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

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Update Information

This is the sixteenth 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 2011*. These changes include the following:

- Inclusion of new Federal standards for certain types of water heaters and secondary heating equipment.
- Inclusion of consensus agreements among equipment manufacturers and efficiency advocates for room air conditioners, refrigerators, freezers, clothes washers, clothes dryers, and dishwashers.
- Revision of the exogenous modeling of televisions, personal computers, and related equipment.
- Update of cost and performance characteristics of solar photovoltaic systems, small wind turbines, and residential fuel cells.
- Incorporation of regional grid interconnection limitations based on the presence of State-level rules, regulations, and policies affecting distributed generation.
- Modification of the unit energy consumption of clothes dryers.
- Updates to the heating shares and housing unit 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 used in developing long-term projections and energy policy analysis over the time horizon of 2005 through 2035. The model generates projections of energy demand (or energy consumption; the terms are used interchangeably throughout the 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 2011* (*AEO2011*).

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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 catalogues the input data used to generate projections in list and cross-tabular formats. Appendix B provides mathematical equations that support the program source code in the module. Appendix C is a bibliography of reference materials used in the development process. Appendix D consists of a model abstract. Appendix E discusses data quality issues.

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 2035 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 projected energy demand to the supply and conversion modules 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 mortgage incentives for energy-efficiency.

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 retail cost
- Equipment energy efficiency
- Market share of new appliances
- Efficiency of retiring equipment
- Appliance penetration factors
- Water usage 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 conversion efficiency
- Solar insolation values
- System penetration parameters
- Wind speeds
- Grid interconnection limitations

Energy Consumption Component

- Unit energy consumption (UEC)
- Population-weighted heating and cooling degree-days
- Expected fuel savings based on the Energy Policy Act of 2005 (EPACT05)
- Expected fuel savings based on the Energy Independence and Security Act of 2007 (EISA)
- Expected fuel savings based on the American Recovery and Reinvestment Act of 2009 (ARRA)
- 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 housing unit. 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, liquefied petroleum 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 (electric, natural gas, and LPG)

Clothes dryers (electric and natural gas)

Refrigerators (with top- and side-mounted freezers)

Freezers

Clothes Washers

Lighting (general service, linear fluorescent, torchiere, and reflector)

Solar Photovoltaic Systems

Fuel Cells

Wind Turbines

Variable Classification

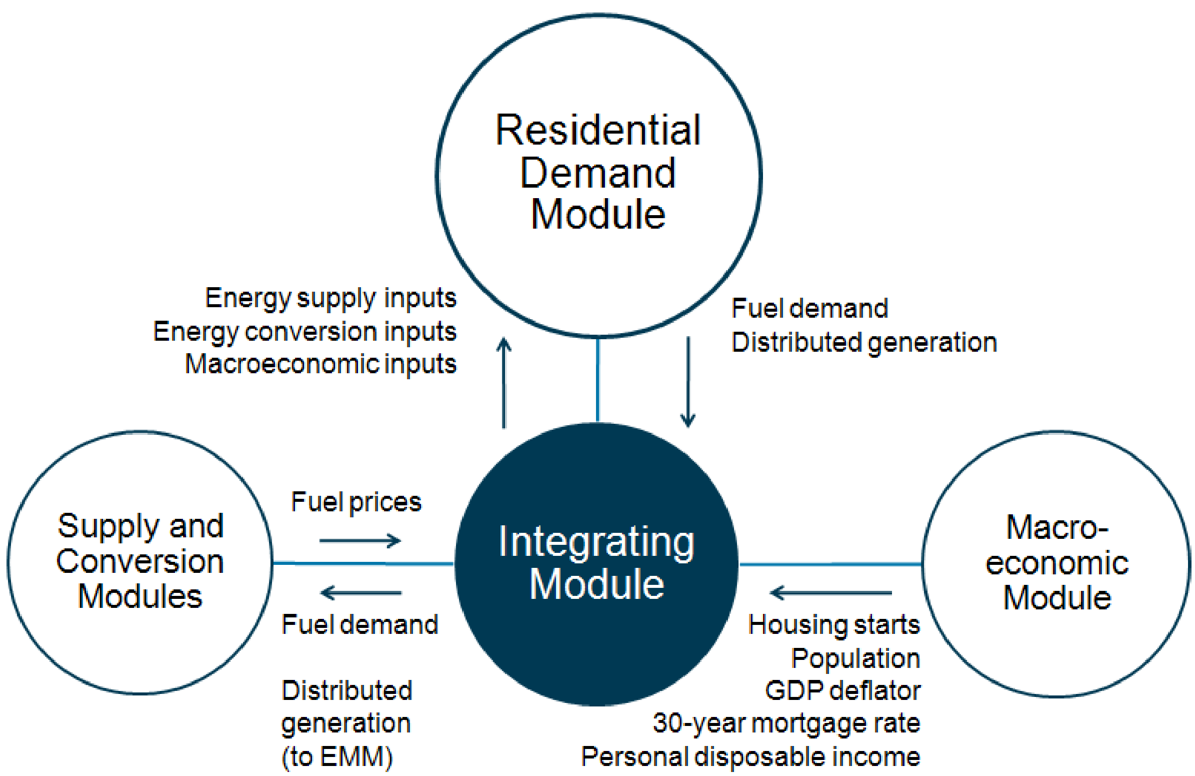
The NEMS modules are designed to provide and use system data at the nine Census Division level of aggregation. There are two primary reasons for using the Census Division level of model specificity: the input data available from the Residential Energy Consumption Survey (RECS) conducted by EIA (which forms the basis for the Residential Sector Demand Module) are generally specified at the nine Census Division level; and the technical constraints of the computing system required in order to run the NEMS model within a reasonable turnaround time. The need to balance data availability, model runtime, and model output detail is best met at the Census Division level. The key outputs from the NEMS Residential Sector Demand Module can be categorized as follows:

#	Census Divisions	Housing Type	Fuels	Technology Choice
1	New England	Single Family	Distillate	Space Heating
2	Middle Atlantic	Multifamily	LPG	Space Cooling
3	East North Central	Mobile Home	Natural Gas	Clothes Washing
4	West North Central		Electricity	Dishwashing
5	South Atlantic		Kerosene	Water Heating
6	East South Central		Wood	Cooking
7	West South Central		Geothermal	Clothes Drying
8	Mountain		Coal	Refrigeration
9	Pacific		Solar	Freezing

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, housing starts by Census Division and housing type, a gross domestic product price deflator, and a 30-year residential mortgage rate. The Residential Sector Demand Module uses fuel price projections generated by the NEMS supply and conversion modules to calculate operating costs for technology selections, existing building shell integrity improvements, and short-term behavioral responses. The NEMS supply and conversion modules in turn use the residential sector outputs to determine the fuel mix and the resulting prices for energy delivered to the residential sector. Distributed generation by some technologies is provided to the Electricity Market Module (EMM) for the calculation of renewable energy credits.

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 generates projections of residential sector energy demand, appliance stocks, and market shares.

The Residential Sector Demand Module is a housing and equipment stock/flow model. The stock of housing units 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. Detailed submodules, or components, provide the structure for computation of specific elements of the residential sector within the larger module.

A logistic function[1] is used to estimate the market shares of competing technologies within each service category. Market shares are determined for both new construction equipment decisions and replacement equipment decisions. The Technology Choice Component of the module weights the relative installed capital and operating costs of each equipment type and uses the relative weighted values in the logistic function to calculate the market shares of the technology within the service, region, and housing type.

Only major services with technology characterizations use this approach: space heating, space cooling, clothes washing, dishwashing, water heating, cooking, clothes drying, lighting, refrigeration, and freezing. Since air-source and geothermal heat pumps are used for both space heating and space cooling, heat pump market shares for space cooling are assigned from the heating choice calculations.

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

For new construction, market shares of building shell options are also determined using a similar logistic calculation. The shell options are linked to heating and cooling equipment, as building codes can be met using more efficient equipment in addition to structural options (like windows and insulation levels). The linked, minimum efficiencies for heating and cooling equipment in new construction can be increased, but not decreased, based on the logistic calculation.

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 on 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 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, ranges, and clothes dryers may be replaced (up to a user-specified 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 and new home HVAC systems are a function of the life-cycle cost of competing building shell and HVAC packages.

- Two housing vintages are assumed: 2005 and prior (existing housing) and 2006 and subsequent (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 a portion of those homes, which varies by housing type, 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, based on an analysis of historical housing unit growth and housing starts.

- It is assumed that a constant 1.2 percent share of existing housing is renovated each year, increasing the square footage of the conditioned (heated and cooled) 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

American Recovery and Reinvestment Act of 2009 (ARRA)

The ARRA legislation passed in February 2009 provides energy efficiency funding for Federal agencies, State energy programs, and block grants, as well as a sizable increase in funding for weatherization. To account for the impact of this funding, it is assumed that the total funding is aimed at increasing the efficiency of the existing housing stock. The assumptions regarding the energy savings for heating and cooling are based on evaluations of the impact of weatherization programs over time.[2] Further, it is assumed each house requires a $2,600 investment to achieve the heating and cooling energy savings estimated in the evaluations, with a 20-year life expectancy of the measures.

The ARRA provisions remove the cap on the 30 percent tax credit for ground-source heat pumps through 2016. Additionally, the cap for the tax credits for other energy efficiency improvements, such as windows and efficient furnaces, was increased to $1500 through the end of 2010.

Successful deployment of smart grid projects based on ARRA09 funding could stimulate more rapid investment in smart grid technologies, especially smart meters on buildings and homes, which might make consumers more responsive to electricity price changes. To represent this, the price elasticity of demand for residential electricity was increased for the services that have the ability to alter energy intensity (e.g., lighting).

Energy Independence and Security Act of 2007 (EISA)

The passage of the EISA in December 2007 provides additional minimum efficiency standards for various types of residential equipment. The standards contained in EISA include the following: a nearly 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 to be implemented between 2010 and 2012.

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[2] Oak Ridge National Laboratory, Estimating the National Effects of the U.S. Department of Energy's Weatherization Assistance Program with State-Level Data: A Metaevaluation Using Studies from 1993 to 2005, September 2005.

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

EPACT05 provided for additional minimum efficiency standards for residential equipment and provided tax credits to producers and purchasers of energy efficient equipment and builders of energy efficient homes. The standards contained in EPACT05 include the following: 190-watt maximum for torchiere lamps starting in 2006; dehumidifier standards starting in 2007 and 2012; and ceiling fan light kit standards starting in 2007. Producers of manufactured homes that are 30 percent better than the latest code can claim a $1000 tax credit . Likewise, builders of homes that are 50 percent better than code can claim a $2000 credit. 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, 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 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, 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 a $2000 cap).

EIEA extended the tax credits specified in EPACT05 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.

Consensus Agreements among Efficiency Advocates and Equipment Manufacturers

Energy efficiency advocates, such as the American Council for an Energy-Efficient Economy (ACEEE), and groups of residential equipment manufacturers represented by the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) or the Association of Home Appliance Manufacturers (AHAM) have committed to negotiating efficiency levels of select equipment in advance of Congressional legislation or Department of Energy rulemakings. In 2009, stakeholders agreed on region-based efficiency levels for air conditioners, furnaces, and heat pumps. The agreement divided the nation into three regions based on heating degree-days so that region-based efficiency levels could be implemented that might not pass a cost-benefit analysis at a nationwide level. These regions were generally mapped to Census divisions: for modeling purposes, divisions 1,2,3,4,and 8 are considered ‘North’ and divisions 5,6,7, and 9 are considered ‘South.’ In 2010, stakeholders provided nationwide efficiency levels for refrigerators, freezers, clothes washers, room air conditioners and clothes dryers.

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 log-linear function calculates the installed capital cost of equipment in new construction. 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 number of each State’s last 10 years (2000-2009) of heating and cooling degree-days is used as a proxy for normal weather. State-level degree days are aggregated to the Census division level using State-level populations. Projected changes in degree days are based only on relative population shifts among States.

Technology and Fuel Switching

Space heaters, air conditioners (heat pumps and central air conditioners), water heaters, ranges, 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-dependent logistic function calculates the retail cost of replacement equipment for technologies not considered ‘mature’.

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, in solar water heating systems, 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.

Through-the-Door Refrigerators

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 on recent appliance shipment data.

Clothes Dryers

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 on analysis of the RECS database. The unit energy consumption of clothes dryers was based partly on analysis[3] from the Lawrence Berkeley National Laboratory which updated assumptions for number of cycles per year, weight per load, and remaining moisture content after clothes washing.

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 reduce the demand for hot water.

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3 Lawrence Berkeley Laboratory, “Clothes Dryers UEC Derivation” Berkeley, CA, June 2010.

Lighting

The module partitions lighting into four main categories of bulb type: general service, reflector, linear fluorescent, and torchiere. Within the general service 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[4] an average hours of use for lamp choice purposes.

Televisions and Set-top Boxes

The module uses exogenous modeling of saturation data from RECS, assumptions on future penetration, a trend towards larger screen size, and increasing market penetration of Energy Star products.

Personal Computers and Related Equipment

The module uses exogenous modeling of desktop computers, monitors, laptops, printers, speakers, high-speed modems, network equipment, and uninterruptable power supplies based on saturation data from RECS, assumptions on future penetration, a trend towards larger monitor size, and increasing market penetration of Energy Star products.

Furnace Fans

The number of housing units that have fossil fuel-fired central forced-air heating determines furnace fan energy consumption. The relative level 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.[5] UEC estimates were extrapolated for post-2030 projections.

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4 U.S. Department of Energy, *U.S. Lighting Market Characterization: Volume1: National Lighting Inventory and Energy Consumption Estimate*, Washington, DC, September, 2002

5 "*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

In single-family housing, solar photovoltaic systems, fuel cells, and small wind turbines compete, through a cash-flow formulation, with purchased electricity to generate electricity on-site. Penetration is limited by factors outlined in the detailed description of the distributed generation submodule in Appendix B. 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 a series of algorithms that account 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, equipment 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 or UEC.

Energy efficiency can be defined as the ratio of service demand to energy input. For relatively simple devices such as space heaters or light bulbs, service demand is a unit of heat or light, respectively, and thus efficiency is described in terms of heat per unit energy (such as coefficient of performance (COP) or annual fuel utilization efficiency (AFUE)) or light per unit energy (lumens per Watt).

For other equipment, service demand can be more difficult to quantify, or other factors beyond the primary service demand may contribute to a unit's energy consumption. In the case of refrigerators, the primary service demand is the volume of interior space refrigerated, but features such as an icemaker or through-the-door water dispenser can add to the unit's energy consumption. Another example is televisions, where service demand may be described as the area of the visual display, but other factors such as its power draw in standby and off modes affects its consumption. For this reason, some equipment is described by a UEC (typically in units of kilowatt-hours per year) rather than an energy efficiency metric.

