated. In the case of solar photovoltaics only 90% of the properly oriented half of roof area is considered to be suitable for PV installation. Available roof area per house is developed from floorspace and number of floors estimated from RECS 2001 and provided as part of the niche inputs in rgentk.txt. The modules are also assumed to be placed at "latitude tilt" which requires roughly twice the roof area for minimum rack spacing when installed on flat roofs. On sloped roofs modules are assumed to be close enough to "flush-mounted" so that a one square foot module requires roof area of one square foot. An estimated 75% of residential roofs are sloped, so on average, for a given amount of available residential roof area, 75%*1.0 + 25%*2.0 (or 1.25) square feet of roof area are required to mount a one square foot module. Based on roof area constraints, the kW capacity of the maximum number of module area is calculated as:

$$xCalcKW_{t=1,n,l,y} = RoofAreaPerHH_{n,l} / 1.25 \cdot 90\% \cdot 50\% / xSqftperkW_y \qquad \text{(B-154)}$$

(Note: see equation (B-163) below for the calculation of *xSqftperKW* which is recalculated each year based on module conversion efficiency for the appropriate year vintage.)

Installed Equipment Cost:

$$EqCost_{t,y} = (AdjCost_{t,y} + InstCost_{t,y}) \cdot kW_{t,y} \qquad \text{(B-155)}$$

For solar photovoltaics, $kW_{t,y}$ is replaced by $xCalcKW_{t,n,l,y}$ from (B-154).

Initial Outlay Cost:

$$DownPay_{t,y} = EqCost_{t,y} \cdot DownPayPct \qquad \text{(B-156)}$$

Annual levelized payment calculation:

$$Payment_{t,y} = \left[EqCost_{t,y} - DownPay_{t,y}\right] \cdot \frac{IntRate}{1-(1+IntRate)^{-Term}} \qquad \text{(B-157)}$$

where the term in brackets is the amount financed, *IntRate* is the interest rate for the loan and *Term* is the number of years over which the loan payments are amortized.

Outlays for capital relating to down payments and borrowing costs:

$$Outlay_{t,y,Y=1} = DownPay_{t,y}$$
$$Outlay_{t,y,1<Y\leq Term} = Payment_{t,y} \qquad \text{(B-158)}$$
$$Outlay_{t,y,Y>Term} = 0$$

Calculations of loan interest paid and the value of tax credits:

$$Prin_{t,y,Y} = Payment_{t,y} - IntAmt_{t,y,Y}$$
$$where \quad IntAmt_{t,y,Y} = IntRate \cdot LoanBal_{t,y,Y-1}, and \qquad \text{(B-159)}$$
$$1 < Y \leq Term$$

$Prin_{t,y,Y}$ is the amount of principal paid on the loan in each year Y of the cash flow analysis and is also used to determine the loan balance for the next year of the analysis. It is computed as the difference between the levelized payment and the interest paid: $IntAmt_{t,y,Y}$ is the interest paid for the loan in

loan in each year of the analysis. This variable is a component of the tax deduction calculation. It is computed as last year's ending principal balance, *LoanBal* $_{t,y,Y-1}$, times the interest rate on the loan. *LoanBal* $_{t,y,Y}$ is the principal balance of the loan for each year of the analysis. The loan balance reduces over time according to the formula:

$$LoanBal_{t,y,Y} = LoanBal_{t,y,Y-1} - Prin_{t,y,Y}$$ (B-160)

TaxCredit $_{t,y,Y}$ is the allowed tax credit and can vary both by technology and vintage for distributed generation investments favored by the tax code. The credit is assumed to be collected in Year 3 of the cash flow analysis. EPACT05 provides a tax credit for photovoltaics of 30% for systems installed in 2006 and 2007 up to a maximum credit of $2000. EPACT05 also provides a 30% tax credit for fuel cells (with a maximum of $500 per 0.5 kilowatt) for systems installed in 2006 and 2007.

$$TaxCredit_{t,y,Y} \equiv MAX \langle EqCost_{t,y} \cdot TaxCreditPct_{t,y}, TxCreditMax_{t,y} \rangle,$$
$$if \ Y = 3,$$ (B-161)
$$0, \quad if \ Y \neq 3$$

Annual kWh generated by technology:
AnnualKWH $_{t,n,y}$ represents the base level of annual system kWh generation for a new system for the specific technology and vintage being analyzed.

For photovoltaics (technology, t=1) annual generation is determined by system size, efficiency and solar availability as follows:

$$AnnualKWH_{t,n,y} = \left(\frac{ElEff_{t,y} \cdot SolarIns_n \cdot 365.25 \cdot}{xSqftperKW_y \ / \ 10.8 \cdot LossFac_{t,y}} \right) \cdot xCalcKW_{t,n,y}$$ (B-162)

The parenthetical expression represents the kWh generated by a 1-kW system, so this amount is then multiplied by system kW to yield the annual generation amount. Solar insolation, *SolarIns* $_n$ varies within a Census division by niche, and is expressed in average daily kWh falling on a square meter area and annualized in equation (B-162). The insolation value is then adjusted for module

B-99

square footage (10.8 square feet per square meter) and the electrical efficiency of a prototypical photovoltaic technology. Finally a loss factor (the percentage of the generation reaching the outlet) allows further adjustment of annual kWh available to the building by accounting for downstream electrical losses. The prototypical PV module has 14% efficiency and requires an area of 77 square feet for a 1-kW system. The variable for the estimated photovoltaic array square footage for a 1-kw system, $xSqftperKW_y$, depends inversely on the efficiency of the as follows:

$$xSqftperKW_y = 77 \cdot \frac{0.14}{ElEff_{1,v}}$$

(B-163)

The higher the efficiency, the smaller the square footage that will be required for a 1-kw system. When system size is allowed to be endogenous (2015 and after), higher efficiency modules lead to higher capacity systems being potentially selected.

For fuel cells (t=2), annual system generation for a 1-kw unit is determined by hours-of-use multiplied by an availability factor and a loss factor. Annual generation is determined by multiplying the amount for a 1-kW system by system capacity:

$$AnnualKWH_{t,y} = \left(OperHours_t \cdot Avail_{t,y} \cdot LossFac_{t,y} \right) \cdot kW_{t,y}$$

(B-164)

For distributed wind turbines (t=3), annual system generation is determined by turbine capacity ($kW_{3,y}$), efficiency and average wind speeds as follows::

$$
\begin{aligned}
AnnualKWH_{t,n,y} = & \\
& \left(\frac{ElEff_{t,y}}{ElEff_{t,1}} \cdot (.0645 - .0670 \cdot xMpS_n + .0210 \cdot xMpS_n^2 - \right. \\
& \left. .0011 \cdot xMpS_n^3) \right) \\
& \cdot LossFac_{t,y} \cdot kW_{t,y}
\end{aligned}
$$

(B-165)

xMpS denotes average wind speed in meters per second. Distributed wind turbine penetration is also assumed appropriate and suitable for only rural residences (developed from RECS 2001 and input in rgentk) due to permitting issues and site limitations.

$KWH_{t,y,Y}$ is the actual kWh generated in each of the years of the cash flow analysis. The actual generation is the ideal generation adjusted for degradation as the system ages. Currently, only photovoltaic generation has a non-zero degradation factor. Its value of 0.01 assumes a 1-percent per year loss in output as the modules age. Degradation begins in the year after the system is fully in use, which for the cash flow model assumptions is year 3.

$$KWH_{t,y,Y} = AnnualKWH_{t,[n],y} \cdot \left(1 - Degredation_{t,y}\right)^{(Y-2)}$$

(B-166)

Fuel consumption for fuel-using distributed generation technologies:

Fuel consumption for fuel cells (t=2) is denoted by the variable $FuelInput_{t,y}$ and is calculated in MMBtu of the input fuel used by the technology:

$$FuelInput_{t,y} = \frac{0.003412 \cdot OperHours_t \cdot Avail_{t,y}}{ElEff_{t,y}} \cdot kW_{t,y}$$

(B-167)

Calculation of waste heat available for water heating and space heating use:

$BTUWasteHeat_{t,y}$ represents the amount of waste heat potentially available for providing an offset to home water heating. It is also computed in MMBtu and is the difference between the fuel input and the energy expended on electricity generation multiplied by the waste heat recovery efficiency specific to this technology and vintage.

$$BTUWasteHeat_{t,y} = \left(FuelInput_{t,y} - .003412 \cdot AnnualKWH_{t,y}\right) \cdot WhRecoveryEff_{t,y}$$

(B-168)

The amount of available waste heat is used to offset water heating end use service demand up to the average consumption from RECS:

$$WaterHeatingMMBtu_{t,y} = MIN\left\langle BTUWasteHeat_{t,y}, AvgWaterHtgMMBtu \right\rangle$$

(B-169)

Any amount of waste heat generated beyond the average water heating requirements is assumed to be not utilized to offset end use fuel requirements.

Net fuel cost:

BaseYrFuelCost$_{t,y}$ is the initial fuel costs for operating the generation technology net of savings stemming from displaced water heating or space heating. It is calculated from the current fuel price and fuel input and converted into the same year dollars as the technology capital costs (currently 2003 constant dollars).

$$BaseYrFuelCost_{t,y} = \left(FuelInput_{t,y} - WaterHtgMMBtu_{t,y}\right) \cdot FuelPrice_{r,y} \tag{B-170}$$

FuelCost$_{t,y,Y}$ is the nominal dollar value fuel cost for the technology net of any water heating cost savings from using waste heat:

$$FuelCost_{t,y,Y} = BaseYrFuelCost_{t,y} \cdot \left(1 + inflation\right)^{(Y-2)} \tag{B-171}$$

The value of electricity savings calculations:

ValElecSaveBase$_{t,n,l,y}$ represents the calculated value of generated electricity for the initial year of the cash flow simulation for a particular solar and price level niche (n,l). This value is further adjusted to account for inflation and generation efficiency degradation in a later calculation described below.

Case 1: Photovoltaics

If generation is less than average electricity usage (i.e., *AnnualKWH$_{t,y}$* <= *AvgKWH*), then savings are valued at the air conditioning price, *PELRSOUT$_{r,y,AC}$* (since photovoltaic generation tends to correlate with the need for air conditioning):

$$ValElecSaveBase_{t=1,n,l,y} = \begin{bmatrix} PELRSOUT_{r,y,AC} \cdot xRateScalar_{n,l} \cdot .003412 + \\ EPRPSPR_y / 1000 \cdot xScaleRPS_t \end{bmatrix} \cdot AnnualKWH_{t,[n],y} \tag{B-172}$$

The factor .003412 converts prices in dollars per million Btu to dollars per kWh. The potential to model renewable portfolio standard credits (often referred to as the "RPS" credits) is incorporated in NEMS. The credit is received if it applies, however in current reference case runs RPS credits are not received. The credit amount, *EPRPSPR$_y$* , is provided by the NEMS Electricity Market Module and must be divided by 1000 since it is in provided "mills" per kWh units. If the credit is received, the

the scalar is set to a value greater than zero (e.g., for triple credits, the scalar is 3). Since RPS credits often have a last year or "sunset" year, the cashflow simulation also tracks the calendar year of each of the simulated years and zeros out the credit if the calendar year exceeds the sunset year. If generation exceeds average usage, then the excess kWh are sold to the grid at the marginal price for utility purchases ($PELME_{r,y}$) and the value is:

$$
\begin{aligned}
ValElecSaveBase_{t,n,l,y} = \\
.003412 \cdot \begin{bmatrix} PELRSOUT_{r,y,AC} \cdot xRateScalar_{n,l} \cdot AvgKwh \\ + PELME_{r,y} \cdot (AnnualKWH_{t,y} - AvgKwh) \end{bmatrix} \\
+ EPRPSPR_{y} / 1000 \cdot xScaleRPS_{t} \cdot AnnualKWH_{t,y}
\end{aligned}
\tag{B-173}
$$

Case 2: All other technologies

The air conditioning price, $PELRSOUT_{r,y,AC}$, is replaced by $PELRS_{r,y}$, the average residential electricity price. RPS credits are generally not available for the non-renewable technologies, therefore the when RPS credits are modeled, scalars for non-renewable technologies are set to zero.

$ValElecSave_{t,n,l,y,Y}$ is the nominal dollar (inflated) value of $ValElecSaveBase_{t,n,l,y}$ with adjustment for output degradation:

$$
\begin{aligned}
ValElecSav\, e_{t,n,l,y,Y} = \\
ValElecSav\, eBase_{t,n,l,y} \cdot (1 + inflation)^{(Y-2)} \\
\cdot (1 - Degredatio\, n_{t,y})^{(Y-2)}
\end{aligned}
\tag{B-174}
$$

Maintenance cost calculations:

$MaintCost_{t,y,Y}$ is the calculated nominal dollar cost of maintenance for the specific technology and vintage being analyzed. $MaintCostBase_{t,y}$ is the annual maintenance cost per kW and $xIntervalCst_{t=1,y}$ is the "interval" maintenance cost for inverter replacement per kW if the technology being evaluated is a photovoltaic system (i.e., technology index 1). $xIntervalCst_{t=1,y}$ is non-zero only if the cash flow model year, Y, is an inverter replacement year based on the replacement interval for photovoltaic

photovoltaic system vintage, y.

$$MaintCost_{t,y,Y} = kW_{t,y} \cdot \left[MaintCostBase_{t,y} + xIntervalCst_{t=1,y} \right]$$
$$\cdot \left(1 + inflation\right)^{(Y-2)}$$

(B-175)

Deductible expenses for personal income taxes:

$$TaxDeduct_{t,y,Y} =$$
$$\begin{pmatrix} IntAmt_{t,y,Y-1} - MaintCost_{t,y,Y-1} + \\ FuelCost_{t,y,Y-1} - ValElecSave_{t,y,Y-1} \end{pmatrix} \cdot$$
$$TaxRate + TaxCredit_{t,y,Y}$$

(B-176)

Cash flow and investment payback years:

$NetCashFlow_{t,n,l,y,Y}$, $CumCashFlow_{t,n,l,y,Y}$ and $SimplePayback_{t,n,l,y}$ years:

$$NetCashFlow_{t,n,l,y,Y} =$$
$$ValElecSave_{t,n,l,y,Y} + TaxDeduct_{t,y,Y} - OutLay_{t,y,Y} -$$
$$FuelCost_{t,y,Y} - MaintCost_{t,y,Y}$$

(B-177)

$CumCashFlow_{t,n,l,y,Y}$ is defined as the accumulated sum of all prior $NetCashFlow_{t,n,l,y,Y}$ amounts.

Simple payback years:

$SimplePayback_{t,n,l,y}$ is defined as the first year in the cashflow stream for which an investment has a positive $CumCashFlow_{t,n,l,y,Y}$ (i.e., the "Y" if and when $CumCashFlow_{t,n,l,y,Y}$ first becomes greater than or equal to 0). Note that $SimplePayback_{t,n,l,y}$ is stored as a real (floating point) number and not rounded off to "whole" years – this will affect the calculated maximum penetration of technology as described below.

Real-valued simple payback calculation:

Let Y' be the integer-valued year in the 30-year cash flow simulation for which $CumCashFlow_{t,y,Y'}$ achieves a non-negative value. Call this value $IntSimplePayback_{t,n,l,y}$ to represent the integer-valued payback. The real-valued $SimplePayback_{t,n,l,y}$ for this technology is interpolated as follows:

$$SimplePayback_{t,n,l,y} = IntSimplePayback_{t,n,l,y} -$$

$$\frac{CumCashFlow_{t,n,l,y,Y'-1} + NetCashFlow_{t,n,l,y,Y'}}{NetCashFlow_{t,n,l,y,Y'}} \tag{B-178}$$

Since Y' is the first year for which $CumCashFlow_{t,n,l,y,Y}$ is greater than or equal to zero, its prior year value (in year Y'-1) was less than zero. If $CumCashFlow_{t,n,l,y,Y'-1}$ was small in absolute value relative to $NetCashFlow_{t,n,l,y,Y'}$, then the right hand term would approach unity, which is the same as saying that the payback was achieved close to the beginning of Y.

Maximum penetration into new construction:

$$MaxPen_{t,n,l,y} = \frac{PenParm_t}{SimplePayback_{t,n,l,y}} \tag{B-179}$$

$PenParm_t$ is set to 0.3 for all technologies. Thus the asymptotically approached $MaxPen_{t,n,l,y}$ for these technologies with a 1-year payback will be 30%. Since $SimplePayback_{tn,l,y}$ is a real-valued number, it can potentially achieve values of less than one. For a $SimplePayback_{t,n,l,y}$ of 0.5 years, $MaxPen_{t,n,l,y}$ is 60%.

Penetration function formula for new construction:

For a given value of $SimplePayBack_{t,n,l,y}$, penetration in NEMS model year "y" is an increasing function of y.

$$Pen_{t,n,l,y} =$$

$$MaxPen_{t,n,l,y} - \frac{1}{\dfrac{1}{MaxPen_{t,n,l,y}} + e^{\left[\alpha_t \cdot \left(y - RECSYear + 1 - SimplePayBack_{[t],[y]}\right)\right]}} \tag{B-180}$$

$Pen_{t,n,l,y}$ is constrained to a maximum penetration of 75% into new construction.