Table 1. Services and Equipment in NEMS Residential Demand Module

End-Use Equipment	Efficiency Metric
Space Heating	
Air-Source Heat Pump	Coefficient of Performance (COP) [Heating Seasonal Performance Factor (HSPF) / 3.412]
Electric Furnace	COP
Fuel Oil Boiler	Annual Fuel Utilization Efficiency (AFUE)
Fuel Oil Furnace	AFUE
Ground-Source Heat Pump	COP
Kerosene Furnace	AFUE
Liquefied Petroleum Gas (LPG) Furnace	AFUE
Natural Gas Boiler	AFUE
Natural Gas Furnace	AFUE
Natural Gas Heat Pump	COP
Wood Stove	COP
Space Cooling	
Air-Source Heat Pump	COP [Seasonal Energy Efficiency Ratio (SEER) / 3.412]
Central Air Conditioner	COP (SEER / 3.412)
Ground-Source Heat Pump	Energy Efficiency Ratio (EER)
Natural Gas Heat Pump	EER
Room Air Conditioner	COP (SEER / 3.412)
Water Heating	
Electricity Water Heater	Energy Factor (EF)
Fuel Oil Water Heater	EF
LPG Water Heater	EF
Natural Gas Water Heater	EF
Solar Water Heater	EF
Cooking	
Electric Range	kilowatt-hours per year (kWh/yr)
LPG Range	Thermal Efficiency (Btu Out / Btu In)
Natural Gas Range	Thermal Efficiency (Btu Out / Btu In)
Clothes Drying	
Electric Clothes Dryer	EF
Natural Gas Clothes Dryer	EF
Clothes Washing	
Clothes Washer	kWh / cycle (motor), Modified Energy Factor, Water Factor
Dishwashing	

Dishwasher	Energy Factor, Water Factor

Furnace Fans and Boiler Circulation Pumps

Furnace Fan	kWh / yr

Refrigeration

22 cubic foot capacity Refrigerator w/ Top Freezer	kWh / yr
24 cubic foot capacity Refrigerator w/ Side Freezer	kWh / yr

Freezing

Chest Freezer, Manual Defrost	kWh / yr
Upright Freezer, Automatic Defrost	kWh / yr

Lighting

General Service – Compact Fluorescent Lamp (CFL)	lumens / Watt
General Service - Incandescent	lumens / Watt
General Service – Light-Emitting Diode (LED)	lumens / Watt
Linear Fluorescent	lumens / Watt
Reflector	lumens / Watt
Torchiere - CFL	lumens / Watt
Torchiere - Halogen	lumens / Watt
Torchiere - Incandescent	lumens / Watt

Televisions and Set-Top Boxes

Liquid Crystal Display (LCD)	kWh / yr
Plasma	kWh / yr
Cathode-Ray Tube (CRT)	kWh / yr
Projection	kWh / yr

PCs and Related Equipment

Desktop	kWh / yr
Laptop	kWh / yr
Monitor	kWh / yr
Printer	kWh / yr
Modem	kWh / yr
Router	kWh / yr

Secondary Heat

Coal	kWh / yr
Distillate	kWh / yr
Electric	kWh / yr
Gas	kWh / yr
Kerosene	kWh / yr
LPG	kWh / yr
Wood	kWh / yr

Other Uses

Ceiling Fan	kWh / yr
Coffee Maker	kWh / yr
DVD / VCR	kWh / yr
Distillate Other	kWh / yr
Electric Other	kWh / yr
Gas Other	kWh / yr
Home Audio	kWh / yr
LPG Other	kWh / yr
Microwave	kWh / yr
Rechargeables	kWh / yr
Security System	kWh / yr
Spa	kWh / yr

Distributed Generation

Solar Photovoltaic	Electrical Efficiency
Fuel Cell	Electrical Efficiency
Small Wind Turbine	Electrical Efficiency

Appliance Stock Projection

The appliance stock component of the module projects the number of end-use appliances within all occupied housing units. This component tracks equipment additions and replacements. Equipment is required to meet the following services:

Space Heating	Space Cooling	Water Heating	Dishwashing	Cooking
Refrigeration	Freezing	Clothes Washing	Clothes Drying	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 weather-stripping) 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. New housing stock includes homes that meet the 2009 International Energy Conservation Code (IECC), those that meet Energy Star criteria, those that qualify for Federal tax credits for efficient shells, and those that include the most efficient, commercially-available building shell components.

Distributed Generation Component

The distributed generation component allows fuel cells, solar photovoltaic and distributed wind turbine systems to compete with purchased electricity 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 housing unit 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 products of the number of units in the equipment stock and the average technology unit energy consumption (UEC). The average UEC changes as the composition of the equipment stock changes over time. For 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 Macroeconomic Activity Module.

2. Pre-2006 vintage equipment stock is estimated, accounting for housing demolitions and additions.

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

4. The previous year's equipment additions and replacements for both existing (2005 and prior) and new construction (2006 and subsequent) vintageare 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. Consumption can also vary based on projected heating and cooling shell integrities, fuel prices, personal disposable income, and housing unit sizes, and weather if applicable.

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 (1 subroutine)

RDPR reads in fuel prices from the NEMS system.

Initialization Subroutine (1 subroutine)

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

Housing Subroutine (1 subroutine)

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

Existing Equipment Subroutine (1 subroutine)

RDHTRTEC projects pre-2006 (existing) vintage equipment by service. In this subroutine, the following operations are performed:

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

2. Calculate the base year equipment stock or the pre-2006 vintage stock as the product of the share and the number of existing housing units.
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 (5 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 subroutines)

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 subroutines)

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

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

Replacements and Additions - ADD Subroutines (8 subroutines)

The code contains eight equipment replacement and additions subroutines (water heaters and ranges 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 estimated share (from the MAM) of new (post-2005) houses 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 pumps and central air conditioners, water heaters, ranges, 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 pumps and central air conditioners, water heaters, ranges, and clothes dryers in single-family homes.

These subroutines are as follows:

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

End-Use Consumption - CON/CNS Subroutines (15 subroutines)

The 15 end-use consumption subroutines are 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	**RCLCON**	**RWHCON**	**RSTVCON**	**RDRYCON**
RREFCON	**RFRZCON**	**LTCNS**	**APCNS**	**SHTCNS**
APPCNS	**RCWCON**	**RDWCON**	**TVCNS**	**PCCNS**

Distributed Generation (1 subroutine)

RDISTGEN projects the number of housing units with distributed generation technologies and amount of electricity generated.

Overall Consumption - CN Subroutines (2 subroutines)

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

FUELCN calculates fuel consumption

NEMSCN writes out NEMS consumption

Historical Consumption/Calibration Subroutines (2 subroutines)

EXCONS calculates 2005 consumption

RSBENCH calibrates consumption to 2005-2010 SEDS/STEO consumption

Report Subroutines (2 subroutines)

RESDRP aggregates end-uses for NEMS reports

RESDRP2 provides diagnostic reports for internal use

Table 2. Primary NEMS Residential Sector Demand Module Subroutines

Subroutine Name	Description of the Subroutine
RTEKREAD	Read technological characterizations for all equipment
RDSQFT	Read annual average housing floor areas
RMISCREAD	Read miscellaneous data for the module
RDPR	Read prices
PITC	Compute 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	Share out replacement equipment switching among competing technologies for single-family homes up to an input limit
RCWTEC	Choose clothes washing equipment
RCWADD	Calculate new and replacement clothes washing
RCWCON	Calculate consumption for clothes washing
RDWTEC	Choose dishwashing equipment
RDWADD	Calculate new and replacement dishwashers
RDWCON	Calculate consumption for dishwashing
PCCNS	Calculate personal computer consumption
TVCNS	Calculate television consumption
RWHTEC	Choose water heating equipment
REUADD	Calculate new and replacement water heaters and ranges
RWHCON	Calculate consumption for water heating
RSTVTEC	Choose cooking equipment
RSTVCON	Calculate consumption for cooking
RDRYTEC	Choose clothes dryer equipment
RDRYADD	Calculate new and replacement clothes dryers
RDRYCON	Calculate consumption for clothes 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 cooling 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 refrigeration
RFRZTEC	Choose freezing equipment

RFRZADD	Calculate new and replacement freezing 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: Data Sources and Input Parameters

A.1 Data Sources

The Residential Sector Demand Module 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]. Full citations for these references (and other sources referenced in this document) are available in Appendix C.

The remaining text of Appendix A 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.

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

Subscript in Documentation	Subscript in FORTRAN code	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	Annual index
y-1	curiyr-1 or curcalyr-1	Previous year
eg	eqc, reccl	General equipment class within an end use (example: 1 to 11 for space heating)
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

A.2 Input Parameters

Residential Demand Module Input Data Files

Residential Equipment Retirement Fractions for 2005 Equipment

Definition: Retirement fractions for each of the 30 residential equipment classes 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 the following: 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 data for all years.

Equipment Classes Included:

Electric Furnace	Gas Furnace	Kerosene Furnace
Electric Heat Pump	Gas Boiler/Radiator	LPG Furnace

Distillate Furnace	Geothermal Heat Pump	Water Heaters, LPG
Distillate Other	Natural Gas Heat Pump	Water Heaters, Solar
Wood Stoves	Room Air Conditioner	Cooking, Natural Gas
	Central Air Conditioner	Cooking, LPG
	Clothes Washers	Cooking, Electric
	Dishwashers	Dryers, Natural Gas
	Water Heaters, Natural Gas	Dryers, Electric
	Water Heaters, Electric	Refrigerators
	Water Heaters, Distillate	Freezers

Variables: $EQCRET_{y,eg}$= retirement fraction for equipment class *eg* in year *y*.

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 2005-2035.

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 RECS 2005. Census data were aggregated to determine the number of housing units in each Census Division of each building type that use the designated equipment class.

Equipment Classes Included:

Space Heating: Electric Furnace	Refrigerators
Space Heating: Electric Heat Pump	Freezers
Space Heating: Gas Furnace	Lighting: General Service
Space Heating: Gas Boiler/Radiator	Lighting: Tubular Fluorescent
Space Heating: Kerosene Furnace	Lighting: Torchiere
Space Heating: LPG Furnace	Lighting: Reflector
Space Heating: Dist Furnace	Furnace Fans
Space Heating: Dist Other	Color Televisions
Space Heating: Wood Stoves	DVDs/VCRs
Space Heating: Geothermal HP	Personal Computers
Space Heating: Natural Gas HP	Ceiling Fans
Space Cooling: Room Air Conditioner	Coffee Makers
Space Cooling: Cent Air Conditioner	Home Audio
Space Cooling: Electric HP	Spas
Space Cooling: Geothermal HP	Security Systems
Space Cooling: Natural Gas HP	Rechargeable Electronics
Clothes Washers	Microwave Ovens
Dishwashers	Electric Appliances
Water Heating: Natural Gas	Secondary Heaters: Natural Gas
Water Heating: EL	Secondary Heaters: Electric
Water Heating: Distillate	Secondary Heaters: Distillate
Water Heating: LPG	Secondary Heaters: LPG
Water Heating: Solar	Secondary Heaters: Kerosene
Ranges: Natural Gas	Secondary Heaters: Coal
Ranges: LPG	Secondary Heaters: Wood
Ranges: Electric	Appliance: Natural Gas
Clothes Dryers: Natural Gas	Appliance: LPG
Clothes Dryers: Electric	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 ranges.

Source: AHAM, GAMA, ARI, LBL 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 from the shipment data.

Equipment classes included:

Electric Furnace	Geothermal Heat Pump	Water Heaters LPG
Electric Heat Pump	Natural Gas Heat Pump	Water Heaters Solar
Natural Gas Furnace	Room Air Conditioner	Ranges Natural Gas
Natural Gas Boil/Radiator	Central Air Conditioner	Ranges LPG
Kerosene Furnace	Clothes Washers	Ranges Electric
LPG Furnace	Dishwashers	Clothes Dryers Natural Gas
Distillate Furnace	Water Heaters Natural Gas	Clothes Dryers Electric
Distillate Other	Water Heaters Electric	Refrigerators
Wood Stoves	Water Heaters Distillate	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, 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, U.S. DOE

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 A-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: 2009, C25/20097-A (www.census.gov/cons/www.charindex.html).

File: RSHTSHR.TXT

Comments: Shares of heating equipment classes in new homes for 2006 through 2009. Each value in the body of the table represents a fraction of aggregated values from the C25 database. First, the Census data were aggregated to determine the number of new houses in each Census Division of each building type that used the designated equipment class. These values were divided by the number of new houses in each Census Division and building type.

Equipment Classes Included:

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

Variables: $HSYSSHR_{2006/7/8,eg,b,r}$

Benchmarking Data from Short-Term Energy Outlook

Definition: Housing unit energy consumption by fuel and Census Division for the years 2006-2010.

Units: Trillion Btu.

Source: EIA.

File: RSSTEO.TXT

Comments: National total energy consumption by fuel and year comes from the Annual

Energy Review for the most recent historical year (2009) and the Short-Term Energy Outlook for near-term forecasts through 2011. Regional consumption by fuel and year for historical years 2006-2008 comes from the State Energy Data System.

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 Residential Demand Module (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 Washing
4=Dishwashing
5=Water Heating
6=Cooking
7=Clothes Drying
8=Refrigeration
9=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 cooking ranges.

$RTCLREPL_{eg}$ 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 44% of new single-family homes, 15% of new multi-family homes, and 100% of new mobile homes with natural gas water heaters have natural gas cooking ranges and the remainder have electric cooking ranges.

$RTFUEL_{eg}$ 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, space heating; 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, which is any space heating 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.

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

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

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

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

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

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

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

Residential Technology Equipment Type Description File

Definition: Technology choice parameters for types of equipment.

Units: See discussion of individual variables below.

Source: Navigant Consulting.

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 be greater than or equal to $RTINITYR_{es}$ for this model; final $RTLASTYR_{es}$ should be at least the last year of the forecast period (2035).

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 water heating load affected by efficiency gains in 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 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; used above constants for installed wholesale and retail capital costs. ‘ADOLESCENT’ = Main cost reductions occurred before base year (1996); function *EQCOST* reduces installed wholesale and retail capital cost with 1996 (or first year of availability) as the inflection point. ‘INFANT’ = All cost reductions expected after first year of availability; function *EQCOST* reduces installed wholesale and retail capital cost with the inflection point in the future.
$RTCOSTP1_{es}$	If ‘MATURE’ technology, not used. If ‘ADOLESCENT’ technology, representative year cost decline began (y_1 in code). If ‘INFANT’ technology, year of inflection of cost trend (y_0 in code).
$RTCOSTP2_{es}$	If ‘MATURE’ technology, not used. If ‘ADOLESCENT’ or ‘INFANT’ technology, logistic curve shape parameter (gamma in code).
$RTCOSTP3_{es}$	If ‘MATURE’ technology, not used. If ‘ADOLESCENT’ technology, total possible proportional decline in

equipment cost from y_0 onward (d in code).

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

$RTECBTA1_{es}$	Efficiency choice model log-linear parameter β_1, weights capital cost.
$RTECBTA2_{es}$	Efficiency choice model log-linear parameter β_2, weights fuel cost.
$RTECBTA3_{es}$	Efficiency choice model log-linear parameter β_3, weights life cycle cost.
$RTECBIAS_{es}$	Efficiency choice model, consumer preference log-linear parameter; fits current market shares to shipment data.
$RTTYNAME_{es}$	Unique name for each equipment type. Do not modify existing names. Add unique names for new types.

Miscellaneous Residential Module Inputs

Definition:	This file supplies a number of tables that define parameters for the RDM. Each of the tables is discussed individually below.
Units:	Discussed for each variable.
Source:	User Options.
File:	RMISC.TXT
Comments:	These variable files are all read line-by-line in the logic of the RDM.
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 UEC by equipment Type, building type, and Census division (first year only).

$NEWFRIDGEUEC_{b,r}$ New construction refrigerator UEC by building type and Census division (first year only).

$NEWCOOLUEC_{b,r}$ New construction central air conditioning 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 2005.

$PCPEN_{y}$ 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 televisions by forecast year.

$TVEFF_{y}$ Stock efficiency of televisons by forecast year.

$CTVSAT_{b,r}$ Number of color televisions per housing unit 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 housing units with dishwashers by building type and Census Division.
$WASHNEW_{b,r}$	Percent of new housing units 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 housing unit 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 for compact fluorescent general service, 2006,2030 for solid-state general service).
$TCHSTKSHR_e$	Stock share for torchiere lamps by bulb type.

$TCHPEN_y$	Number of torchiere lamps per housing unit 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 housing unit 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 housing unit 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 ranges.

Source: Results from vintaging models developed based on shipment data. Shipment data from various sources including: AHAM, GAMA, ARI, LBL (see page A-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	Natural Gas Heat Pump	Water Heaters Distillate
Electric Heat Pump	Room Air Conditioner	Water Heaters LPG
Gas Furnace	Central Air Conditioner	Water Heaters Solar
Gas Boil/Radiator	Electric Heat Pump	Ranges Natural Gas
Kerosene Furnace	Geothermal Heat Pump	Ranges LPG
LPG Furnace	Natural Gas Heat Pump	Ranges Electric
Distill Furnace	Clothes Washers	Clothes dryers Natural Gas
Distill Other	Dishwashers	Clothes dryers Electric
Wood Stoves	Water Heaters Natural Gas	Refrigerators
Geothermal Heat Pump	Water Heaters Electric	Freezers

Variables:

$BASEFF_{y,eg}$ 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 2009 dollars.

Source: ICF International, Inc. (Solar PV and wind)

SENTECH, Incorporated (Fuel cells)

File: RGENTK.TXT

Comments: This file contains baseline data for distributed generation technologies. The data include global assumptions for the distributed generation module calculations; cost, efficiency and performance variables for the three modeled technologies, photovoltaics, fuel cells and wind turbines; niche variables for modeling within census region; and historical installations by census division.

Variables:

xalpha — Penetration function shape parameter.

xpenparm — Penetration function used to calculate maximum market share into new construction parameter.

$xoperhours_t$ — Typical operating hours by technology

$xbeta_t$ — Learning “beta” parameter by technology

$xc0_t$ — Learning “c0” parameter by technology

iRPSStartYear — Year for which renewable portfolios standard (RPS) credits are available for residential photovoltaic generation

iRPSPhaseOutYear — Year for which RPS credits are available for residential photovoltaic generation

iRPSGrandFatherYear — Year for which photovoltaic installations are grandfathered in to receive RPS credits

xinx — Initial interconnection limitation by Census division.

xdecay — Interconnection limitation by Census division, by year.

xterm — Loan term (currently set at 30 years).

xintrate — Residential mortgage rate from the Macroeconomic Activity Module.

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

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.

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

$xdegred_{t,v}$ — Degradation of conversion efficiency of technology and vintage.

$xeleff_{t,v}$ — Electrical conversion efficiency of the technology and vintage.

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

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

$xinstcost_{t,v}$ Installation cost in 2009$/kW.

$xcapcost_{t,v}$ Capital cost of the investment in 2009 $/kW.

$xmaintcst_{t,v}$ Annual maintenance cost in 2009 $/kW.

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

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

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

$xkW_{t,v}$ Capacity (kW) of typical system. Note capacity must remain constant across vintages for a given technology.

$xlossfac_{t,v}$ Conversion losses (for systems that are rated "at the unit" rather than per available alternating current wattage) if appropriate.

Solar insolation and electricity rate level "niche-dimensioned" variables within each census division from RECS:

$xSolarInsolation_{r.n,rl}$ estimated solar insolation (kWh per square meter per day) for census division r, solar niche n, and electricity rate level, rl

$xHHShare_{r.n,rl}$ RECS share of households in niche n, rl

$xRateScalar_{r.n,rl}$ RECS ratio of electricity cost for niche n, rl to census division average cost

$xAvgKWH_{r.n,rl}$ RECS average annual electricity consumption in kWh for niche n, rl

$xRoofAreaPerHH_{r.n,rl}$ estimated roof area per household for niche n, rl

$xWindSpeed_{r.n,rl}$ estimated wind speed in meters per second

$xRuralPctHH_{r.n,rl}$ RECS percentage of households that are considered "rural" in niche n, rl

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 (2035).
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 2006-2009.
File:	RSUEC11.TXT
Source:	EPA spreadsheet on State level builds, 2009 Energy Star Qualified New Homes Market Indices for States

(http://www.energystar.gov/index.cfm?fuseaction=qhmi.showHomesMarketIndex)

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 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 and variable assignment statements 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 equal sign. These statements must not be interpreted as equations. They are computer programming assignment statements that allow 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 equal signs in these statements do not denote equality. Rather, they indicates that the value stored in a location in the computer's memory is being overwritten by a new value.

- The subscript "y" in the documentation refers to the year represented as 1990 through 2035. In the FORTRAN code, the subscript CURIYR represents array dimensions starting with an index of 1 to represent 1990, and CURCALYR represents the calendar years 1990-2035.

- Some variables are documented having a "y" dimension when, in the FORTRAN code, 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. Although previous values are overwritten, the variables do have a "y" dimension. The "y" dimension is shown explicitly 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.

Subscript in Documentation	Subscript in FORTRAN code	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	Annual index
y-1	curiyr-1 or curcalyr-1	Previous year
eg	eqc, reccl	General equipment class within an end use (example: 1 to 11 for space heating)
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

- Unless otherwise stated, the range of "y" for an equation or computer assignment statement is 1990 through 2035.

Table B-1. Definition of Subscripts

Classification

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

1. Space Heating	8. Refrigeration	15. Ceiling Fans
2. Space Cooling	9. Freezing	16. Home Audio
3. Clothes Washing	10. Lighting	17. Security Systems
4. Dishwashing	11. Furnace Fans	18. Spas
5. Water Heating	12. Televisions	19. Rechargeable Devices
6. Cooking	13. Personal Computers	20. Secondary Heating
7. Clothes Drying	14. Coffee Makers	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 comprises 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.

The concept of equipment classes comprising a number of different equipment types that each contain several models underlie the entire discussion of this manual. In earlier editions of the documentation, these two classifications were referred to as *general equipment type* (equipment class), and *specific equipment type* (equipment type). These names survive in the subscripts assigned to the two concepts throughout the document, *eg* and *es*, respectively. In order to reinforce the difference, we often add the modifier *specific* to the term *equipment type*, but we avoid 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.

Space Heating	**Space Cooling**	**Dishwashing**
Electric Furnaces	Room Air Conditioners	**Clothes Washing**
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 Drying**
Distillate Forced Air	Natural Gas	Natural Gas
Distillate Radiators	Electric	Electric
Wood Heaters	Distillate Oil	**Refrigeration**
Geothermal Heat Pumps	LPG	**Freezing**
Natural Gas Heat Pumps	Solar Thermal	

RTEKCL.TXT: Technology Classes

Within the present structure of the Residential Demand Module, there are 31 defined technology classes. These are listed in Table B-2. Here, clothes washing, dishwashing, refrigeration and freezing each have a single technology class for all installed equipment. The list is not exhaustive, in that there is, for example, a small percentage of homes in which wood is burned to heat domestic water; the vast majority of equipment used to satisfy the nine major end uses falls into at least one class. As mentioned above, lighting and other appliances (such as televisions and personal computers) are handled separately within the logic of the RDM. Eighteen variables, described below, are read from the RTEKCL data file.

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 Washing
4=Dishwashing	5=Water Heating	6=Cooking
7=Clothes Drying	8=Refrigeration	9=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 heating 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 heating class to matching cooking class linking cooking fuel choice to water heating 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 ranges.

$RTCLREPL_{eg}$: Replacement class. Required for end use 5; zero otherwise.

If end use = 5: Second pointer from natural gas water heating class to a cooking class. The model assumes that a portion of new homes with natural gas water heaters have natural gas ranges and the remainder have electric ranges.

$RTFUEL_{eg}$: 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 heating shares for systems using major fuels are calculated differently from space heating 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 β. Used only for end use 1; zero otherwise.

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

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

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

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

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

RTEKTY: Technology Types

Within each of the equipment classes defined in the RTEKCL.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 (2035).

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.

$RTRECOST_{es}$: 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 (2005); function *EQCOST* reduces installed wholesale and retail capital cost with 2005 (or first year of availability) as the inflection point.

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

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

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

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

RTCOSTP2$_{es}$: If ‘MATURE' technology, not used.

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

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

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

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

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

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

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

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

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

Equipment Survival, Housing Survival, and Housing Additions

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 Macroeconomic Activity Module (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.

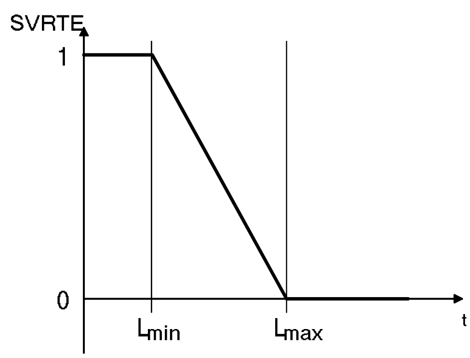
SVRTE (Equipment Survival Function)

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

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

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 argument. However, the first argument is currently not used in the calculations. Since it is not used in the definition of the function in (B-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 housing unit 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

$$
\begin{aligned}
EH_{y,b,r} &= RECS\,data\ ,if\ \ y = 2005 \\
EH_{y,b,r} &= EH_{y-1,b,r} * HDR_b\ ,if\ \ y > 2005
\end{aligned}
\tag{B-2}
$$

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 estimated by the NEMS Macroeconomic Module. The total number of new additions in a given year is computed as

$$
\begin{aligned}
NH_{y,r} = {} & MC\_HUSPS1_{y,r} + MC\_HUSPS2A_{y,r} \\
& + MC\_HUSMFG_{y,r}
\end{aligned}
\tag{B-3}
$$

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 housing unit 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, let

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

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

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.

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 as follows:

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

Televisions, personal computers, home audio, furnace fans, ceiling fans, coffee makers, microwave ovens, spas, security systems, and rechargeable devices are modeled differently and in less detail than the major services listed above.

Space Heating

Space heating is modeled in two stages. For new construction, the first-stage choice is the "HVAC/shell" package which is a combination of heating equipment, air conditioning equipment and building shell levels. There are up to five HVAC/shell packages available, generally named relative to the code level that is met: no code, the IECC code, and three more advanced Energy Star qualified shells performing 30 percent, 40 percent and 50 percent better than IECC. Not all equipment combinations are modeled for advanced shells. The HVAC/shell packages are fuel specific, so once chosen, the fuel choice is also determined. The second-stage choice models increases in efficiency for the heating and air conditioning equipment if available (for some of the advanced packages, the equipment may already be the most efficient available). For existing construction, the first stage considers fuel-choice and the second stage equipment efficiency for the selected equipment class.

New equipment operating costs are computed by the expression

$$\begin{aligned} OPCOST_{y,es,b,r,v} &= PRICES_{f,r,y} * EQCUEC_{y,eg,b} * HDDFACT_{r,y} \\ &* RTEFFAC_{eg,v} * HSHELL_{y-1,r,v} \end{aligned} \quad \text{(B-9)}$$

where

$OPCOST_{y,es,b,r,v}$	is the operating cost for the specific equipment type by year, housing type, 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 an adjustment factor for abnormal weather in either the base year or the current year; it is computed as the ratio of the numbers of heating degree days in the current (numerator) and base (denominator) years;
$RTEFFAC_{eg,v}$	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, heating and cooling choices are linked and therefore operating cost is a function of both the heating and cooling operating costs, with the shell efficiency also accounted for as:

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

where,

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

$CDDFACT_{r,y}$ is the cooling degree-day adjustment factor, 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-dependent 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). The formulation allows for three general classifications of equipment: mature equipment – no further time-dependent cost declines occur, adolescent and infant equipment – costs declines occur, but at different rates as set by the parameters and described below. For each of the three general classifications, the following equations describe the calculations for mature, adolescent and infant technologies respectively:

$$EQCOST_{es,y,CAP} = RTEQCOST_{es} \ , if \ \ RTMATURE_{es} = MATURE$$
$$EQCOST_{es,y,RET} = RTRECOST_{es} \ , if \ \ RTMATURE_{es} = MATURE \tag{B-11}$$

$$EQCOST_{es,y,CAP} = \frac{RTEQCOST_{es} * 2 * d}{1 + \left(\frac{y - y_1}{y_0 - y_1}\right)^{\gamma}} + (1-d) * RTEQCOST_{es},$$
$$if \ \ RTMATURE_{es} = ADOLESCENT$$
$$EQCOST_{es,y,RET} = \frac{RTRECOST_{es} * 2 * d}{1 + \left(\frac{y - y_1}{y_0 - y_1}\right)^{\gamma}} + (1-d) * RTRECOST_{es},$$
$$if \ \ RTMATURE_{es} = ADOLESCENT \tag{B-12}$$

$$EQCOST_{es,y,CAP} = \frac{RTEQCOST_{es} * d}{1 + \left(\frac{y - y_1}{y_0 - y_1}\right)^{\gamma}} + (1-d) * RTEQCOST_{es},$$
$$if \ \ RTMATURE_{es} = INFANT$$
$$EQCOST_{es,y,RET} = \frac{RTRECOST_{es} * d}{1 + \left(\frac{y - y_1}{y_0 - y_1}\right)^{\gamma}} + (1-d) * RTRECOST_{es},$$
$$if \ \ RTMATURE_{es} = INFANT \tag{B-13}$$

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 and from y_1 onward if INFANT,

☐ is the assumed 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:

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

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 2030 and beyond) will advance forward by 10 years to 2020 (as long as the doubling starts by 2021). Shifts from 0 to 10 years are allowed in the current model formulations. For nearer term technologies, shifts are limited to a lesser number of years by the algorithm to ensure that "over-shifting" does not occur (i.e., future technologies cannot 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:

$$SHIFTYEARS_f = \frac{\left(PRICE\Delta_f - 1.0\right)}{0.10} \tag{B-15}$$

subject to the constraints listed above. The initial technology year, RTINITYR, used in equations (B-11) to (B-13) is adjusted according by the year shift obtained in equation (B-15).