The figure below shows the logistic-shaped penetration function for a variety of years to achieve positive cumulative net cashflow:

Penetration Rate of Distributed Generation into New Construction for Selected Years to Positive Cumulative Net Cash Flow:
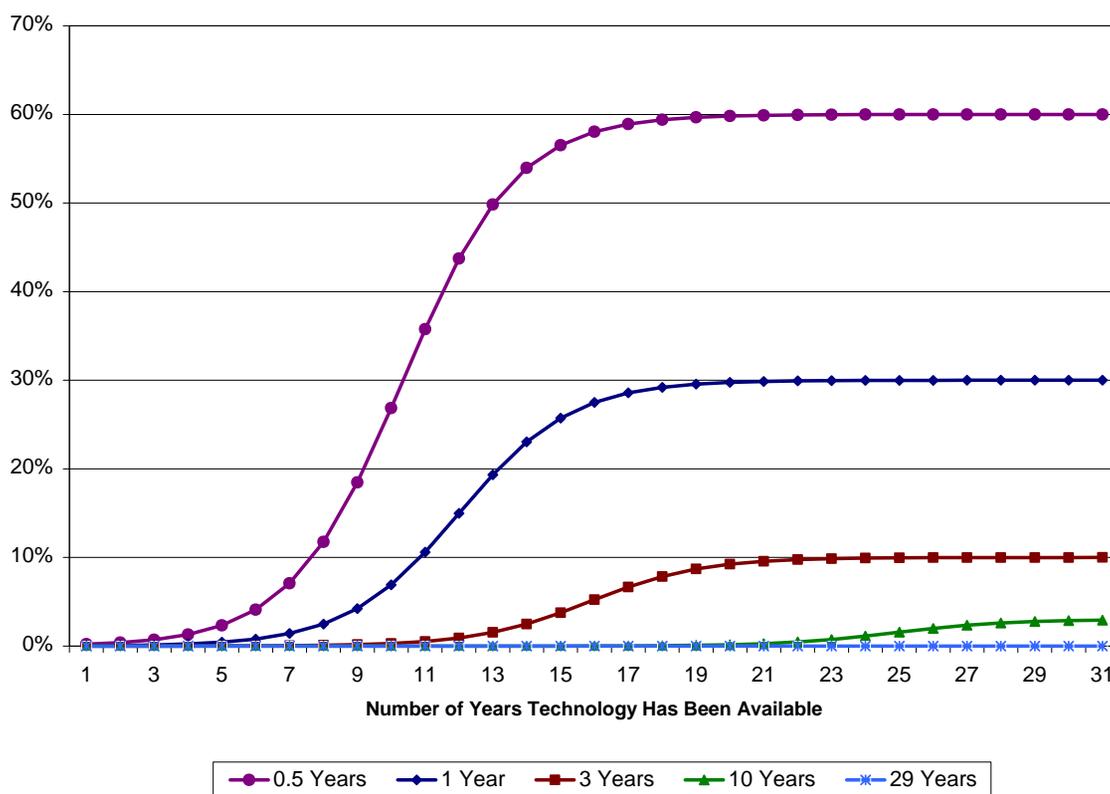
Penetration function formula for existing construction:

Penetration of distributed generation into the existing housing stock is limited to a maximum of 0.5% or one-fortieth of the penetration into new construction, whichever is less. It is denoted by $DeltaPen_{t,n,l,y}$.

Outputs to the Residential Module and NEMS:

Explicit recognition of the Census division dimension commences here. $Units_{y,r,t}$ denote the accumulated total units in NEMS model year y employing the relevant type of generation technology by Census division and is the sum of $Units_{y-1,r,t}$ plus penetration into new construction (HSEADD) plus

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plus penetration into existing housing units (EH) for the current NEMS model year plus additional exogenous penetration (program driven amounts). The subscripts denoting Census division are restored for this section of the documentation, to explicitly describe the interface with NEMS.

$Units_{y,r,t}$ accumulates the number of projected distributed generation units based on penetration rates into new (HSEADD) and existing housing units (EH):

$$Units_{y,r,t} = Units_{y-1,r,t}$$

$$+ \sum_{n,l \in r} \begin{bmatrix} \left(ExogPen_{y,r,t} - ExogPen_{y-1,r,t} \right) + \\ \left(Pen_{t,n,l,y} \cdot HSEADD_{r,y} + DeltaPen_{t,n,l,y} \cdot EH_{r,y} \right) \end{bmatrix} \qquad \text{(B-181)}$$
$$\cdot xHHShare_{n,l}$$

$Trills_{y,r,t}$ accumulates total generation (own use plus grid sales) and converts to trillions of Btu:

$$Trills_{y,r,t} = Trills_{y-1,r,t}$$

$$+ \sum_{n,l \in r} \begin{bmatrix} \left(ExogPen_{y,r,t} - ExogPen_{y-1,r,t} \right) + \\ \left(Pen_{t,n,l,y} \cdot HSEADD_{r,y} + DeltaPen_{t,n,l,y} \cdot EH_{r,y} \right) \end{bmatrix} \qquad \text{(B-182)}$$
$$\cdot xHHShare_{n,l} \cdot AnnualKWH_{t,n,l,y} \cdot 3412 \cdot 10^{-}$$

$TrillsOwnUse_{y,r,t}$ accumulates total electricity generation for on-site consumption, "own use," and converts to trillions of Btu. It is the minimum of 1) the average electric consumption from RECS, and 2) the annual generation.

$$TrillsOwnUse_{y,r,t} = TrillsOwnUse_{y-1,r,t} +$$

$$\begin{bmatrix} \sum_{n,l \in r} \begin{bmatrix} \left(ExogPen_{y,r,t} - ExogPen_{y-1,r,t} \right) + \\ \begin{pmatrix} Pen_{t,n,l,y} \cdot HSEADD_{r,y} + DeltaPen_{t,n,l,y} \\ \cdot EH_{r,y} \end{pmatrix} \end{bmatrix} \\ \cdot xHHShare_{n,l} \\ \cdot MAX \left\langle AnnualKWH_{t,n,l,y}, RECSAvgKwh_{n,l} \right\rangle \\ \cdot 3412 \cdot 10^{-12} \end{bmatrix} \qquad \text{(B-183)}$$

FuelUsage$_{y,r,t}$ accumulates *FuelInput$_{r,t,y}$* and converts from MMBtu to trillions of Btu:

$$FuelUsage_{y,r,t} = FuelUsage_{y-1,r,t} +$$

$$\sum_{n,l \in r} \left[\begin{array}{l} \left(ExogPen_{y,r,t} - ExogPen_{y-1,r,t} \right) + \\ \left(Pen_{t,n,l,y} \cdot HSEADD_{r,y} + DeltaPen_{t,n,l,y} \cdot EH_{r,y} \right) \end{array} \right] \quad \text{(B-184)}$$

$$\cdot xHHShare_{n,l} \cdot FuelInput_{r,t,y} \cdot 10^{-6}$$

HWBtu$_{y,r,t}$ accumulates *WaterHtgMMBtu$_{r,t,y}$* and converts to trillions of Btu:

$$HWBtu_{t,y} = HWBtu_{t,y-1} +$$

$$\sum_{n,l \in r} \left[\begin{array}{l} \left(ExogPen_{y,r,t} - ExogPen_{y-1,r,t} \right) + \\ \left(Pen_{t,n,l,y} \cdot HSEADD_{r,y} + DeltaPen_{t,n,l,y} \cdot EH_{r,y} \right) \end{array} \right] \quad \text{(B-185)}$$

$$\cdot xHHShare_{n,l} \cdot WaterHtgMMBtu_{r,t,y} \cdot 10^{-6}$$

Invest$_{y,r,t}$ is the current year investment in distributed generation resources in millions of 2005 dollars:

$$Invest_{y,r,t} = Invest_{y-1,r,t} +$$

$$\sum_{n,l \in r} \left[\begin{array}{l} \left(ExogPen_{y,r,t} - ExogPen_{y-1,r,t} \right) + \\ \left(Pen_{t,n,l,y} \cdot HSEADD_{r,y} + DeltaPen_{t,n,l,y} \cdot EH_{r,y} \right) \end{array} \right] \quad \text{(B-186)}$$

$$\cdot xHHShare_{n,l} \cdot EqCost_{t,y} \cdot kW_t \cdot 10^{-6}$$

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

$$
\begin{aligned}
RSFLCN_{y,ng,r} = \\
\frac{\left(\begin{array}{l} HTRCON_{y,ng,r} + H2OCON_{y,ng,r} + CKCON_{y,ng,b,r} + GASINPUT_{y,r} + \\ DRYCON_{y,ng,r} + COOLCN_{y,ng,r} + SHTCON_{y,ng,r} + APLCON_{y,ng,r} \end{array}\right)}{1000000} \\
* LEAPYR
\end{aligned}
\tag{B-187}
$$

Electricity

$$
\begin{aligned}
RSFLCN_{y,el,r} = \\
\frac{\left(\begin{array}{l} HTRCON_{y,el,r} + H2OCON_{y,el,r} + CKCON_{y,el,b,r} + REFCON_{y,r} + \\ DRYCON_{y,el,r} + COOLCN_{y,el,r} + SHTCON_{y,el,r} + APCCON_{y,r} + \\ FRZCON_{y,r} + CSWCON_{y,r} + DSWCON_{y,r} + LTCON_{y,r} + \\ SPACON_{y,r} + CFCON_{y,r} + CMCON_{y,r} + MOCON_{y,r} + \\ RCCON_{y,r} + HACON_{y,r} + SSCON_{y,r} + \\ FANCON_{y,r} + PCCON_{y,r} + TVCON_{y,r} - ANNUALKWH_{y} \end{array}\right)}{1000000} \\
* LEAPYR
\end{aligned}
\tag{B-188}
$$

Distillate

$$RSFLCN_{y,ds,r} = \frac{\left(HTRCON_{y,ds,r} + H2OCON_{y,ds,r} + SHTCON_{y,ds,r} + APLCON_{y,ds,r}\right)}{1000000} * LEAPYR \qquad \text{(B-189)}$$

LPG

$$RSFLCN_{y,lpg,r} = \frac{\left(\begin{array}{l} HTRCON_{y,lpg,r} + H2OCON_{y,lpg,r} + CKCON_{y,lpg,b,r} + \\ SHTCON_{y,lpg,r} + APLCON_{y,lpg,r} \end{array}\right)}{1000000} * LEAPYR \qquad \text{(B-190)}$$

Kerosene

$$RSFLCN_{y,ks,r} = \frac{\left(HTRCON_{y,ks,r} + SHTCON_{y,ks,r}\right)}{1000000} * LEAPYR \qquad \text{(B-191)}$$

Coal

$$RSFLCN_{y,cl,r} = \frac{SHTCON_{y,cl,r}}{1000000} * LEAPYR \qquad \text{(B-192)}$$

Wood

$$RSFLCN_{y,wd,r} = \frac{\left(HTRCON_{y,wd,r} + SHTCON_{y,wd,r}\right)}{1000000} * LEAPYR \qquad \text{(B-193)}$$

Geothermal

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$$RSFLCN_{y,geo,r} = \frac{\left(HTRCON_{y,geo,r} + COOLCN_{y,geo,r}\right)}{1000000} * LEAPYR \qquad \text{(B-194)}$$

National Total

$$RSFLCN_{y,US,r} = \sum_{r}\left(RSFLCN_{y,f,r}\right) \qquad \text{(B-195)}$$

Appendix C: 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 C-1 shows the correspondence between the subscripts in the documentation and the subscripts in the FORTRAN source code.

Table C-1 Definition of Subscripts

Subscript in Documentation	Subscript in the FORTRAN Code	Brief Description
r	r or d	Census Division
t	y or t	Calendar year index
f	f	Fuel types
b	b	Housing type
y	curiyr or curcalyr	the annual index
y-1	curiyr-1 or curcalyr-1	Previous year
eg	eqc, reccl	General equipment class within an end use (e.g., 1 to 11 for heat)
egsw	eqcsw	Equipment class within an end use available to switch to another equipment class
es	eqt	Specific equipment type within an end use
v	v	Vintage of equipment

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

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 2030. In the FORTRAN code, the subscripts for CURIYR represent array dimensions starting with an index of 1 to represent 1990, and CURCALYR represents the calendar year 1990 through 2030.

- 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 2030.

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-2006" vintage, and new additions to the housing stock are referred to as the "post-2005" 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: $HDR_2 = 0.999$

Mobile Homes: $HDR_3 = 0.976$

The surviving 2005 housing stock is defined by

$$EH_{y,b,r} = RECS\ data\ ,\ if\ y = 2005$$
$$EH_{y,b,r} = EH_{y-1,b,r} * HDR_b\ ,\ if\ y > 2005$$

(C-1)

where,

$EH_{y,b,r}$ is 2005 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:

$$NH_{y,r} =$$
$$MC\_HUSPS1_{y,r} + MC\_HUSPS2A_{y,r} + MC\_HUSMFG_{y,r}$$

(C-2)

where,

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

$MC\_HUSPS1_{y,r}$ is single-family housing added by year and Census Division,

$MC\_HUSPS2A_{y,r}$ is multifamily housing added by year and Census Division,

$MC\_HUSMFG_{y,r}$ 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 ten 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,

$$OPCOST_{y,es,b,r,v} =$$
$$PRICES_{f,r,y} * EQCUEC_{y,eg,b} * HDDFACT_{r,y} * RTEFFAC_{es,v} \qquad \text{(C-3)}$$

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 specific equipment type 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:

$$EQCOST_{es,y,CAP} = RTEQCOST_{es} \ , if \ RTMATURE_{es} = MATURE$$
$$EQCOST_{es,y,RET} = RTRECOST_{es} \ , if \ RTMATURE_{es} = MATURE \qquad \text{(C-4)}$$

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

$$EQCOST_{es,y,RET} = \frac{RTRECOST_{es} * 2 * d}{1 + \left(\dfrac{y - y_1}{y_0 - y_1} \right)^y} + (1 - d) * RTRECOST_{es} \ ,$$
$$if \ RTMATURE_{es} = ADOLESCENT$$

$$\text{(C-5)}$$

$$EQCOST_{es,y,CAP} = \frac{RTEQCOST_{es} * d}{1 + \left(\dfrac{y - y_1}{y_0 - y_1}\right)^y} + (1 - d) * RTEQCOST_{es},$$

$$if\ RTMATURE_{es} = INFANT$$

$$EQCOST_{es,y,RET} = \frac{RTRECOST_{es} * d}{1 + \left(\dfrac{y - y_1}{y_0 - y_1}\right)^y} + (1 - d) * RTRECOST_{es},$$

$$if\ RTMATURE_{es} = INFANT$$

(C-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 \$2007 per unit for new homes, remains constant for MATURE technologies only (used when ctype = CAP),
$RTRECOST_{es}$	Retail capital cost in \$2007 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,

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,

$$LFCY_{y,es,b,r,v} = CAPITAL_{es} + OPCOST_{y,es,b,r,v} * \left(\frac{1 - (1 + DISRT)^{-HORIZON}}{DISRT} \right) \qquad (\text{C-7})$$

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},

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

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,

$$HEATSYS_{y,eg,b,r} = e^{\left(RFTBIAS_{eg}+RFTCBETA_{eg}*LFCY_{y,eg,b,r,1}\right)} \qquad \text{(C-8)}$$

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 type 1 (new construction), 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:

$$SYSTOT_{y,b,r} = \sum_{eg=1}^{eg=11} HEATSYS_{y,eg,b,r} \qquad \text{(C-9)}$$

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

$$HTYSSHR_{y,eg,b,r} = \frac{HEATSYS_{y,eg,b,r}}{SYSTOT_{y,b,r}}, if\ SYSTOT_{y,b,r} > 0$$

$$HTYSSHR_{y,eg,b,r} = 0, otherwise \qquad \text{(C-10)}$$

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,

$$EQWTN_{y,es,b,r} = e^{\left(RTECBTA\ 1_{es}*CAPITAL_{es} + RTECBTA\ 2_{es}*OPCOST_{y,es,b,r,1}\right)} \tag{C-11}$$

$$EQWTR_{y,es,b,r} = e^{\left(RTECBTA\ 1_{es}*CAPITAL_{es} + RTECBTA\ 2_{es}*OPCOST_{y,es,b,r,2}\right)} \tag{C-12}$$

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 (1=new, 2=existing)
$RTECBTA1_{es}$, $RTECBTA2_{es}$	are parameter values of the same fit.