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

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

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 $RTEQCOST1_{es}$,
$OPCOST_{y,es,b,r,v}$	is the operating cost for the specific equipment type by year, housing type, Census Division, and vintage,
HORIZON	is the number of years into the future 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

$$
\begin{aligned}
HEATSYS_{y,eg,b,r} &= (1 - LAGFACTOR) * HEATSYS_{y-1,eg,b,r} + \\
&LAGFACTOR * \exp\left(RFTBIAS_{y,eg} + RTFCBETA_{eg} * LFCY_{y,eg,b,r,v}\right)
\end{aligned}
\qquad \text{(B-17)}
$$

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:

$$SYSTOT_{y,b,r} = \sum_{eg=1}^{11} HEATSYS_{y,eg,b,r} \qquad \text{(B-18)}$$

where

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

The equipment class fuel share is computed as

$$HTYSSHR_{y,eg,b,r} = \frac{HEATSYS_{y,eg,b,r}}{SYSTOT_{y,b,r}}, if \;\; SYSTOT_{y,b,r} > 0$$
$$HTYSSHR_{y,eg,b,r} = 0, otherwise \tag{B-19}$$

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

$$EQWTN_{y,es,b,r} = \exp\left(RTECBTA1_{es} * CAPITAL_{es} + RTECBTA2_{es} * OPCOST_{y,es,b,r,1}\right) \tag{B-20}$$

$$EQWTN_{y,es,b,r} = \exp\left(RTECBTA1_{es} * CAPITAL_{es} + RTECBTA2_{es} * OPCOST_{y,es,b,r,2}\right) \tag{B-21}$$

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$_{es}$, and

RTECBTA2$_{es}$ these two parameters give relative weights to the capital and operating costs in the equipment choice determination – their ratio is approximately the discount rate used valuing the operating cost savings from more efficient equipment.

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

$$TOTEWTN_{y,eg,b,r} = \sum_{es \in eg} EQWTN_{y,es,b,r} \tag{B-22}$$

$$TOTEWTR_{y,eg,b,r} = \sum_{es \in eg} EQWTR_{y,es,b,r} \tag{B-23}$$

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 share within a general equipment class is computed as

$$\begin{aligned} EQFSHRN_{y,es\in eg,b,r} &= \frac{EQWTN_{y,es\in eg,b,r}}{TOTEWTN_{y,eg,b,r}}, if\ TOTEWTN_{y,eg,b,r} > 0 \\ EQFSHRN_{y,es\in eg,b,r} &= 0, otherwise \end{aligned} \tag{B-24}$$

$$\begin{aligned} EQFSHRR_{y,es\in eg,b,r} &= \frac{EQWTR_{y,es\in eg,b,r}}{TOTEWTR_{y,eg,b,r}}, if\ TOTEWTR_{y,eg,b,r} > 0 \\ EQFSHRR_{y,es\in eg,b,r} &= 0, otherwise \end{aligned} \tag{B-25}$$

where

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

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

$$WTEQCEFFN_{y,eg,b,r} = \frac{\sum_{es \in eg} \left[\frac{EQFSHRN_{y,es,b,r}}{RTEQEFF_{y,es}} \right]}{\sum_{es \in eg} EQFSHRN_{y,es,b,r}}, if \sum_{es \in eg} EQFSHRN_{y,es,b,r} > 0$$
$$WTEQCEFFN_{y,eg,b,r} = \frac{1}{RTBASEFF_{eg}}, otherwise \tag{B-26}$$

$$WTEQCEFFR_{y,eg,b,r} = \frac{\sum_{es} \left[\frac{EQFSHRR_{y,es,b,r}}{RTEQEFF_{y,es}} \right]}{\sum_{es} EQFSHRR_{y,es,b,r}}, if \sum_{es} EQFSHRR_{y,es,b,r} > 0$$
$$WTEQCEFFR_{y,eg,b,r} = \frac{1}{RTBASEFF_{eg}}, otherwise \tag{B-27}$$

where

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

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

$WTEQCEFFR_{y,es,b,r}$ 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 are 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

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

Housing Units Added From 2006 through 2035

Equipment	UEC	Shell
EQCADD	EQCHVUEC	NHSHELL
EQCREP	EQCNUEC	AHSHELL
EQCSUR	EQCAHVUEC	AHSHELL

The equipment categories for pre-2006 housing units are as follows:

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

EQCSR90 represents equipment stock in pre-2006 homes that has been added as a replacement 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 pre-2006 housing units that has been replaced post-2005,

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

EQCAHVUEC is the average UEC for heating and cooling equipment in surviving 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 procedure 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

$$
\begin{aligned}
SVRTE_{y-t,L_{min},L_{max}} &= 1.0 \\
SVRTE_{y-t,L_{min},L_{max}} &= \frac{L_{max}-(y-t)}{L_{max}-L_{min}}, if\ \ L_{min} < y-t < L_{max} \\
SVRTE_{y-t,L_{min},L_{max}} &= 0.0, if\ \ y-t \geq L_{max}
\end{aligned}
\tag{B-28}
$$

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

$$
EQCADD_{y,eg,b,r} = HSEADD_{y,b,r} * SHARESN_{y,eg,b,r} \tag{B-29}
$$

where

$EQCADD_{y,eg,b,r}$	is the number of post-2005 vintage equipment units added to new houses in year y, 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

$$EQCREP_{y,eg,b,r} = \sum_{t=2006}^{t=y-1} \left(EQCADD_{t,eg,b,r} * HDR_b^{\ y-t} * \left(1 - SVRTE_{y-t,L_{\min},L_{\max}} \right) \right) \qquad \text{(B-30)}$$

where

$EQCREP_{y,eg,b,r}$ 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 is the age of the equipment.

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

$$EQCRP90_{y,eg,b,r} = EQCESE_{2005,eg,b,r} * EQCRET_{y,eg} * HDR_b \qquad \text{(B-31)}$$

where

$EQCRP90_{y,eg,b,r}$ is the number of replacement units required for pre-2006 homes in year *y*, 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. The number of units needing replacement is estimated as

$$EQCRP90RP_{y,eg,b,r} = \sum_{t=2006}^{t=y-1} \left(EQCRP90_{t,eg,b,r} + EQCRP90RP_{t,eg,b,r} \right) * \left(1 - SVRTE_{y-t,L_{\min},L_{\max}} \right) \qquad \text{(B-32)}$$

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).

$$ELIGIBLE_{y,eg,b,r} = \sum_{eg} \begin{pmatrix} EQCRP90_{y,eg,b,r} + EQCRP90RP_{y,eg,b,r} \\ + EQCREP_{y,eg,b,r} \end{pmatrix} * \left(SWFACT_{eg}\right) \quad \text{(B-33)}$$

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

$$RPWEIGHT_{y,egsw,b,r} = \exp\left(RTSWBIAS_{egsw} + \begin{pmatrix} RTWSBETA_{egsw} \\ * \left(LFCY_{y,egsw,b,r,v} + RPINSCOST_{eg,egsw}\right) \end{pmatrix} \right). \quad \text{(B-34)}$$

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

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

$LFCY_{y,eg,b,r,v}$ Life cycle cost for the equipment class by year, housing type, and Census Division, and vintage, and

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

Shares are summed over all equipment types:

$$TOTSH_{y,b,r} = \sum_{egsw=1}^{egsw=11} RPWEIGHT_{y,egsw,b,r} \quad \text{(B-35)}$$

The totals are used to normalize the shares, forcing them to add to 100 percent:

$$RPSHARE_{y,egsw,b,r} = \frac{RPWEIGHT_{y,egsw,b,r}}{TOTSH_{y,b,r}}, if\ TOTSH_{y,b,r} > 0$$
$$RPSHARE_{y,egsw,b,r} = 0, otherwise \quad \text{(B-36)}$$

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 values that influence purchasing decisions,
$LFCY_{y,essw,b,r,v}$	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

$$EQCSR90_{y,eg,b,r} = \sum_{t=2006}^{t=y-1} \left(\begin{array}{l} \left(EQCRP90_{t,y,eg,b,r} + EQCRP90RP_{t,y,eg,b,r}\right) \\ * SVRTE_{y-t,L_{\min},L_{\max}} * HDR_b^{\ y-t} \end{array} \right) \tag{B-37}$$

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,
$EQCRP90_{t,eg,b,r}$	is the number of replacement (post-2005 vintage) equipment units demanded each year in pre-2006 houses by housing type and Census Division,
$EQCRP90RP_{t,eg,b,r}$	is the number of replacements of the EQCRP90 equipment units demanded each year by housing type and Census Division,
$SVRTE_{y-t,Lmin,Lmax}$	is the equipment survival function,
HDR_b	is the housing survival rate by housing type, and
$y-t$	is the age of the equipment.

Surviving post-2005 equipment, originally purchased as additions or replacements in post-2005 houses, is calculated as

$$EQCSUR_{y,eg,b,r} = \sum_{t=2006}^{t=y-1} \left(\begin{array}{l} \left(EQCADD_{t,eg,b,r} + EQCREP_{t,eg,b,r}\right) \\ * SVRTE_{y-t,L_{\min},L_{\max}} * HDR_b^{\ y-t} \end{array} \right) \tag{B-38}$$

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 only increases in response to fuel price changes) 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

$$\begin{aligned}
&EHSHELL_{y,f,r,b} = EHSHELL_{y-1,f,r,b}, if \;\; EHSHELL_{y,f,r,b} > EHSHELL_{y-1,f,r,b} \\
&EHSHELL_{y,f,r,b} = LIMIT, if \;\; EHSHELL_{y,f,r,b} < LIMIT \\
&EHSHELL_{y,f,r,b} = EHSHELL_{RECSYEAR,f,r,b} * RSELAST_{y,f,r,alpha,ef1,ef2,ef3,RECSYEAR} \\
&* TECHG_{e,r,b} \;, otherwise
\end{aligned} \qquad \text{(B-39)}$$

where

$EHSHELL_{y,f,r,b}$ is the shell integrity index for existing housing by year, fuel, Census Division, and building type,

LIMIT is the maximum shell index efficiency index of 0.3 (i.e., maximum shell efficiency is limited to a 70-percent improvement on the base year value),

$TECHG_{1,d,b}$ 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 which distributes the price effect to the current year (EF1) and the prices in the two preceeding years with weights EF1, EF2, and EF3, and α, the total short-term price elasticity. This function assumes the consumer adjusts behavior more slowly than in a single year – current model usage assumes the factors are 0.5, 0.35 and 0.15.

$$
\begin{aligned}
&RSELAST_{y,f,r,\alpha,ef1,ef2,ef3,RECSYEAR} = \\
&\left(PRICES_{f,r,y} / PRICES_{f,r,RECSYEAR}\right)^{EF1*\alpha} \times \\
&\left(PRICES_{f,r,y-1} / PRICES_{f,r,RECSYEAR}\right)^{EF2*\alpha} \times \\
&\left(PRICES_{f,r,y-2} / PRICES_{f,r,RECSYEAR}\right)^{EF3*\alpha}
\end{aligned}
\tag{B-40}
$$

The new housing heating shell index is calculated as

$$
NHSHELL_{y,f,r,b} = \sum_{t=2006}^{t=y-1} \left(EQFSHRN_{t,es,b,r} * SHELLEFF_{t,es,b,r}\right) \tag{B-41}
$$

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

$$
AHSHELL_{y,f,r,b} = \frac{\sum_{eg \in f} \left[\begin{array}{l} NHSHELL_{y,r,r,b} * EQCADD_{y,eg,b,r} + AHSHELL_{y-1,f,r,b} \\ * \left(EQCREP_{y,eg,b,r} + EQCSUR_{y,eg,b,r}\right) \end{array} \right]}{\sum_{eg \in f} \left[EQCADD_{y,eg,b,r} + EQCREP_{y,eg,b,r} + EQCSUR_{y,eg,b,r}\right]} \tag{B-42}
$$

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 housing units 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

$$\begin{aligned} EQCNUEC_{y,eg,b,r} &= EQCUEC_{r,eg,b} * WTEQCEFFN_{y,eg,b,r} \\ &* RTBASEFF_{2005,eg} * HDDFACT_{y,r} * SQFTADJ_{y,b,r} \end{aligned} \qquad \text{(B-43)}$$

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

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * WTEQCEFFR_{y,eg,b,r} * RTBASEFF_{2005,eg} * HDDFACT_{y,r} \tag{B-44}$$

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

$$EQCSUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * HDDFACT_{y,r} * \frac{RTBASEFF_{2005,eg}}{RTBASEFF_{y,eg}} \tag{B-45}$$

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 in the pre-2006 stock is calculated as

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

$$EQCAUEC_{y,eg,b,r} = \frac{\begin{pmatrix} (EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + \\ EQCRP90RP_{y,eg,b,r}) * EQCNUEC_{y,eg,b,r} \\ + (EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r}) \\ * EQCAUEC_{y-1,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \end{pmatrix}}{\begin{pmatrix} EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} + EQCSR90_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} + EQCRP90_{y,eg,b,r} \end{pmatrix}}, \quad otherwise \tag{B-46}$$

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. The consumption during the first year of the forecast is computed initially as

$$HTRCON_{y=2006,f,r} = \sum_b \sum_{eg} \left[\begin{pmatrix} EQCESE_{y,eg,b,r} * ECQCUEC_{eg,b,r} * EHSHELL_{y,f,r,b} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * NHSHELL_{y,f,r,b} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} * EHSHELL_{y,f,r,b} \end{pmatrix} \right. \\ \left. * RSELAST\left(f,r,\alpha,EF1,EF2,EF3,2005\right) \right] \tag{B-47}$$

Subsequent annual consumption (for y ≥ 2007) is computed as

$$HTRCON_{y,f,r} = \sum_{b}\sum_{eg}\left[\begin{pmatrix} EQCESE_{y,eg,b,r} * ECQCUEC_{eg,b,r} * EHSHELL_{y,f,r,b} \\ + EQCADD_{y,eg,b,r} * EQCHVUEC_{y,eg,b,r} * NHSHELL_{y,f,r,b} * RBN_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} * EHSHELL_{y,f,r,b} * RBR_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * EHSHELL_{y,f,r,b} * RBN_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} * EHSHELL_{y,f,r,b} * RBA_{y,eg,b,r} \\ + EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * AHSHELL_{y,f,r,b} * RBN_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} * EQCAHVUEC_{y,eg,b,r} * AHSHELL_{y,f,r,b} * RBA_{y,eg,b,r} \end{pmatrix} \\ * RSELAST\left(f, r, \alpha, EF1, EF2, EF3, 2005\right)\right] \tag{B-48}$$