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

$$TOTEWTN_{y,eg,b,r} = \sum_{es=loweff}^{es=hieff} EQWTN_{y,es,b,r} \tag{C-13}$$

$$TOTEWTR_{y,eg,b,r} = \sum_{es=loweff}^{es=hieff} EQWTR_{y,es,b,r} \tag{C-14}$$

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

$$EQFSHRN_{y,es,b,r} = \frac{EQWTN_{y,es,b,r}}{TOTEWTN_{y,eg,b,r}}, if\ TOTEWTN_{y,eg,b,r} > 0$$

$$EQFSHRN_{y,es,b,r} = 0,\ otherwise$$

(C-15)

$$EQFSHRR_{y,es,b,r} = \frac{EQWTR_{y,es,b,r}}{TOTEWTR_{y,eg,b,r}}, if\ TOTEWTR_{y,eg,b,r} > 0$$

$$EQFSHRR_{y,es,b,r} = 0,\ otherwise$$

(C-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,

$$NEQTSHR_{y,es,b,r} = EQFSHRN_{y,es,b,r}$$

(C-17)

$$REQTSHR_{y,es,b,r} = EQFSHRR_{y,es,b,r}$$

(C-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,

$$WTEQCEFFN_{y,eg,b,r} = \frac{\sum_{es}\left[\dfrac{NEQTSHR_{y,es,b,r}}{RTEQEFF_{y,es}}\right]}{\sum_{es}NEQTSHR_{y,es,b,r}}, if \sum_{es}NEQTSHR_{y,es,b,r} > 0 \qquad (C\text{-}19)$$

$$WTEQCEFFN_{y,eg,b,r} = \frac{1}{RTBASEFF_{eg}}, otherwise$$

$$WTEQCEFFR_{y,eg,b,r} = \frac{\sum_{es}\left[\dfrac{REQTSHR_{y,es,b,r}}{RTEQEFF_{y,es}}\right]}{\sum_{es}REQTSHR_{y,es,b,r}}, if \sum_{es}REQTSHR_{y,es,b,r} > 0 \qquad (C\text{-}20)$$

$$WTEQCEFFR_{y,eg,b,r} = \frac{1}{RTBASEFF_{eg}}, otherwise$$

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,

$RTEQEFF_{y,es}$ is the efficiency of the equipment type,

$RTBASEFF_{eg}$ is the 2005 stock-average efficiency of the equipment class, and

$WTEQCEFFR_{y,eg,b,r}$ 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 C-2 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 2006 (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 seven categories of equipment that are tracked.

Table C-2. Heating Equipment, UEC and Housing Shell Accounting Scheme

Housing Units that Existed in 2005			Housing Units Added From 2006 through 2030		
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-2006 housing units are:

EQCESE denotes the surviving pre-2006 equipment stock in pre-2006 homes,

EQCSR90 represents equipment stock in pre-2006 homes that has been replaced after 2005 and that still survives, and

EQCRP90 is current-year replacement equipment for pre-2006 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-2005 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 2005 equipment in housing units that existed in
2005,
EQCSUEC is the average UEC for surviving equipment in pre-2006 housing units,
EQCAUEC is the average UEC for surviving equipment in post-2006 housing units,
EQCRUEC is the UEC for all equipment added in the current year to replace pre-2006
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-2006 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-2006 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-2006 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,

$$SVRTE_{y-t,L_{min},L_{max}} = 1.0$$

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

$$SVRTE_{y-t,L_{min},L_{max}} = 0.0, if\ y-t \geq L_{max}$$

where,

$SVRTE_{y\text{-}t,L_{min},L_{max}}$	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-2005 (new) houses is the product of the number of new houses and the market share of each equipment class. This is expressed as,

$$EQCADD_{y,t,eg,b,r} = HSEADD_{y,b,r} * SHARESN_{y,eg,b,r} \qquad \text{(C-22)}$$

where,

$EQCADD_{y,t,eg,b,r}$	is the number of post-2005 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-2005 equipment units in post-2005 houses is calculated as:

$$EQCREP_{y,t,eg,b,r} = \sum_{t=2006}^{t=y-1}\left(EQCADD_{t,eg,b,r} * HDR_b^{\,y-t} * \left(1-SVRTE_{eg}\right)\right) \qquad \text{(C-23)}$$

where,

EQCREP$_{y,t,eg,b,r}$ is the number of equipment replacements of post-2005 equipment in post-2005 houses,

HDR$_b$ is the housing survival rate by housing type, and

y-t   represents the age of the equipment.

Post-2005 replacement units required for pre-2006 houses in the current year are calculated as,

$$EQCRP90_{y,t,eg,b,r} = \sum_{t=2006}^{t=y-1} EQCESE_{2005,eg,b,r} * EQCRET_{y,eg} * HDR_b$$

(C-24)

where,

EQCRP90$_{y,t,eg,b,r}$ is the number of replacement units required for pre-2006 homes in year *y*, vintaged to year *t* by housing type and Census Division,

EQCRET$_{y,eg}$ is the equipment retirement rate for pre-2006 houses by forecast year,

EQCESE$_{2005,eg,b,r}$ is the pre-2006 vintage stock of equipment in pre-2006 vintage houses in 2005 by housing type and Census Division.

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

$$EQCRP90RP_{y,t,eg,b,r} =$$
$$\sum_{t=2006}^{t=y-1} \left(EQCRP90_{t,eg,b,r} + EQCRP90RP_{y,t,eg,b,r}\right) * \left(1-SVRTE_{eg}\right)$$

(C-25)

where,

EQCRP90RP$_{y,t,eg,b,r}$ is the number of replacement units required to replace post-2005 equipment in pre-2006 houses by forecast year y, vintaged to year t, by 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).

$$ELIGIBLE_{y,eg,b,r} =$$

$$\sum_{t=2006}^{y-1} \left(EQCRP90_{y,t,eg,b,r} + EQCRP90RP_{y,t,eg,b,r} + EQCREP_{y,t,eg,b,r} \right) * \left(SWFACT_{eg} \right) \quad \text{(C-26)}$$

where,

  $ELIGIBLE_{y,eg,b,r}$ is the number of replacements eligible to switch technology types by housing type and Census Division, and

  $SWFACT_{eg}$ is the fraction who may switch from equipment class eg.

The switching weight for each equipment type is calculated as,

$$RPWEIGHT_{y,egsw,b,r} = e^{\left(RTSWBIAS_{egsw} + RTSWBETA_{egsw} * \left(LFCY_{y,eqsw,b,r,v} + RPINSCOST_{eg,egsw} \right) \right)} \quad \text{(C-27)}$$

Summing over all equipment types,

$$TOTSH_{y,b,r} = \sum_{egsw=1}^{egsw=11} RPWEIGHT_{y,egsw,b,r} \quad \text{(C-28)}$$

allows for shares summing to 100 percent.

$$RPSHARE_{y,egsw,b,r} = \frac{RPWEIGHT_{y,egsw,b,r}}{TOTSH_{y,b,r}}, \text{if } TOTSH_{y,b,r} > 0$$

$$RPSHARE_{y,egsw,b,r} = 0, \text{otherwise} \quad \text{(C-29)}$$

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 weights.

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

The surviving post-2005 vintage equipment in pre-2006 houses is computed as,

$$EQCSR90_{y,t,eg,b,r} =$$
$$\sum_{t=2006}^{t=y-1} \left(\left(EQCRP90_{t,y,eg,b,r} + EQCRP90RP_{t,y,eg,b,r} \right) * SVRTE_{eg,y-t,L_{min},L_{max}} * HDR_b^{\,y-t} \right) \quad \text{(C-30)}$$

where,

EQCSR90$_{y,t,eg,b,r}$ is the equipment stock in pre-2006 homes that has been replaced after 2005 and still survives by housing type and Census Division,

EQCRP90$_{t,y,eg,b,r}$ is the number of replacement (post-2005 vintage) equipment units demanded each year in pre-2006 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$_{eg,y-t,Lmin,Lmax}$ 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-2005 equipment, originally purchased as additions or replacements in post-2005 houses, is calculated as,

$$EQCSUR_{y,eg,b,r} = \sum_{t=2006}^{t=y-1} \left(\left(EQCADD_{t,eg,b,r} + EQCREP_{t,eg,b,r} \right) * SVRTE_{eg,\,y-t,L_{min},L_{max}} \right) \quad \text{(C-31)}$$

where,

$EQCSUR_{y,eg,b,r}$	is the surviving post-2005 equipment purchased as additions or replacements in post-2005 houses by housing type and Census Division,
$EQCADD_{t,eg,b,r}$	is the quantity of post-2005 vintage equipment added to post-2005 houses by forecast year, housing type and Census Division,
$SVRTE_{eg,y-t,Lmin,Lmax}$	is the equipment survival function,
$EQCREP_{t,eg,b,r}$	is the number of equipment replacements of post-2005 equipment in post-2005 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-2006 housing stock, and two indices correspond to the post-2005 stock, one for housing constructed in the current year and the other for the average post-2005 stock. The existing shell index is 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. The shell index for newly-constructed homes is based on the choice of HVAC system, which includes the shell characteristics represented as an index.

The existing housing heating shell index is calculated as,

$$EHSHELL_{y,f,r,b} = EHSHELL_{y-1,f,r,b}, if\ EHSHELL_{y,f,r,b} > EHSHELL_{y-1,f,r,b}$$

$$EHSHELL_{y,f,r,b} = LIMIT, if\ EHSHELL_{y,f,r,b} > LIMIT$$

$$EHSHELL_{y,f,r,b} =$$

$$EHSHELL_{RECSYEARf,r,b} * RSELAST\left(y,f,\alpha2,EF1,EF2,EF3,2005\right)$$

$$* TECHG_{e,r,b}, otherwise$$

(C-322)

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

RSELAST is the short-term price elasticity function with distributed lag weights EF1, EF2, and EF3, and   , the total short-term price elasticity,

$TECHG_{1,d,b}$ is a parameter that represents the annual increase in existing shell integrity due to technology improvements, and

The new housing heating shell index is calculated as,

$$NHSHELL_{y,f,r,b} = \sum_{es}\left(EQFSHRN_{y,es,b,r} * SHELLEFF_{y,es,b,r}\right)$$

(C-33)

where,

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

$SHELLEFF_{y,es,b,r}$ is the shell integrity factor associated with each HVAC package available.

The average post-2005 housing heating shell index is calculated as,

$$AHSHELL_{y,f,r,b} = \frac{\sum\limits_{eg}\left[\begin{array}{c} NHSHELL_{y,r,r,b} * EQCADD_{y,eg,b,r} + AHSHELL_{y-1,f,r,b} * \\ \left(EQCREP_{y,eg,b,r} + EQCSUR_{y,eg,b,r}\right) \end{array}\right]}{\sum\limits_{eg}\left[EQCADD_{y,eg,b,r} + EQCREP_{y,eg,b,r} + EQCSUR_{y,eg,b,r}\right]} \quad \text{(C-344)}$$

where,

$AHSHELL_{y,f,r,b}$ is the average post-2005 heating shell index by year, fuel, Census Division, and building type, equal to NHSHELL in 2006,

$NHSHELL_{y,f,r,b}$ 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-2005 equipment in post-2005 houses, and

$EQCSUR_{y,eg,b,r}$ is the surviving post-2005 equipment purchased as additions or replacement in post-2005 houses by forecast year, housing type and Census Division.

In addition to the calculation shown above, the module places an additional restriction upon $AHSHELL_{y,f,r,b}$: it may never increase. If ever $AHSHELL_{y,f,r,b}$ is calculated to increase, its value is set to the prior year's value.

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:

$$EQCNUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * WTEQCEFFN_{y,eg,b,r} *$$

$$RTBASEFF_{2005,eg} * HDDFACT_{y,r} * SQFTADJ_{y,b,r},$$

$$\text{if } WTEQCEFFN_{y,eg,b,r} > 0 \qquad\qquad (C-35)$$

$$EQCNUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * HDDFACT_{y,r} * SQFTADJ_{y,b,r}$$

$$, otherwise$$

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,

$RTBASEFF_{2005,eg}$ is the 2005 stock-average efficiency of the equipment class,

$EQCUEC_{r,eg,b}$ is unit energy consumption for original 2005 stock of the equipment class by Census Division and housing type,

$HDDFACT_{y,r}$ is the heating degree day adjustment factor by Census Division to correct to normal weather relative to 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:

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * WTEQCEFFR_{y,eg,b,r}$$

$$* RTBASEFF_{2005,eg} * HDDFACT_{y,r}, \text{if } WTEQCEFFR_{y,eg,b,r} > 0 \qquad (C-366)$$

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * HDDFACT_{y,r} \qquad , otherwise$$

where,

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

$RTBASEFF_{2005,eg}$ is the efficiency of the weighted average of retiring units from the 2005 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:

$$EQCSUEC_{r-1,eg,b,r} = EQCUEC_{r,eg,b} * HDDFACT_{y,r} * \frac{RTBASEFF_{2005,eg}}{RTBASEFF_{y,eg}}$$ (C-37)

where,

   $EQCSUEC_{y,eg,b,r}$ is the average unit energy consumption of the original 2005 equipment stock that remains after the replacements have taken place.

The average UEC for all equipment is calculated as:

$$EQCAUEC_{y,eg,b,r} = EQCNUEC_{y,eg,b,r} * HDDFACT_{y,r}, if\ y = 2005$$

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

$$EQCAUEC_{y,eg,b,r} =$$

$$\frac{\begin{array}{l}(EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP\ 90\ RP_{y,eg,b,r}\ )* \\ EQCNUEC_{y,eg,b,r} \\ + (EQCSR\ 90_{y,eg,b,r} + EQCSUR_{y,eg,b,r}\ )* EQCAUEC_{y-1,eg,b,r} \\ + EQCRP\ 90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r}\end{array}}{\begin{array}{l}EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP\ 90\ RP_{y,eg,b,r} \\ + EQCSR\ 90_{y,eg,b,r} + EQCSUR_{y,eg,b,r} + EQCRP\ 90_{y,eg,b,r}\end{array}}, otherwise$$ (C-388)

where:

   $EQCAUEC_{y,eg,b,r}$ is the average unit energy consumption for all post-2005 equipment categories.

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,

$$HTRCON_{y=2006,f,r} =$$

$$\sum_{b}\sum_{eg}\left[\begin{pmatrix} EQCESE_{y,eg,b,r} * ECQCUEC_{eg,b,r} * EHSHELL_{y,f,r,b} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * NHSHELL_{y,f,r,b} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} * EHSHELL_{y,f,r,b} \end{pmatrix} \\ * RSELAST(f,r,\alpha,EF1,EF2,2005)\right]$$ (C-39)

and subsequent consumption as,

$$HTRCON_{y,f,r} =$$

$$\sum_{b}\sum_{eg}\left[\begin{pmatrix} EQCESE_{y,eg,b,r} * ECQCUEC_{eg,b,r} * EHSHELL_{y,f,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * NHSHELL_{y,f,r,b} * RBN_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} * EHSHELL_{y,f,r,b} * RBR_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * EHSHELL_{y,f,r,b} * RBN_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} * EHSHELL_{y,f,r,b} * RBA_{y,eg,b,r} \\ + EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * AHSHELL_{y,f,r,b} * RBN_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} * AHSHELL_{y,f,r,b} * RBA_{y,eg,b,r} \end{pmatrix} * \\ RSELAST(f,r,\alpha,EF1,EF2,EF3,2005)\right]$$ (C-390)

where,

HTRCON$_{y,f,r}$ is heating energy consumption by year, fuel type, and region,

RSELAST   is the short-term price elasticity function with distributed lag weights EF1, EF2, and EF3, and   , the total short-term price elasticity, and

the "rebound effect" associated with increasing equipment efficiency for a particular equipment class causes a corresponding change in the price elasticity for the class are represented as:

$$RBN_{r,eg,b,r} = WTEQCEFFN_{y,eg,b,r} * RTBASEFF_{2005,eg}{}^{\alpha_1}$$ (C-401)

$$RBR_{r,eg,b,r} = WTEQCEFFR_{y,eg,b,r} * RTBASEFF_{2005,eg}{}^{\alpha_1} \qquad (C\text{-}41)$$

$$RBA_{r,eg,b,r} = WTEQCEFFA_{y,eg,b,r} * RTBASEFF_{2005,eg}{}^{\alpha_1} \qquad (C\text{-}42)$$

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 D: 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], Navigant Consulting Incorporated (NCI)[2], Gas Appliance Manufacturing Association (GAMA), Association of Home Appliance Manufacturers (AHAM), and the Air Conditioning and Refrigeration Institute (ARI)[3].

The remaining text of Appendix D describes the input data sources for the variables presented in Appendix B.

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

[2] Navigant Consulting Incorporated, "EIA - Technology Forecast Updates," Reference Number 20070831.1, 2007.

[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 2005 Equipment

Definition: Retirement fractions for each of the 30 residential equipment classes in for all forecast years.

Units: Dimensionless (units retired to date/units extant in 2005).

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

File: RSRET01.TXT

Comments: Values in this file give the fraction of 2005 stocks of equipment expected to be retired as of each year. They are calculated in an external EXCEL spreadsheet that vintages efficiencies from the shipment data. Program reads all years.

Equipment Classes Included:

Electric Furnace	Natural Gas Heat Pump	Water Heat Distillate
Electric Heat Pump	Room Air Conditioner	Water Heat LPG
Gas Furnace	Central Air Conditioner	Water Heat Solar
Gas Boiler/Radiator	Electric Heat Pump	Cooking Natural Gas
Kerosene Furnace	Geothermal Heat Pump	Cooking LPG
LPG Furnace	Natural Gas Heat Pump	Cooking Electric
Distillate Furnace	Clothes Washers	Dryers Natural Gas
Distillate Other	Dishwashers	Dryers Electric
Wood Stoves	Water Heat Natural Gas	Refrigerators
Geothermal Heat Pump	Water Heat Electric	Freezers

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 2005-2030.

Units: Square feet.

Source: RECS and Census C25 data series.

File: RSSQRFT.TXT

Comments: Values after the last data year (2005) are based on a log-trend forecast derived from Census data. 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.

Sources: EIA, Aggregation from the Residential Energy Consumption Survey 2005.. TIAX LLC, "Commercial and Residential Sector Miscellaneous Electricity Consumption: Y2005 and Projections to 2030," September 2006. Navigant Consulting, U.S. Lighting Market Characterization, Volume 1: National Lighting Inventory and Energy Consumption Estimate," September 2002.