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 α, 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 represented as

$$RBN_{r,eg,b,r} = WTEQCEFFN_{y,eg,b,r} * RTBASEFF_{2005,eg}^{\alpha_1} \tag{B-49}$$

$$RBR_{r,eg,b,r} = WTEQCEFFR_{y,eg,b,r} * RTBASEFF_{2005,eg}^{\alpha_1} \tag{B-50}$$

$$RBA_{r,eg,b,r} = WTEQCEFFA_{y,eg,b,r} * RTBASEFF_{2005,eg}^{\alpha_1} \tag{B-51}$$

where

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

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

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

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

Consumption by furnace fans 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. For each region *r*,

$$CDDFACT_{y,r} = \left(\frac{CDDADJ_{y,r}}{CDDADJ_{2005,r}} \right)^{1.75} \tag{B-52}$$

where

$CDDFACT_{y,r}$	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:

$$\begin{aligned} OPCOST_{y,es,b,r,v} = PRICES_{f,r,y} * EQCUEC_{y,eg,b} * \\ CDDFACT_{r,y} * RTEFFAC_{eg,v} * CSHELL_{y-1,r,v} \end{aligned} \tag{B-53}$$

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,

$$\begin{aligned} NEQTSHR_{y,es,b,r} &= NEQTSHR_{y,RTTYPNTR_{es},b,r} \\ REQTSHR_{y,es,b,r} &= REQTSHR_{y,RTTYPNTR_{es},b,r} \end{aligned} \qquad \text{(B-54)}$$

and for other cooling equipment,

$$NEQTSHR_{y,es,b,r} = \frac{EQWTN_{y,es,b,r}}{TOTEWTN_{y,eg,b,r}} \quad \text{(B-55)}$$

$$REQTSHR_{y,es,b,r} = \frac{EQWTR_{y,es,b,r}}{TOTEWTR_{y,eg,b,r}} \quad \text{(B-56)}$$

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,
$RTTYPNTR_{es}$	is the equipment type pointer for each equipment class,
$TOTEWTN_{y,eg,b,r}$	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:

$$EQCADD_{y,CAC,b,r} = HSEADD_{y,b,r} * CACSAT_{b,r} \tag{B-57}$$

where

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

$HSEADD_{y,b,r}$ is the number of housing units added 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:

$$EQCADD_{y,RAC,b,r} = HSEADD_{y,b,r} * RACSAT_{b,r} \tag{B-58}$$

where

$EQCADD_{y,RAC,b,r}$ is the number of room air conditioners (RAC) 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 heat pumps installed in the heating additions component:

$$EQCADD_{y,HP,b,r} = EQCADD_{y,RTCLPNTR_{eg}b,r} \quad \text{(B-59)}$$

where

$EQCADD_{y,t,HP,b,r}$ 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 new homes with central air conditioners calculated from the saturation level in equation (61) below, also includes new homes with electric heat pumps. To determine the number of central air conditioners needed, electric heat pumps are first removed. If added electric heat pumps exceed the number of added central air conditioners determined by the saturation rate, ten percent of central air conditioners are left in the additions:

$$EQCADD_{y,CAC,b,r} = EQCADD_{y,CAC,b,r} - EQCADD_{y,e,HP,b,r} \quad \text{(B-60)}$$

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, and

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-38) above. For heat pumps, the stock is equated to that calculated in the space heating subroutines:

$$EQCSR90_{y,eg,b,r} = EQCSR90_{y,RTCLPNTR_{eg},b,r} \quad \text{(B-61)}$$

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:

$$EQCND90_{y,eg,b,r} = EQCND90_{y,eg,b,r} * CACPR_r * HDR_b \tag{B-62}$$

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, and

$CACPR_r$ is the regional penetration rate for central air conditioners from the RMISC file.

The replacement equipment types, EQCREP, EQCRP90, and EQCRP90RP are computed as in (B-33), (B-34), and (B-324) respectively. The surviving new additions, EQCSUR is computed as in (B-39) 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 pumps used for heating, switching on replacement of heat pumps in the cooling end use occurred in RHTRADD, the subroutine for replacing heating equipment types. 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-53) above.

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

$$EQCSUEC_{y,eg,b,r} = EQCUEC_{y,eg,b} * CDDFACT_{y,r} * \frac{RTBASEFF_{2005,eg}}{RTBASEFF_{y,eg}} \quad \text{(B-63)}$$

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 cooling degree-day adjustment factors, and
$RTBASEFF_{y,eg}$	are the annual average efficiencies for the equipment classes.

For new equipment,

$$\begin{aligned} EQCNUEC_{y,eg,b,r} &= EQCUEC_{r,eg,b} * WTEQCEFFN_{y,eg,b,r} \\ &* RTBASEFF_{2005,eg} * CDDFACT_{y,r} * SQFTADJ_{y,b,r} \end{aligned} \quad \text{(B-64)}$$

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 cooling degree day adjustment factor by Census Division to correct for differences in weather from 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:

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * WTEQCEFFR_{y,eg,b,r} * RTBASEFF_{2005,eg} * CDDFACT_{y,r} \tag{B-65}$$

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-47) above.

Cooling shell efficiency is calculated similarly to heating shell efficiency computed in equations (B-40) through (B-43).

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

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

$$\sum_{b}\sum_{eg}\left[\begin{pmatrix} EQCESE_{2006,eg,b,r} * ECQCUEC_{eg,b,r} * ECSHELL_{2006,r,b} \\ + EQCADD_{2006,eg,b,r} * EQCNUEC_{2006,eg,b,r} * NCSHELL_{2006,r,b} \\ + EQCRP90_{2006,eg,b,r} * EQCRUEC_{2006,eg,b,r} * ECSHELL_{2006,r,b} \end{pmatrix} \\ * RSELAST(f,r,\alpha,EF1,EF2,EF3,2005)\right] \quad \text{(B-66)}$$

Subsequent consumption is computed as

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

$$\sum_{b}\sum_{eg}\left[\begin{pmatrix} EQCESE_{y,eg,b,r} * ECQCUEC_{eg,b,r} * ECSHELL_{y,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * NCSHELL_{y,r,b} * RBN_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} * ECSHELL_{y,r,b} * RBR_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * ECSHELL_{y,r,b} * RBN_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} * ECSHELL_{y,r,b} * RBA_{y,eg,b,r} \\ + EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * ACSHELL_{y,r,b} * RBN_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} * ACSHELL_{y,r,b} * RBA_{y,eg,b,r} \end{pmatrix} \\ * RSELAST(f,r,\alpha,EF1,EF2,EF3,2005)\right] \quad \text{(B-67)}$$

where

RSELAST is the short-term price elasticity function with distributed lag weights EF1, EF2, and EF3, and α, 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-50) through (B-52).

Clothes Washing

RCWTEC (Clothes Washing Technology Choice Component)

Compute current year operating costs:

$$OPCOST_{y,es,b,r,v} = PRICES_{f,r,y} * EQCUEC_{y,eg,b} * \frac{RTBASEFF_{2005,eg}}{RTEQEFF_{es}} \qquad \text{(B-68)}$$

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:

$$NEQTSHR_{y,es,b,r} = \frac{EQWT_{y,es,b,r}}{TOTEWT_{y,eg,b,r}} \quad \text{for es in eg} \tag{B-69}$$

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.

Since efficiency improvements in clothes washers tend to affect the amount of hot water used in a housing unit, 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:

$$\begin{aligned} TEMP &= \sum_{es \in eg} EQWT_{y,es,b,r} \\ NCWLOAD_{y,eg,b,r} &= \frac{\sum_{es \in eg}\left(EQWT_{y,es,b,r} * LOADADJ_{es}\right)}{TEMP}, \quad if\ TEMP > 0 \\ NCWLOAD_{y,eg,b,r} &= NCWLOAD_{y-1,eg,b,r}\ , otherwise \end{aligned} \tag{B-70}$$

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 Washing Additions Component)

New clothes washing equipment is calculated using a saturation level for newly-bought equipment

$$EQCADD_{y,eg,b,r} = HSEADD_{y,b,r} * \frac{WASHNEW_{b,r}}{100} \tag{B-71}$$

where

EQCADD$_{yeg,b,r}$ 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, 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-38) 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-39) above.

EQCREP$_{y,eg,b,r}$ 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-32) above.

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-

33) above.

$EQCRP90RP_{y,eg,b,r}$ 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-34) above.

RCWCON (Clothes Washing Energy Consumption Component)

To calculate the energy consumption attributable to clothes washers, first calculate the unit energy consumption for each vintage of home. The calculations are similar to those presented in equations (B-44) through (B-47).

$EQCSUEC_{y,eg,b,r}$ 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 the calculation for most of the other end uses:

$$CSWCON_{y,r} = \sum_{b,eg} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \end{pmatrix}, if\ y = 2006 \tag{B-72}$$

$$CSWCON_{y,r} =$$

$$\sum_{b,eg}\begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \\ + EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \end{pmatrix}, \quad if \;\; y > 2006 \tag{B-73}$$

Dishwashing

RDWTEC (Dishwashing 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-68) 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 purchase equipment class. It is computed as in (B-22) above.
$TOTEWTR_{y,eg,b,r}$	is the sum of equipment weights for the replacement purchase equipment

class. It is computed as in (B-23) above.

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

$$NEQTSHR_{y,es,b,r} = \frac{EQWT_{y,es,b,r}}{TOTEWT_{y,eg,b,r}} \tag{B-74}$$

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$_{eg,b,r}$ is the sum of equipment weights for the new equipment class, and

EQWT$_{y,es,b,r}$ is the equipment weight for new equipment.

RDWADD (Dishwashing Additions Component)

New dishwashing equipment is calculated using a saturation level for newly-bought equipment

$$EQCADD_{y,eg,b,r} = HSEADD_{y,b,r} * DISHNEW_{b,r} \tag{B-75}$$

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, 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-38) 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-39) above.

$EQCREP_{y,eg,b,r}$ 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-32) above.

$EQCRP90_{y,eg,b,r}$ 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-33) above.

$EQCRP90RP_{y,eg,b,r}$ 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-34) above.

RDWCON (Dishwashing Energy Consumption Component)

To calculate the energy consumption attributable to dishwashers, first calculate the unit energy consumption for each vintage of home. The calculations are similar to those presented in equations (B-44) through (B-47).

$EQCSUEC_{y,eg,b,r}$ 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 the calculation for most of the other end uses:

$$DSWCON_{y=2006,r} = \sum_{b,eg} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \end{pmatrix}, \quad if \;\; y = 2006 \tag{B-76}$$

$$DSWCON_{y,r} = \sum_{b,eg} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \\ + EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \end{pmatrix}, \quad if \;\; y > 2006 \tag{B-77}$$

Water Heating

RWHTEC (Water Heating 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:

$$TOTN_{b,r} = \sum_{eg} HSYSSHR_{y,eg,b,r} \quad \text{(B-78)}$$

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:

$$NH2OSH_{y,b,r} = \frac{\sum_{eg} HSYSSHR_{y,RTCLEQCL_{SH}=RTCLPNTR_{WH,b,r}}}{TOTN_{b,r}} \quad \text{(B-79)}$$

where

$NH2OSH_{y,b,r}$ is the market share of each new water heater class by housing type and Census Division. There are five equipment classes for water heaters: natural gas, electric, distillate, LPG, and solar thermal.

$TOTN_{b,r}$ 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-68) 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 finally defined:

$$NEQTSHR_{y,f,b,r} = EQFSHRN_{y,es,b,r} \tag{B-80}$$

$$REQTSHR_{y,f,b,r} = EQFSHRR_{y,es,b,r} \tag{B-81}$$

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:

$$\begin{aligned} EQCND90_{y,eg,b,r} &= EQCESE_{2005,eg,b,r} * HDR_b \quad ,if \;\; y = 2006 \\ EQCND90_{y,eg,b,r} &= EQCESE_{y-1,eg,b,r} * HDR_b \quad ,if \;\; y > 2006 \end{aligned} \tag{B-82}$$

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, purchases are calculated for new housing,

$$EQCADD_{y,eg,b,r} = HSEADD_{y,b,r} * SHARE_{y,eg,b,r} \tag{B-83}$$

where

$EQCADD_{y,eg,b,r}$ is the number of 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

$SHARE_{y,eg,b,r}$ 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 ranges 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-38) 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-39) above.

$EQCREP_{y,eg,b,r}$ 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-32) above.

$EQCRP90_{y,eg,b,r}$ 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-33) above.

$EQCRP90RP_{y,eg,b,r}$ 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-34) above.

RWHCON (Water Heating 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 housing units are the number of inhabitants and the usage and efficiency of clothes washers. The component therefore calculates an average housing unit size that will be used with an elasticity to account for this determinant:

$$HHSIZE_{y,r} = \frac{MC\_NP16A_{r,y}}{\sum_b \left(EH_{y,b,r} + NH_{y,b,r}\right)} \tag{B-84}$$

where

$HHSIZE_{y,r}$	is the average number of persons over age 16 per housing unit 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, for the surviving base-year homes,

$$EQCSUEC_{r,eg,b,r} = EQCUEC_{r,eg,b} * \left(\frac{HHSIZE_{y,r}}{HHSIZE_{2005,r}}\right)^{HHSELAS} * \frac{RTBASEEFF_{2005,eg}}{RTBASEFF_{y,eg}} \tag{B-85}$$

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 housing unit size by year and Census Division,
$HHSELAS$	is an elasticity parameter for the increase in hot water intensity due to increases in housing unit size, estimated at 0.315, and
$RTBASEFF_{y,eg}$	are the annual average efficiencies for the equipment classes.

For new purchases,

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

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 housing unit size by year and Census Division,
$HHSELAS$	is an elasticity parameter for the increase in hot water intensity due to increases in housing unit size, estimated at 0.315, and
$RTBASEFF_{y,eg}$	is the efficiency of the water heating equipment classes.