File: RSEQP93.TXT

Comments: Each value in the body of the table represents aggregated values from the Residential Energy Consumption Survey 2005. 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:

Space Heating: Electric Furnace	Drying: Electric
Space Heating: Electric Heat Pump	Refrigeration
Space Heating: Gas Furnace	Freezing
Space Heating: Gas Boiler/Radiator	Lighting: General Service
Space Heating: Kerosene Furnace	Lighting: Tubular Fluorescent
Space Heating: LPG Furnace	Lighting: Torchiere
Space Heating: Dist Furnace	Lighting: Reflector
Space Heating: Dist Other	Furnace Fans
Space Heating: Wood Stoves	Color Televisions
Space Heating: Geothermal HP	DVDs/VCRs
Space Heating: Natural Gas HP	Personal Computers
Space Cooling: Room Air Conditioner	Ceiling Fans
Space Cooling: Cent Air Conditioner	Coffee Makers
Space Cooling: Electric HP	Home Audio
Space Cooling: Geothermal HP	Spas
Space Cooling: Natural Gas HP	Security Systems
Clothes Washers	Rechargeable Electronics
Dishwashers	Microwave Ovens
Water Heater: Natural Gas	Electric Appliances
Water Heater: EL	Secondary Heater: Natural Gas
Water Heater: Distillate	Secondary Heater: Electric
Water Heater: LPG	Secondary Heater: Distillate
Water Heater: Solar	Secondary Heater: LPG
Cooking: Natural Gas	Secondary Heater: Kerosene
Cooking: LPG	Secondary Heater: Coal
Cooking: Electric	Secondary Heater: Wood
Drying: Natural Gas	Appliance: Natural Gas
	Appliance: LPG
	Appliance: Distillate

Variables: $EQCESE_{2005,eg,b,r}$

Residential Retired Equipment Efficiencies of 2005 stock

Definition: Retiring efficiencies for each of the 30 residential equipment classes in forecasted years.

Units: Dimensionless (energy out/energy in) except refrigerator, freezers, and stoves.

Source: Results from vintaging models developed based on shipment data. Shipment data from various sources including: AHAM, GAMA, ARI, LBL (See page D-1 for source details).

File: RSEFF01.TXT

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

efficiencies from the shipment data.

Equipment classes included:

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

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 30 major classes, plus 4 classes of lighting, furnace fans, color televisions, DVDs/VCRs, personal computers, spas, security systems, microwave ovens, handheld rechargeable devices, ceiling fans, home audio, coffee makers, 7 secondary heater types, and 4 appliance types.

Units: MMBtu/unit/yr

Sources: EIA, National Energy Modeling System.   U.S. DOE, U.S. Lighting Market Characterization, Volume I, September 2002.

File: RSUEC10.TXT

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 2005.

Equipment Classes Included: Same as those described for 2005 equipment stock on page D-4.

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: 2007, C25/2007-A (www.census.gov/cons/www.charindex.html).

File: RSHTSHR.TXT

Comments: Shares of heating equipment classes in new homes for 2006 and 2007. 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	Distillate Furnace
Electric Heat Pump	Distillate Other
Gas Furnace	Wood Stoves
Gas Boiler/Radiator	Geothermal Heat Pump
Kerosene Furnace	Natural Gas Heat Pump
LPG Furnace	

Variables: $HSYSSHR_{2006/7,eg,b,r}$

Benchmarking Data from Short-Term Energy Outlook

Definition: Household energy consumption by fuel and Census Division for the years 2005-2009.

Units: Trillion Btu.

Source: Short-Term Integrated Forecasting System October 2008.

File: RSSTEO.TXT

Comments: National total energy consumption by fuel and year comes from STEO, based on history through 2006 and forecasts through 2009.

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: RECS 2005 and vintaging analyses.

File: RTEKCL.TXT.

Comments: Each of the 30 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.TXT file.

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

$RTCLTYPT_{eg}$ Required pointer from equipment class to a representative equipment type. This is the only pointer from RTEKCL.TXT to RTEKTY.TXT. 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.TXT 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 = 5: 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 1,2,4,5, 7: base efficiency for this equipment class.

End uses 3, 6, 8, 9: intensity for this equipment class.

$RTALPHA_{eg}$ Equipment life parameter for exponential decay (not used currently).

$RTMINLIF_{eg}$ 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 . 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 . 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: Navigant Consulting, 2007 for cost, performance, and availability.

File: RTEKTY.TXT

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.TXT file.

$RTTYEQCL_{es}$ Equipment class for this equipment type. MUST match a class number, $RTCLEQCL_{eg}$, in the RTEKCL.TXT 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.TXT 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 residential module base year (2005); 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 (2030).

$RTCENDIV$ Census Division (1-9)

$HVACPT$ Pointer to identify the unique HVAC system number.

$RTTYPNTR_{es}$ 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

CWMEF$_{es}$	Modified energy factor (MEF). Used only for clothes washers.
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, 4, 5, 7: Equipment type efficiency (AFUE, COP, etc.).
	If end use = 3, 6, 8, 9: Energy consumption for prototypical models (e.g., annual Kwh consumption for 18 cu ft refrigerators).
RTEQCOST$_{es}$	Installed capital cost in \$2007 per unit.
RTRECOST$_{es}$	Retail capital cost in \$2007 per unit.
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 $_1$, weights capital cost.
RTECBTA2$_{es}$	Efficiency choice model log-linear parameter $_2$, weights fuel cost.
RTECBTA3$_{es}$	Efficiency choice model log-linear parameter $_3$, 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.TXT

Comments: These variable files 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.

$EH_{2005,b,r}$ Existing Houses in 2005 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).

DISHPEN   Dishwasher penetration rate (1.+x).

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

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

$ELDRYPR_{b,r}$ Electric Dryer Penetration Rate by Building Type and Census Division (1.+ x / the number of years to reach saturation).

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

$NSHTSHR_{r,f,b}$ Secondary Heating Share for post-2005 construction by Fuel, Building Type, and Census Division.

$NEWHEATUEC_{e,b,r}$ New Construction Heating Unit Energy Consumption (UEC) by Equipment Type, Building Type, and Census Division (First Year Only).

$NEWFRIDGEUEC_{b,r}$ New Construction Refrigerator Unit Energy Consumption (UEC) by Building Type and Census Division (First Year Only).

$NEWCOOLUEC_{b,r}$	New Construction Central Air Conditioning Unit Energy Consumption (UEC) by Building Type, and Census Division (First Year Only).
$BASELOAD_e$	Heating/Cooling Efficiency Associated with Base Load for New Construction.
$LEARNFACT_{b,r}$	New Construction Learning Factor for Capital Cost Coefficient.
$ELASTIC_{s,r}$	Elasticity of Service Demand with respect to Square Footage by End Use and Census Division.
$HDDADJ_{y,r}$	Heating Degree Days by Census Division and Year.
$CDDADJ_{y,r}$	Cooling Degree Days by Census Division and Year.
$RTFCBIAS_{e,b,r}$	New Construction Bias Term for Heating Choice Module.
$NEWDRYSAT_{eg,b,r}$	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 2001.
$PCPEN_y$	Percent of housing stock with personal computers by forecast year.
$WTPCEFF_y$	Weighted stock efficiency of personal computers by forecast year.
$TVPEN_y$	Percent of housing stock with color televisions by forecast year.
$TVEFF_y$	Stock efficiency of color televisons by forecast year.
$CTVSAT_{b,r}$	Number of color televisions per household by building type and Census Division in 2005.
$HAPEN_y$	Percent of housing stock with home audio equipment by forecast year.
$HAEFF_y$	Stock efficiency of home audio equipment by forecast year.
$CFPEN_y$	Percent of housing stock with ceiling fans by forecast year.
$CFEFF_y$	Stock efficiency of ceiling fans by forecast year.
$CMPEN_y$	Percent of housing stock with coffee makers by forecast year.
$CMEFF_y$	Stock efficiency of coffee makers by forecast year.
$MOPEN_y$	Percent of housing stock with microwave ovens by forecast year.
$MOEFF_y$	Stock efficiency of microwave ovens by forecast year.
$SPAPEN_y$	Percent of housing stock with spas by forecast year.
$SPAEFF_y$	Stock efficiency of spas by forecast year.
$SSPEN_y$	Percent of housing stock with home security systems by forecast year.
$SSEFF_y$	Stock efficiency of home security systems by forecast year.
$RCPEN_y$	Percent of housing stock with rechargeable electronics by forecast year.
$RCEFF_y$	Stock efficiency of rechargeable electronics by forecast year.

$DVPEN_y$	Percent of housing stock with home DVDs/VCRs by forecast year.
$DVEFF_y$	Stock efficiency of DVDs/VCRs by forecast year.
$DISHNEW_{b,r}$	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.
$ICBINUSE_{bin}$	Share of lighting energy by each of the 6 general use lighting bins,
$ICHOURS_{bin}$	Hours of use assigned to each of the 6 general use lighting bins,
$ICSHARE_{bin}$	Share of lighting bulb stock by each of the 6 general use lighting bins,
$LAMPSPERHH_b$	Number of lamps per household by housing type,
$LAMPSHARE_e$	Share of each bulb type in 2005,
$NLAMPSHR_{e,bin}$	Sales share of each bulb type by bin in initial model year (2006),
$BASEFF_{bin,d}$	Wattage of installed stock by bin and Census division,
$WATTS_e$	Wattage of new bulbs available for purchase,
$ICLIFE_{e,bin}$	Life expectancy in years of each bulb type for each hourly use bin,
$CAPITAL_{e,bin,y}$	Cost of each bulb type by bin for prescribed years (2005, 2010, 2013, 2020, 2030),
$LTBETA1$	Efficiency choice parameter for capital cost in general use lighting,
$LTBETA2$	Efficiency choice parameter for operating cost in general use lighting,
$COMPETE_{bin,y}$	Fraction of retiring bulbs that compete (non-like replacements) by bin and prescribed years (2006, 2014),
$TCHSTKSHR_e$	Stock share for torchiere lamps by bulb type,
$TCHPEN_y$	Number of torchiere lamps per household by year (2005, 2015, 2020),
$BASETWATT$	Stock wattage of torchiere lamps,
$TCHHOURS$	Number of hours per day of torchiere lamp use,
$TCHLIFE_e$	Life expectancy of torchiere lamp bulb by type in years,
$TCHCAP_{e,y}$	Capital cost of torchiere lamps by bulb type and prescribed year (2005, 2010, 2013, 2020, 2030),
$TBETA1$	Efficiency choice parameter for capital cost in torchiere lighting,
$TBETA2$	Efficiency choice parameter for operating cost in torchiere lighting,
$LFLPERHH_b$	Number of tubular fluorescent lamps per household by housing type
$LFLSTKSHR_e$	Stock share for tubular fluorescent lamps by bulb type,
$BASEFWATT$	Stock wattage of tubular fluorescent lamps,
$LFLWATT$	New wattage of tubular fluorescent lamps,

LFLHOURS	Number of hours per day of tubular fluorescent lamp use,
LFLLIFE$_e$	Life expectancy of tubular fluorescent lamp bulb by type in years,
LFLCAP$_{e,y}$	Capital cost of tubular fluorescent lamps by bulb type and prescribed year (2005, 2010, 2013, 2020, 2030),
LFBETA1	Efficiency choice parameter for capital cost in tubular fluorescent lighting,
LFBETA2	Efficiency choice parameter for operating cost in tubular fluorescent lighting,
REFPERHH$_b$	Number of reflector lamps per household by housing type
REFSTKSHR$_e$	Stock share for reflector lamps by bulb type,
BASERWATT	Stock wattage of reflector lamps,
REFLWATT	New wattage of reflector lamps,
REFHOURS	Number of hours per day of reflector lamp use,
REFLIFE$_e$	Life expectancy of reflector bulb by type in years,
REFCAP$_{e,y}$	Capital cost of reflector lamps by bulb type and prescribed year (2005, 2010, 2013, 2020, 2030),
REFBETA1	Efficiency choice parameter for capital cost in reflector lighting,
REFBETA2	Efficiency choice parameter for operating cost in reflector lighting
ELAST	Elasticity parameters for calculating model price elasticities.

Residential Average Stock Equipment Efficiencies of 2005 stock

Definition:	Stock efficiencies for each of the 30 residential equipment classes in forecasted years.
Units:	Dimensionless (energy out/energy in) except refrigerators, freezers, and stoves.
Source:	Results from vintaging models developed based on shipment data. Shipment data from various sources including: AHAM, GAMA, ARI, LBL (see page D-1 for details on sources).
File:	RSSTKEFF.TXT
Comments:	Values in this file give the average efficiencies of equipment remaining from the 2005 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	Kerosene Furnace	Wood Stoves
Electric Heat Pump	LPG Furnace	Geothermal Heat Pump
Gas Furnace	Distill Furnace	
Gas Boil/Radiator	Distill Other	

Nat Gas Heat Pump
Room Air Conditioner
Central Air Conditioner
Electric Heat Pump
Geothermal Heat Pump
Nat Gas Heat Pump
Clothes Washers
Dishwashers
Water Heaters Nat Gas
Water Heaters Electric

Water Heaters Distillate
Water Heaters LPG
Water Heaters Solar
Cooking Nat Gas
Cooking LPG
Cooking Electric
Dryers Nat Gas
Dryers Electric
Refrigerators
Freezers

Variables:

$\text{BASEFF}_{y,eg}$ Stock efficiency for remaining 2005 equipment by year.

Residential Distributed Generation Equipment File

Definition:	Cost, performance, and penetration parameters for fuel cells and photovoltaic equipment.
Units:	Technology cost in 2003 dollars.
Source:	Navigant Consulting and National Renewable Energy Laboratory.
File:	RGENTK.TXT
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:

$\text{xdegred}_{t,d}$	Degradation of conversion efficiency of technology.
$\text{xeleff}_{t,d}$	The electrical conversion efficiency of the technology and vintage.
$\text{xeqlife}_{t,d}$	Life of the equipment, specific to the equipment type as well as vintage.
$\text{xwhrecovery}_{t,d}$	waste heat recovery factor for technologies that burn fuel (i.e., not photovoltaics).
xinstcost_t	Installation cost in 2005 dollars per kw.
$\text{xcapcost}_{t,v}$	Capital cost of the investment in 2005 dollars per kw.
$\text{xmaintcst}_{t,v}$	Annual maintenance cost in 2005 dollars per kw.
$\text{xavail}_{t,v}$	Percentage of time available (1 – forced outage rate – planned outage rate) applied to typical operating hours
$\text{xtxcrpct}_{t,v}$	Tax credit percentage that applies to a given technology's total installed cost (if any).
$\text{xtxcrmax}_{t,v}$	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 (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 Market Module.
$pelrs_{r,y}$	Residential electricity price in 1987 dollars per million Btu from NEMS Electric Market Module.
$pelme_{r,y}$	Marginal price for sales to grid in 1987 dollars per million Btu from NEMS Electric 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 degradation 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 10,000 kwh 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 2005$.

Residential HVAC Technology Equipment Type Description File

Definition:	HVAC technology data for new homes.
Units:	See discussion of individual variables below.
File:	RTEKTYC.TXT
Comments:	Each of the lines of this data file gives the important user-modifiable parameters for HVAC equipment in new homes.

Variable Descriptions:

RSCENDIV   Census division number (1-9).

RSBTYPE   Building type number (1-3).

HVHTEQCL   HVAC heating equipment class. Same as the RTCLTYPT pointer in the RTEKCL.TXT file for heating.

HVHTEQTY   HVAC heating equipment type. Same as the RTEQTYPE variable in the RTEKTY.TXT file for heating.

HVCLEQCL   HVAC cooling equipment class. Same as the RTCLTYPT pointer in the RTEKCL.TXT file for cooling.

HVCLEQTY   HVAC cooling equipment type. Same as the RTEQTYPE variable in the RTEKTY.TXT file for cooling.

HVFYEAR   Initial calendar year for this model of this equipment type. The first HVFYEAR for a model within a type should be the NEMS base year (2005); subsequent initial years for a model must be previous $RTLASTYR_{es}$+1.

HVLYEAR   Last calendar year for this model of this equipment type. Must be greater than or equal to HVFYEAR for this model; final HVLYEAR should be the last year of the forecast period (2030).

HVHEATFACT   Elasticity of the heating shell factor based on square footage.

HVCOOLFACT   Elasticity of the cooling shell factor based on square footage.

HTSHEFF   Heating shell efficiency index for HVAC system type.

CLSHEFF   Cooling shell efficiency index for HVAC system type.

SHELCOST   Installed capital cost for shell measures in $2007 per unit for new homes.

HVBETA1   HVAC efficiency choice model log-linear parameter β_1, weights capital cost.

HVBETA2   HVAC efficiency choice model log-linear parameter β_2, weights fuel cost.

HVPACKG   HVAC shell efficiency package number (1-5).

HVPGNAME   Unique name for each HVAC shell efficiency package type.

Historical Energy Star Home Saturation File

Definition: Number of Energy Star homes built 2006-2008.

File: RSUEC11.TXT

Source: EPA spreadsheet on State level builds.

Variable Descriptions:

$HVEQWTN_{y,e,s,d}$ Percent of homes meeting Energy Star Home criteria or better by heating technology type, shell level type, and Census division.

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 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.

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 2005 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 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.

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[1]   U.S. Department of Energy, Energy Information Administration, Residential Energy Consumption Survey 2005.

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 liquefied propane gas (LPG) are contacted in Stage II. For the 2005 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.

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