For replacements in all years,

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

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

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

$$EQCAUEC_{y,eg,b,r} = \frac{\begin{pmatrix} (EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP90RP_{y,eg,b,r}) \\ * EQCNUEC_{y,eg,b,r} \\ +(EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r})* EQCAUEC_{y-1,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \end{pmatrix}}{\begin{pmatrix} EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP90RP_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r} + EQCRP90_{y,eg,b,r} \end{pmatrix}}, \quad if \ \ y > 2006 \tag{B-88}$$

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,

$$WTEQCEFFA_{y=2006,eg,b,r} = WTEQCEFFN_{y=2006,eg,b} \tag{B-89}$$

If y > 2006,

$$WTEQCEFFA_{y,eg,b,r} = \frac{\begin{pmatrix} (EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP90RP_{y,eg,b,r}) \\ *WTEQCEFFN_{y,eg,b,r} \\ +(EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r})*WTEQCEFFA_{y-1,eg,b,r} \\ +EQCRP90_{y,eg,b,r} * WTEQCEFFR_{y,eg,b,r} \end{pmatrix}}{\begin{pmatrix} EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP90RP_{y,eg,b,r} \\ +EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r} + EQCRP90_{y,eg,b,r} \end{pmatrix}} \quad \text{(B-90)}$$

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 each vintage of equipment:

$$H2OSHRCW_{y,f,b,r,v} = H2OSHR_{y,f,b,r,v} * NUMCW_{y,b,r,v} \quad \text{(B-91)}$$

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 each vintage 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:

$$H2OCONCW_{y,f,b,r,v} = H2OSHRCW_{y,f,b,r,v} * H2OUEC_{y,f,b,r,v} * LDADJCW_{y,b,r} \quad \text{(B-92)}$$

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,

$$H2OCON_{y,f,r} = \sum_{b} \left(\left(\begin{pmatrix} EQCESE_{y,eg,b,r} * EQCSUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \end{pmatrix} + \sum_{v} H2OCONCW_{y,f,b,r,v} \right) * RSELAST(f, r, \alpha, EF1, EF2, EF3, 2005) \right) \quad \text{(B-93)}$$

If y > 2006,

$$H2OCON_{y,r} = \sum_{b}\left(\left(\left(\begin{array}{l} EQCESE_{y,eg,b,r} * EQCSUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \\ + EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \end{array}\right) + \sum_{v} H2OCONCW_{y,f,b,r,v}\right) * RSELAST\left(f,r,\alpha,EF1,EF2,EF3,2005\right)\right) \quad \text{(B-94)}$$

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 α, the total short-term price elasticity.

Cooking Equipment

RSTVTEC (Choose Cooking Equipment Component)

Throughout this document, cooking equipment is characterized as a ‘range’ which is a unit that contains both an oven and a cooktop. 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 ranges; homes that heat with LPG cook with LPG; homes that heat water with distillate oil cook with electricity. (Replacement ranges in single-family homes are not so constrained.) These constraints are embodied in the technology choice by using the water heater equipment market shares for calculating the cooking equipment market shares:

$$NCKSH_{y,eg,b,r} = NH2OSH_{y,eg,b,r} * NGNGFACT, \text{ } if \ \ eg = gas\,stove$$
$$NCKSH_{y,eg,b,r} = NH2OSH_{y,eg,b,r} \ \ , if \ \ eg = LPG \ stove$$
$$NCKSH_{y,eg,b,r} = \sum\left(NH2OSH_{y,eg,b,r}\right) + NH2OSH_{y,eg,b,r} * \left(1. - NGNGFACT\right), \quad if \ \ eg = other \tag{B-95}$$

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 constant that defines the fraction of new homes having gas water heaters that have gas ranges.

In the formula, the summation in the case of *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-68) 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,

$$
\begin{aligned}
NEQTSHRD_{y,eg,b,r} &= NCKSH_{y,eg,b,r} * EQFSHRN_{y,es,b,r} \\
REQTSHRD_{y,eg,b,r} &= NCKSH_{y,eg,b,r} * EQFSHRR_{y,es,b,r}
\end{aligned}
\qquad \text{(B-96)}
$$

where

$NEQTSHRD_{y,es,b,r}$ is the new equipment type share for ranges by equipment type, housing type and Census Division,

$REQTSHRD_{y,es,b,r}$ is the replacement equipment type share for ranges 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 ranges by equipment type, housing type and Census Division, and

$EQFSHRR_{y,es,b,r}$ is the replacement market share for ranges 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:

$$WTEQCEFFA_{y,eg,b,r} = \frac{\sum_{es \in eg} \left(NEQTSHR_{y,es,b,r} * RTEQEFF_{es} \right)}{\sum_{es \in eg} NEQTSHR_{y,es,b,r}} \quad \text{(B-97)}$$

where

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

$RTEQEFF_{es}$ is the 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 in the water heating section.

RSTVCON (Cooking Energy Consumption Component)

The unit energy consumption for the surviving equipment is calculated by,

$$EQCSUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * \frac{RTBASEFF_{2005,eg}}{RTBASEFF_{y,eg}} \quad \text{(B-98)}$$

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 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,

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

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,

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * \frac{WTEQCEFFR_{y,eg,b,r}}{RTBASEFF_{2005,eg}} \quad \text{(B-100)}$$

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,

$$EQCAUEC_{y,eg,b,r} = EQCNUEC_{r,eg,b} \quad \text{(B-101)}$$

If y > 2006,

$$EQCAUEC_{y,eg,b,r} = \frac{\begin{pmatrix} (EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP90RP_{y,eg,b,r}) \\ * EQCNUEC_{y,eg,b,r} \\ + (EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r}) * EQCAUEC_{y-1,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \end{pmatrix}}{\begin{pmatrix} EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP90RP_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r} + EQCRP90_{y,eg,b,r} \end{pmatrix}} \quad \text{(B-102)}$$

And energy consumption is defined as

$$CKCON_{y,r} = \sum_{b,eg} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \end{pmatrix}, \quad if \ \ y = 2006 \quad \text{(B-103)}$$

$$CKCON_{y,r} = \sum_{b,eg} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \\ + EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \end{pmatrix}, \quad if \ \ y > 2006 \quad \text{(B-104)}$$

Clothes Drying

RDRYTEC (Clothes Drying 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-68) 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 computed next:

$$NEQTSHR_{y,es,b,r} = \frac{EQWT_{y,es,b,r}}{TOTEWT_{y,eg,b,r}} \tag{B-105}$$

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:

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

$$WTEQCEFFA_{y,eg,b,r} = \frac{\sum_{es}\left(EQWT_{y,es,b,r} \big/ RTEQEFF_{es} \right)}{TEMP}, if\ TEMP > 0 \qquad \text{(B-106)}$$

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

where

$WTEQCEFFA_{y,es,b,r}$ is the weighted average usage of clothes dryer equipment classes in the current year by housing type and Census Division, and

$EQWT_{y,es,b,r}$ is the equipment weight for each type of new equipment.

DRYADD (Clothes Drying Additions Component)

New clothes drying equipment is calculated using a saturation level for newly-bought equipment

$$EQCADD_{y,eg,b,r} = \sum_{es}\left(HSEADD_{y,b,r} * NEQTSHR_{y,es,b,r} * \frac{NEWDRYSAT_{b,r}}{100} \right) \qquad \text{(B-107)}$$

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-38) 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-39) 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-32).

$EQCRP90_{y,eg,b,r}$ 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-33) 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-34) above.

RDRYCON (Clothes Drying Energy Consumption Component)

The unit energy consumption for surviving equipment is calculated as

$$EQCSUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * \frac{RTBASEFF_{2005,eg}}{RTBASEFF_{y,eg}} \tag{B-108}$$

Bookmark – we might want to discuss were the rtbaseff comes from – I think this is the vintaging spreadsheet that does shipment weighted averages and then models the die-off of older stuff where

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

$RTBASEFF_{y,eg}$ is the base efficiency of the same general equipment category in each year, and

$EQCUEC_{r,eg,b}$ is unit energy consumption for equipment in 2005 housing by Census Division, equipment class and housing type.

For new equipment,

Bookmark

I'm eliminating the base efficiency subscripts here and in the next equation too which had included b,r, but are also not mentioned in the definition right after. We don't know what base efficiency is by building and region..

$$EQCNUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * WTEQCEFFN_{y,eg,b,r} * RTBASEFF_{y,eg} \tag{B-109}$$

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,

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * WTEQCEFFR_{y,eg,b,r} * RTBASEFF_{y,eg} \tag{B-110}$$

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 computed as follows:
If y = 2006,

$$EQCAUEC_{y,eg,b,r} = EQCNUEC_{r,eg,b} \tag{B-111}$$

If y > 2006,

$$EQCAUEC_{y,eg,b,r} = \frac{\begin{pmatrix} (EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP90RP_{y,eg,b,r}) \\ * EQCNUEC_{y,eg,b,r} \\ + (EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r}) * EQCAUEC_{y-1,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \end{pmatrix}}{\begin{pmatrix} EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP90RP_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r} + EQCRP90_{y,eg,b,r} \end{pmatrix}} \tag{B-112}$$

And energy consumption is defined as

$$DRYCON_{y=2006,r} = \sum_{b,eg} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \end{pmatrix}, \quad if \;\; y = 2006 \tag{B-113}$$

$$DRYCON_{y,r} = \sum_{b,eg} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} \\ + EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ + EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \\ + EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSUR_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \end{pmatrix}, \quad if \;\; y > 2006 \qquad \text{(B-114)}$$

Refrigeration

RREFTEC (Refrigeration Technology Choice Component)

Refrigeration is modeled somewhat differently than most other end uses. It can be thought of as having two general types – French door style with through-the-door (TTD) water and ice dispensing, versus all other types (prototypically modeled as refrigerators with top-mounted freezers). But from RECS we have only a single UEC, therefore rather than modeling these two different general types as classes (e.g., see electric dryers, where there are multiple classes and multiple UECs), the through-the-door types are treated as just another refrigerator type, but with some further special treatment. So for refrigeration, “eg” is just 1, and is not needed as a subscript as for other end uses.

The special treatment of through-the-door refrigerators takes the form of an assumed share of the market (“*TTDSHR”*), whereas market shares for the other types are determined based on the standard logistic equipment choice for other end uses based on the relationship between operating cost and capital cost. Through-the-door refrigerators provide additional services (the convenience of ice and water dispensing without opening the door), are generally more costly, and are also generally less efficient. Thus, the assumed market share for through-the-door refrigerators is needed because if modeled “competitively” as just another refrigerator type (“es”) they would not receive a significant market share, even though in practice they are popular. For AEO 2011 the assumed market share is 29.3 percent. In the equations that follow, the subscript "es" will be distinguished as to whether it refers to through-the-door refrigerators vs other types when the distinction is necessary. Equipment operating cost for refrigerators other than through-the-door is

$$OPCOST_{y,es\neq TTD,b,r,v} = PRICES_{f,r,y} * RTEQEFF_{es\neq TTD} * FACTOR \tag{B-115}$$

where

$OPCOST_{y,es\neq TTD,b,r,v}$	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,
$RTEQEFF_{es\neq TTD}$	is the efficiency (represented as unit energy consumption for this service) of the refrigerator type, 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:

$LFCY_{es\neq TTD,r,v}$	is the life cycle cost for the type of equipment by Census Division and vintage. It is computed as in (B-16) above.
$EQWTN_{es\neq TTD,b,r}$	is the equipment weight for new equipment type by housing type and Census Division. It is computed as in (B-20) above.
$EQWTR_{es\neq TTD,b,r}$	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 general types of refrigerators, through-the-door and others, have market sharesas follows:

$$NEQTSHR_{y,es-TTD,b,r} = TTDSHR$$
$$REQTSHR_{y,es=TTD,b,r} = TTDSHR \qquad \text{(B-116)}$$

$$NEQTSHR_{y,es\neq TTD,b,r} = \frac{EQWTN_{es,b,r}}{TOTEWTN_{b,r}} * \left(1 - TTDSHR\right) \qquad \text{(B-117)}$$

$$REQTSHR_{y,es\neq TTD,b,r} = \frac{EQWTR_{es,b,r}}{TOTEWTR_{b,r}} * \left(1 - TTDSHR\right) \qquad \text{(B-118)}$$

where

$NEQTSHR_{y,es\neq TTD,b,r}$ is the market share for new refrigerators of the equipment type in the current year by housing type and Census Division,

$REQTSHR_{y,es\neq TTD,b,r}$ is the market share for the replacements of equipment type in the current year by housing type and Census Division, and

TTDSHR is the assumed share of side-by-side refrigerators with through-the-door access features.

For the refrigerators with modeled market shares, their calculated market shares are "deflated" by the assumed share for through-the-door refrigerators, ensuring that the market shares sum to unity.

$$WTEQCEFFN_{y,b,r} = \frac{\sum_{es}\left(NEQTSHR_{y,es,b,r} * RTEQEFF_{es}\right)}{\sum_{es} NEQTSHR_{y,es,b,r}} \qquad \text{(B-119)}$$

$$WTEQCEFFR_{y,b,r} = \frac{\sum_{es}\left(REQTSHR_{y,es,b,r} * RTEQEFF_{es}\right)}{\sum_{es} REQTSHR_{y,es,b,r}} \qquad \text{(B-120)}$$

where

$WTEQCEFFN_{y,b,r}$	is the weighted average usage of new refrigerator classes by housing type and Census Division,
$WTEQCEFFR_{y,b,r}$	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 Refrigeration 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

$$\begin{aligned} EQCADD_{y,b,r} &= HSEADD_{y,b,r} * RFADDFAC, \; if \; b=1 \\ EQCADD_{y,b,r} &= HSEADD_{y,b,r}, \; otherwise \end{aligned} \tag{B-121}$$

where

$EQCADD_{y,b,r}$	is the amount of new (post-2005 vintage) refrigerators added in new housing units in the current year by housing type and Census Division,
$HSEADD_{y,b,r}$	is the number of new housing units constructed in the current year by housing type and Census Division, and
$RFADDFAC$	is the percent of new single-family housing units with two refrigerators.

The following variables are computed as in the equations indicated:

$EQCSR90_{y,b,r}$	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-38) above.

$EQCRP90_{y,b,r}$ is the number of replacement (post-2005 vintage) equipment in pre-2006 housing units in the current year by housing type and Census Division. It is computed as in (B-33) above.

$EQCRP90RP_{y,b,r}$ 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-34) above.

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

$EQCREP_{y,b,r}$ is the number of replacement units (post-2005 vintage) demanded in new (post-2005 vintage) housing units by housing type and Census Division. It is computed as in (B-32) above.

RREFCON (Refrigeration Energy Consumption Component)

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

$$EQCSUEC_{y,b,r} = EQCUEC_{r,b} * \frac{RTBASEFF_{y}}{RTBASEFF_{2005}} \qquad \text{(B-122)}$$

where

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

$EQCUEC_{r,b}$ is the UEC for the original 2005 equipment in each equipment class, by housing type and Census Division, and

$RTBASEFF_{y}$ is the base efficiency (represented by unit energy consumption for this service).

For new refrigerators,

$$EQCNUEC_{y,b,r} = EQCUEC_{r,b} * \frac{WTEQCEFFN_{y,b,r}}{RTBASEFF_{2005}} \qquad \text{(B-123)}$$

where

$EQCNUEC_{y,b,r}$ 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 2005 refrigerators by housing type and Census Division,

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

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

For replacement refrigerators,

$$EQCRUEC_{y,b,r} = EQCUEC_{r,b} * \frac{WTEQCEFFR_{y,b,r}}{RTBASEFF_{2005}} \qquad \text{(B-124)}$$

where

$EQCRUEC_{y,b,r}$ 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,

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

The weighted average of the three UEC sets is calculated here.

If y = 2006,

$$EQCAUEC_{y,b,r} = EQCNUEC_{y,b,r} \qquad \text{(B-125)}$$

If y > 2006,

$$EQCAUEC_{y,b,r} = \frac{\begin{pmatrix} (EQCREP_{y,b,r} + EQCADD_{y,b,r} + EQCRP90RP_{y,b,r}) \\ \quad * EQCNUEC_{y,b,r} \\ + (EQCSR90_{y,b,r} + EQCSUR_{y,b,r}) * EQCAUEC_{y-1,b,r} \\ + EQCRP90_{y,b,r} * EQCRUEC_{y,b,r} \end{pmatrix}}{\begin{pmatrix} EQCREP_{y,b,r} + EQCADD_{y,b,r} + EQCRP90RP_{y,b,r} \\ + EQCSR90_{y,b,r} + EQCSUR_{y,b,r} + EQCRP90_{y,b,r} \end{pmatrix}} \tag{B-126}$$

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.

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

$$WTEQCEFFA_{y,b,r} = \frac{\begin{pmatrix} (EQCREP_{y,b,r} + EQCADD_{y,b,r} + EQCRP90RP_{y,b,r}) \\ \quad * WTEQCEFFN_{y,b,r} \\ + (EQCSR90_{y,b,r} + EQCSUR_{y,b,r}) * WTEQCEFFA_{y-1,b,r} \\ + EQCRP90_{y,b,r} * WTEQCEFFR_{y,b,r} + EQCADD_{y,b,r} * \\ \quad RTBASEFF_{2005,eg} \end{pmatrix}}{\begin{pmatrix} EQCREP_{y,b,r} + EQCADD_{y,b,r} + EQCRP90RP_{y,b,r} \\ + EQCSR90_{y,b,r} + EQCSUR_{y,b,r} + EQCRP90_{y,b,r} \end{pmatrix}} \tag{B-127}$$

$$, otherwise$$

And energy consumption is estimated as

$$REFCON_{y=2006,r} = \sum_b \begin{pmatrix} EQCESE_{y,b,r} * EQCUEC_{b,r} \\ + EQCADD_{y,b,r} * EQCNUEC_{y,b,r} \\ + EQCADD_{y,b,r} * EQCUEC_{,b,r} \\ + EQCRP90_{y,b,r} * EQCRUEC_{y,b,r} \\ + EQCRP90RP_{y,b,r} * EQCNUEC_{y,b,r} \end{pmatrix}, \quad if \;\; y = 2006 \tag{B-128}$$

$$REFCON_{y,r} = \sum_b \begin{pmatrix} EQCESE_{y,b,r} * EQCUEC_{b,r} \\ + EQCADD_{y,b,r} * EQCNUEC_{y,b,r} \\ + EQCADD_{y,b,r} * EQCUEC_{b,r} \\ + EQCRP90_{y,b,r} * EQCRUEC_{y,b,r} \\ + EQCRP90RP_{y,b,r} * EQCNUEC_{y,b,r} \\ + EQCSR90_{y,b,r} * EQCAUEC_{y,b,r} \\ + EQCREP_{y,b,r} * EQCNUEC_{y,b,r} \\ + EQCSUR_{y,b,r} * EQCAUEC_{y,b,r} \end{pmatrix}, \quad if \;\; y > 2006 \tag{B-129}$$

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.

Freezing

RFRZTEC (Freezing Technology Choice Component)

Freezing is parallel to refrigeration so it is modeled without reference to “eg” which is implicitly 1, and where upright freezers (with “es” equal “UP”) conceptually take the place of through-the-door refrigerators and receiving an assumed market share. For AEO 2011 “UPSHR” is assumed to be 42.7 percent. The other characterized freezers are assumed to be of the horizontal or “chest” type. The processing of the market share weights is performed as for similar to refrigeration. The following variables are computed as in the equations indicated:

$OPCOST_{y,es \neq UP,b,r,v}$ is the operating cost of freezers by housing type and Census Division in the current year. It is computed as for refrigerators in (B-114) above.

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

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

$EQWTR_{es \neq UP,b,r}$ 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 by a method similar to the method used for other equipment types:

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

$$NEQTSHR_{y,es,b,r} = \frac{EQWTN_{es,b,r}}{TOTEWTN_{b,r}} * (1 - UPSHR), otherwise \tag{B-130}$$

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

$$REQTSHR_{y,es,b,r} = \frac{EQWTR_{es,b,r}}{TOTEWTR_{b,r}} * (1 - UPSHR), otherwise \tag{B-131}$$

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 weighted average efficiencies for new and replacement equipment are computed as for other equipment categories:

$$WTEQCEFFN_{y,b,r} = \frac{\sum_{es}\left(NEQTSHR_{y,es,b,r} * RTEQEFF_{es}\right)}{\sum_{es} NEQTSHR_{y,es,b,r}} \tag{B-132}$$

$$WTEQCEFFR_{y,b,r} = \frac{\sum_{es}\left(REQTSHR_{y,es,b,r} * RTEQEFF_{es}\right)}{\sum_{es} REQTSHR_{y,es,b,r}} \tag{B-133}$$

where

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

Census Division, and

$REQTSHR_{y,b,r}$ is the market share for the replacements n the current year by housing type and Census Division.

RFRZADD (Additions to the Freezing Stock Component)

Calculations of changes in the freezing equipment stock are computed for include all seven vintage categories. For additions after 2006,

$$EQCADD_{y,b,r} = HSEADD_{y,b,r} * \left(\frac{FRZSAT_{b,r}}{100} \right) \tag{B-134}$$

where

$EQCADD_{y,b,r}$ 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-38) above.

$EQCRP90_{y,b,r}$ is the number of replacement (post-2005 vintage) equipment in pre-2006 housing units in the current year by housing type and Census Division. It is computed as in (B-33) 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-39) 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-32) above.

$EQCRP90RP_{y,b,r}$ 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-33) above.

FRZCON (Freezing Energy Consumption Component)

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

$EQCSUEC_{y,b,r}$ is the UEC for surviving 2005 equipment in each equipment class, by housing type and Census Division, calculated as in equation (B-122),

$EQCNUEC_{y,b,r}$ 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-123),

$EQCRUEC_{y,b,r}$ 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-124).

Weighted average usages are calculated:

$$\begin{aligned}
&WTEQCEFFA_{y,b,r} = WTREFFN_{y,b,r}, \; if \;\; y = 2006 \\
&WTEQCEFFA_{y,b,r} = \\
&\frac{\begin{pmatrix} (EQCREP_{y,b,r} + EQCADD_{y,b,r} + EQCRP90RP_{y,b,r}) \\ \quad *WTEQCEFFN_{y,b,r} \\ +(EQCSR90_{y,b,r} + EQCSUR_{y,b,r})*WTEQCEFFA_{y-1,b,r} \\ +EQCRP90_{y,b,r} *WTEQCEFFR_{y,b,r} \end{pmatrix}}{\begin{pmatrix} EQCREP_{y,b,r} + EQCADD_{y,b,r} + EQCRP90RP_{y,b,r} \\ +EQCSR90_{y,b,r} + EQCSUR_{y,b,r} + EQCRP90_{y,b,r} \end{pmatrix}}, \\
&otherwise
\end{aligned} \tag{B-135}$$

And regional energy consumption is estimated as

$$FRZCON_{y=2006,r} = \sum_b \begin{pmatrix} EQCESE_{y,b,r} * EQCUEC_{b,r} \\ + EQCADD_{y,b,r} * EQCNUEC_{y,b,r} \\ + EQCRP90_{y,b,r} * EQCRUEC_{y,b,r} \\ + EQCRP90RP_{y,b,r} * EQCNUEC_{y,b,r} \end{pmatrix}, \quad if \;\; y = 2006 \tag{B-136}$$

$$FRZCON_{y,r} = \sum_b \begin{pmatrix} EQCESE_{y,b,r} * EQCUEC_{b,r} \\ + EQCADD_{y,b,r} * EQCNUEC_{y,b,r} \\ + EQCRP90_{y,b,r} * EQCRUEC_{y,b,r} \\ + EQCRP90RP_{y,b,r} * EQCNUEC_{y,b,r} \\ + EQCSR90_{y,b,r} * EQCAUEC_{y,b,r} \\ + EQCREP_{y,b,r} * EQCNUEC_{y,b,r} \\ + EQCSUR_{y,b,r} * EQCAUEC_{y,b,r} \end{pmatrix}, \quad if \;\; y > 2006 \tag{B-137}$$

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.

Lighting

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

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

The lighting end use is separated into four distinct segments: general service, torchiere, linear fluorescent, and reflector. General service represents “Edison-type” sockets – the typical screw base bulbs found on incandescent, compact fluorescent and LED bulbs. This segment is most important in terms of energy consumption for the residential sector, therefore it also has the most detailed accounting of the four segments. The equations below are generalized to represent each of the four segments — the only difference among them is that the general service category is further partitioned into hours-of-use bins, which affects the relationship between operating and capital costs, as documented below. Torchiere, linear fluorescent and reflector segments implicitly have only a single hours-of-use bin. The capital costs for general service lighting included in the RMISC.TXT file account for the fact that in some cases multiple bulb replacements are needed to satisfy the hours of use for a particular bin on an annual basis.

Operating costs for general service lighting are estimated for each hours of use bin as

$$OPCOST_{y,bin,es,b,r} = PRICES_{y,r} * WATTS_{es,y} * FACTOR * HOURS_{bin} * 365 \tag{B-138}$$

where

$OPCOST_{y,bin,es,b,r}$	are the operating costs for specific general service 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,
$HOURS_{bin}$	are the number of hours of use per day for a particular bin, and
365	are the number of days in a year.

For the three other lighting segments similar calculations are made, but without the hours-of-use bin dimension.

Market shares are computed as follows:

$$MKTSHR_{y,es,b,r} = \frac{exp^{\beta_1 * EQCOST_{y,es} + \beta_2 * OPCOST_{y,es,b,r}}}{\sum_{es} exp^{\beta_1 * EQCOST_{y,es} + \beta_2 * OPCOST_{y,es,b,r}}} \tag{B-139}$$

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 four lighting segments. Specifically,

$$WTLEFF_{y,b,r} = \sum_{es} \left(\frac{1}{EFF_{es}} * MKTSHR_{y,es,b,r} \right) \quad \text{(B-140)}$$

where

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

EFF_{es} are efficiencies of the four classes of light bulbs, and

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

Stock accounting of bulbs is performed separately for new and replacement units as shown in equations (B-32) to (B-39). The number of bulbs needed for each hours-of-use bin is annualized, because some bins require more than one bulb per year, based on hourly life expectancy and annual hourly usage.

Next, the component calculates unit energy consumption for the four classes of lighting (*LTNUEC* represents the general service segment and similar calculations apply to *TCHUEC, LFLUEC, and REFUEC* for the other three segments),

$$LTNUEC_{y,r,b} = \sum_{bin} LTUEC_{bin,r,b} * WTLEFF_{y,bin,b,r} * BASEFF_{bin} \quad \text{(B-141)}$$

where

$LTNUEC_{y,r,b}$ is the unit energy consumption for lighting by year, Census Division and housing type,

$LTUEC_{bin,r,b}$ is base year unit energy consumption for general service lighting (that is lighting with the Edison-type socket which can either be incandescent, compact fluorescent or LED) by Census Division and housing type, from the RSUEC10.TXT file,

$WTLEFF_{y,bin,b,r}$ is the weighted-average usage for lighting calculated above, and
$BASEFF_{bin}$ is the base efficiency for lighting equipment.

For general service lighting, *LTNUEC* is calculated over the various hours-of-use bins as shown in equation (B-141). For the three other segments the bin dimension is not present. The final step of this component is to calculate consumption for the lighting service category:

$$LTCON_{y,r} = \sum_{b} \left(\begin{pmatrix} \left(LTSTOCK_{y,b,r} * SQFTLTS_{y,b,r} \right) * LTNUEC_{y,r,b} \\ + \left(TCHSTOCK_{y,b,r} \right) * TCHUEC_{y,b,r} \\ + \left(LFLSTOCK_{y,b,r} * LFLUEC_{y,b,r} \right) \\ + \left(REFSTOCK_{y,b,r} * REFUEC_{y,b,r} \right) \end{pmatrix} \\ * RSELAST\left(f, r, \alpha, EF1, EF2, EF3, 2005 \right) \right) \tag{B-142}$$

where

α	is the short-term price elasticity, presently valued at -0.25.
$LTCON_{y,r}$	is the energy consumption for lighting by year and Census Division,
$LTSTOCK_{y,b,r}$	is the number of general service 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 linear fluorescent bulbs in the current year by housing type and Census Division,
$REFSTOCK_{y,b,r}$	is the number of reflector bulbs in the current year by housing type and Census Division,
$LTNUEC_{y,r,b}$	is the unit energy consumption for general service 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 α, the total short-term price elasticity,

$LFLUEC_{y,b,rt}$ is the UEC for linear fluorescent lamps by year, Census Division and housing type, and

$REFUEC_{y,b,r}$ is the UEC for reflector bulbs by year, Census Division, and housing type.

PCCNS (Personal Computer Energy Consumption Component)

This submodule is similar 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 rates 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/housing unit) and usage trend. Specifically,

$$PCNUEC_{y,r,b} = PCUEC_{r,b} * WTPCEFF_{y,} * \left(\frac{INCOME_{y,r}}{INCOME_{2005,r}} \right)^{0.1} \qquad \text{(B-143)}$$

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.

$$PCEQP_{y,r,b} = \left(\frac{PCSAT_{r,b}}{EH_{y=2005,r,b}} \right) * PCPEN_y * \left(EH_{y,b,r} + NH_{y,b,r} \right) \qquad \text{(B-144)}$$

where

$PCEQP_{y,r,b}$	is the number of personal computers by year, Census Division and housing type,
$PCPEN_y$	is the estimated penetration of personal computers for future years, and
$EH_{y,r,b}$	is the existing housing stock by year, Census Division, and housing type, and
$NH_{y,r,b}$	is the new housing stock by year, Census Division, and housing type.

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

$$PCCON_{y,r} = \sum_b \begin{pmatrix} \left(PCEQP_{y,b,r} * PCNUEC_{y,b,r} \right) * \\ RSELAST\left(f, r, \alpha, EF1, EF2, EF3, 2005 \right) \end{pmatrix} \qquad \text{(B-145)}$$

where

$PCCON_{y,r}$	is the energy consumption of 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 α, the total short-term price elasticity.

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

This submodule is similar 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 rates 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/housing unit) and usage trend. Specifically,

$$TVNUEC_{y,r,b} = TVUEC_{r,b} * WTDTVEFF_{y,} \quad \text{(B-146)}$$

where

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

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

$$TVEQP_{y,r,b} = \left(EH_{y,b,r} * NH_{y,b,r}\right) * TVPEN_y * CTVSAT_{2005} \quad \text{(B-147)}$$

where

$TVPEN_y$	is the estimated penetration of televisions and set-top boxes for future years,
$CTVSAT_{2005}$	is the television and set-top box saturation rate in 2005, and
$TVEQP_{y,r,b}$	is the number of televisions and set-top boxes by year, Census Division and housing type, and
$EH_{y,r,b}$	is the existing housing stock by year, Census Division, and housing type, and
$NH_{y,r,b}$	is the new housing stock by year, Census Division, and housing type.

The final step of this component is to calculate consumption for televisions and set-top boxes:

$$TVCON_{y,r} = \sum_b \begin{pmatrix} \left(TVEQP_{y,b,r} * TVNUEC_{y,b,r}\right) \\ * RSELAST\left(f, r, \alpha, EF1, EF2, EF2, 2005\right) \end{pmatrix} \quad \text{(B-148)}$$

where

$TVCON_{y,r}$	is the energy consumption for 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 α, 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 are as follows: 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: an efficiency trend and a penetration trend. The computations for all the services follow the formulation given in equations (B-146) to (B-148), except for ceiling fans, which adds a regional dimension for the usage estimate, because warmer regions have higher usage rates for these devices.

The remaining electricity consumption 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 computes the UEC on a per housing unit basis, by housing type and Census division. Based on historical data, a growth rate is estimated and applied to the UEC to project future energy consumption.

APCNS (Other Electric Appliance Energy Consumption Component)

Electric appliance energy consumption is computed as follows:

$$APCON_{y,r} = \sum_{b} \begin{array}{l} \left(EAUEC_{y,r} * EAPEN_{y,r}\right) * \left(EH_{y,r,b} + NH_{y,r,b}\right) \\ \qquad * RSELAST\left(f, r, \alpha, EF1, EF2, EF3, 2005\right) \end{array} \qquad \text{(B-149)}$$

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 α, the total short-term price elasticity, and

$EH_{y,r,b}$ is the existing housing stock by year, Census Division, and housing type, and

$NH_{y,r,b}$ is the new housing stock by year, Census Division, and housing type.

Secondary Space Heating

Secondary space heating refers to small supplemental heaters, normally portable, fired by electricity, kerosene or other fuels, that are used for spot heating or other occasional stopgaps.

SHTCNS (Secondary Heating Energy Consumption Component)

Energy consumption by secondary heaters is calculated directly from shares by fuel read into the model from a user file:

$$SHTCON_{y,f,r} = \sum_b \begin{pmatrix} SHTSHR_{r,f} * EH_{y,b,r} * SHTUEC_{r,f,b} \\ * AHSHELL_{y,gas,r,b} \\ * RSELAST(f,r,\alpha,EF1,EF2,EF3,2005) \end{pmatrix}, if\ \ f = coal$$

$$SHTCON_{y,f,r} = \sum_b \begin{pmatrix} SHTSHR_{r,f} * (NH_{y,b,r} + EH_{y,b,r}) * SHTUEC_{r,f,b} \\ * AHSHELL_{y,f,r,b} \\ * RSELAST(f,r,\alpha,EF1,EF2,EF3,2005) \end{pmatrix} otherwise \tag{B-150}$$

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 α, 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:

$$APLCON_{y,f,r} = \sum_{b} \begin{pmatrix} \left(\left(EH_{y,b,r} + NH_{y,b,r}\right) * APPUEC_{y,b,r}\right) \\ * RSELAST\left(f, r, \alpha, EF1, EF2, EF3, 2005\right) \end{pmatrix} \quad \text{(B-151)}$$

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 α, 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:

- 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. The interval length is flexible in the number of years it represents, and new technologies do not necessarily have to be different from the previous versions. The present practice is to characterize a “vintage” for each projection year in order to readily model proposed legislation; for extended NEMS time frames, however, multi-year time intervals beyond 2035 can be added for simplicity.
- Economic assumptions (tax rates, inflation rates for projecting results in the cashflow model, and financing assumptions such as down payment percentages and loan terms).
- Program-driven penetrations of technologies by Census division. These are viewed as non-economic, supplemental to any economic penetrations.
- Niche variables developed from RECS 2005 data 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, into three cases: high, average, and low prices. In addition to solar insolation and electricity price relatives, the niche variables also include average wind speed, the Census division share of housing units within a niche, average annual energy use (in kWh) per single family housing unit, average roof area per single family housing unit and the percentage of housing units considered “rural” (for wind turbine modeling). In total there are 25 solar niches. These are cross-classified by three levels of electricity prices, yielding a total of 75 niche areas that are modeled separately.

- Utility interconnection limitations for each Census division. These limitations are intended to reflect State-level laws, regulations, and policies that encourage or limit distributed generation integration. State-level scores on a scale of zero (closed to interconnection) to one (open to interconnection) are aggregated to the Census division level by population.

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. Because tax credits are included 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 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 through 2016 based on recent legislation. These are modeled as one-time payments back to the consumer and 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. 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% and 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 with the appropriate dimensions (indicating loops in the program), even if they are overwritten when the computer code is executed.

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

$$AdjCost_{t,y} = MIN\left\langle CapCost_{t,y}, C_{0,t} \cdot CumShip_{t,y}^{-\beta_t} \right\rangle \qquad \text{(B-152)}$$

where $CapCost_{t,y}$ is the tentative maximum cost from the distributed generation input file, and $C_{0,t}$ and β_t are technology-specific (hence subscript t) 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 photovoltaic, fuel cell technologies and wind turbines.

Calculated Maximum kW for Photovoltaic Systems:

The calculated maximum capacity (in kW) for photovoltaic systems, $xCalcKW_{t=1,n,l,y}$ is allowed to vary from the menu capacity in the rgentk.txt input file. The capacity is 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 2005 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, solar modules are assumed to be close enough to be "flush-mounted" so that a one square foot module requires one square foot of roof area. 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 these constraints, the kW capacity of the maximum module area is calculated as

$$xCalcKW_{t=1,n,l,y} = RoofAreaPerHH_{n,l} / 1.25 \cdot 90\% \cdot 50\% / xSqftperkW_y \qquad \text{(B-153)}$$

(Note: see equation (B-162) below for the calculation of *xSqftperKW* which is recalculated each year based on module conversion efficiency for the appropriate year vintage.)

Installed Equipment Cost:

Installed equipment cost, $EqCost_{t,y}$, is the learning-adjusted cost from above plus the installation cost which is an input from the distributed generation input file times the system capacity:

$$EqCost_{t,y} = (\, AdjCost_{t,y} + InstCost_{t,y}\,) \cdot kW_{t,y} \qquad \text{(B-154)}$$

For solar photovoltaics, $kW_{t,y}$ is replaced by $xCalcKW_{t,n,l,y}$ from (B-153).

Initial Outlay Cost:

$$DownPay_{t,y} = EqCost_{t,y} \cdot DownPayPct \qquad \text{(B-155)}$$

Annual levelized payment calculation:

$$Payment_{t,y} = \left[EqCost_{t,y} - DownPay_{t,y} \right] \cdot \frac{IntRate}{1-(1+IntRate)^{-Term}} \qquad \text{(B-156)}$$

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:

$$
\begin{aligned}
&Outlay_{t,y,Y=1} = DownPay_{t,y}\\
&Outlay_{t,y,1<Y\leq Term} = Payment_{t,y}\\
&Outlay_{t,y,Y>Term} = 0
\end{aligned}
\qquad \text{(B-157)}
$$

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

$$
\begin{aligned}
&Prin_{t,y,Y} = Payment_{t,y} - IntAmt_{t,y,Y}\\
&where \quad IntAmt_{t,y,Y} = IntRate \cdot LoanBal_{t,y,Y-1}, and\\
&\qquad\quad 1 < Y \leq Term
\end{aligned}
\qquad \text{(B-158)}
$$

$Prin_{t,y,Y}$ 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 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:

$$LoanBal_{t,y,Y} = LoanBal_{t,y,Y-1} - Prin_{t,y,Y} \qquad \text{(B-159)}$$

$TaxCredit_{t,y,Y}$ 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. The tax credits have since been modified to remove the maximum credit limit for photovoltaics, to include wind turbines, and to apply to systems installed through 2016.

$$TaxCredit_{t,y,Y} \equiv MIN\left\langle EqCost_{t,y} \cdot TaxCreditPct_{t,y}, TxCreditMax_{t,y}\right\rangle, \quad \text{if } Y = 3, \qquad 0, \quad \text{if } Y \neq 3 \tag{B-160}$$

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:

$$AnnualKWH_{t,n,y} = \begin{pmatrix} ElEff_{t,y} \cdot SolarIns_n \cdot 365.25 \cdot \\ xSqftperKW_y \,/\, 10.8 \cdot LossFac_{t,y} \end{pmatrix} \cdot xCalcKW_{t,n,y} \tag{B-161}$$

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-161). The insolation value is then adjusted for module 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 in 2009 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 as follows:

$$xSqftperKW_y = 77 \cdot \frac{0.14}{ElEff_{1,v}} \tag{B-162}$$

The higher the efficiency, the smaller the square footage that will be required for a 1-kw system. As system size is allowed to vary, 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:

$$AnnualKWH_{t,y} = \left(OperHours_t \cdot Avail_{t,y} \cdot LossFac_{t,y}\right) \cdot kW_{t,y} \qquad \text{(B-163)}$$

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

$$\begin{aligned} &AnnualKWH_{t,n,y} = \\ &\quad \left(\begin{aligned} &\frac{ElEff_{t,y}}{ElEff_{t,1}} \cdot (.0645 - .0670 \cdot xMpS_n + .0210 \cdot xMpS_n{}^2 - \\ &.0011 \cdot xMpS_n{}^3\ ) \end{aligned} \right) \\ &\cdot LossFac_{t,y} \cdot kW_{t,y} \end{aligned} \qquad \text{(B-164)}$$

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 2005 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, in the cash flow model assumptions, is year 3.

$$KWH_{t,y,Y} = AnnualKWH_{t,[n],y} \cdot \left(1 - Degradation_{t,y}\right)^{(Y-2)} \qquad \text{(B-165)}$$

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:

$$FuelInput_{t,y} = \frac{0.003412 \cdot OperHours_t \cdot Avail_{t,y}}{ElEff_{t,y}} \cdot kW_{t,y} \qquad \text{(B-166)}$$

Calculation of waste heat available for water 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.

$$\begin{aligned} &BTUWasteHeat_{t,y} = \\ &\left(FuelInput_{t,y} - .003412 \cdot AnnualKWH_{t,y}\right) \cdot WhRecoveryEff_{t,y} \end{aligned} \qquad \text{(B-167)}$$

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

$$\begin{aligned} &WaterHeatingMMBtu_{t,y} \\ &= MIN\left\langle BTUWasteHeat_{t,y}, AvgWaterHtgMMBtu\right\rangle \end{aligned} \qquad \text{(B-168)}$$

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. It is calculated from the current fuel price and fuel input and converted to the same year dollars as the technology capital costs (currently 2009 constant dollars).

$$\begin{aligned} &BaseYrFuelCost_{t,y} = \\ &\left(FuelInput_{t,y} - WaterHtgMMBtu_{t,y}\right) \cdot FuelPrice_{r,y} \end{aligned} \qquad \text{(B-169)}$$

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:

$$FuelCost_{t,y,Y} = BaseYrFuelCost_{t,y} \cdot \left(1 + inflation\right)^{(Y-2)} \qquad \text{(B-170)}$$

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):

$$ValElecSaveBase_{t=1,n,l,y} = \begin{bmatrix} PELRSOUT_{r,y,AC} \cdot xRateScalar_{n,l} \cdot .003412 + \\ EPRPSPR_{y} / 1000 \cdot xScaleRPS_{t} \end{bmatrix} \cdot AnnualKWH_{t,[n],y} \quad \text{(B-171)}$$

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 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

$$ValElecSaveBase_{t,n,l,y} = .003412 \cdot \begin{bmatrix} PELRSOUT_{r,y,AC} \cdot xRateScalar_{n,l} \cdot AvgKwh \\ + PELME_{r,y} \cdot \left(AnnualKWH_{t,y} - AvgKwh\right) \end{bmatrix} + EPRPSPR_y / 1000 \cdot xScaleRPS_t \cdot AnnualKWH_{t,y} \quad \text{(B-172)}$$

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, 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:

$$ValElecSave_{t,n,l,y,Y} = ValElecSaveBase_{t,n,l,y} \cdot \left(1+inflation\right)^{(Y-2)} \cdot (1-Degredation_{t,y})^{(Y-2)} \quad \text{(B-173)}$$

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 system vintage, y.

$$MaintCost_{t,y,Y} = kW_{t,y} \cdot \left(MaintCostBase_{t,y} + xIntervalCst_{t=1,y}\right) \cdot \left(1+inflation\right)^{(Y-2)} \quad \text{(B-174)}$$

Deductible expenses for personal income taxes:

$$TaxDeduct_{t,y,Y} = \left(\begin{array}{l} IntAmt_{t,y,Y-1} - MaintCost_{t,y,Y-1} + \\ FuelCost_{t,y,Y-1} - ValElecSave_{t,y,Y-1} \end{array} \right) \cdot TaxRate + TaxCredit_{t,y,Y} \quad \text{(B-175)}$$

Cash flow and investment payback years:

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

$$NetCashFlow_{t,n,l,y,Y} = ValElecSave_{t,n,l,y,Y} + TaxDeduct_{t,y,Y} - OutLay_{t,y,Y} - FuelCost_{t,y,Y} - MaintCost_{t,y,Y} \quad \text{(B-176)}$$

$CumCashFlow_{t,n,l,y,Y}$ 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 the 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:

$$SimplePayback_{t,n,l,y} = IntSimplePayback_{t,n,l,y} - \frac{CumCashFlow_{t,n,l,y,Y'-1} + NetCashFlow_{t,n,l,y,Y'}}{NetCashFlow_{t,n,l,y,Y'}} \quad \text{(B-177)}$$

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 $CumCashFlow_{t,n,l,y,Y'-1}$ is small in absolute value relative to $NetCashFlow_{t,n,l,y,Y'}$, the right hand term is near unity, indicating that the payback was achieved close to the beginning of Y.

Maximum penetration into new construction:

$$MaxPen_{t,n,l,y} = \frac{PenParm_t}{SimplePayback_{t,n,l,y}} \tag{B-178}$$

$PenParm_t$ 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%.

Easing of interconnection limitations:

$$Inxdecay_{r,y} = MIN\left\langle 1.0, Inx_r + (1.0 - Inx_r)\cdot\frac{y - Inxfy}{Inxly - Inxfy}\right\rangle \tag{B-179}$$

Inxfy and *Inxly* define the interval (in calendar years) over which interconnection limitations decrease to 0 and $Inxdecay_{r,y}$ approaches 1. Inx_r values range between 0 and 1 and are aggregated from state to Census division level by population. State scores are based on the presence of rules, regulations, and policies that affect utility grid interconnection of distributed generation.

Penetration function formula for new construction:

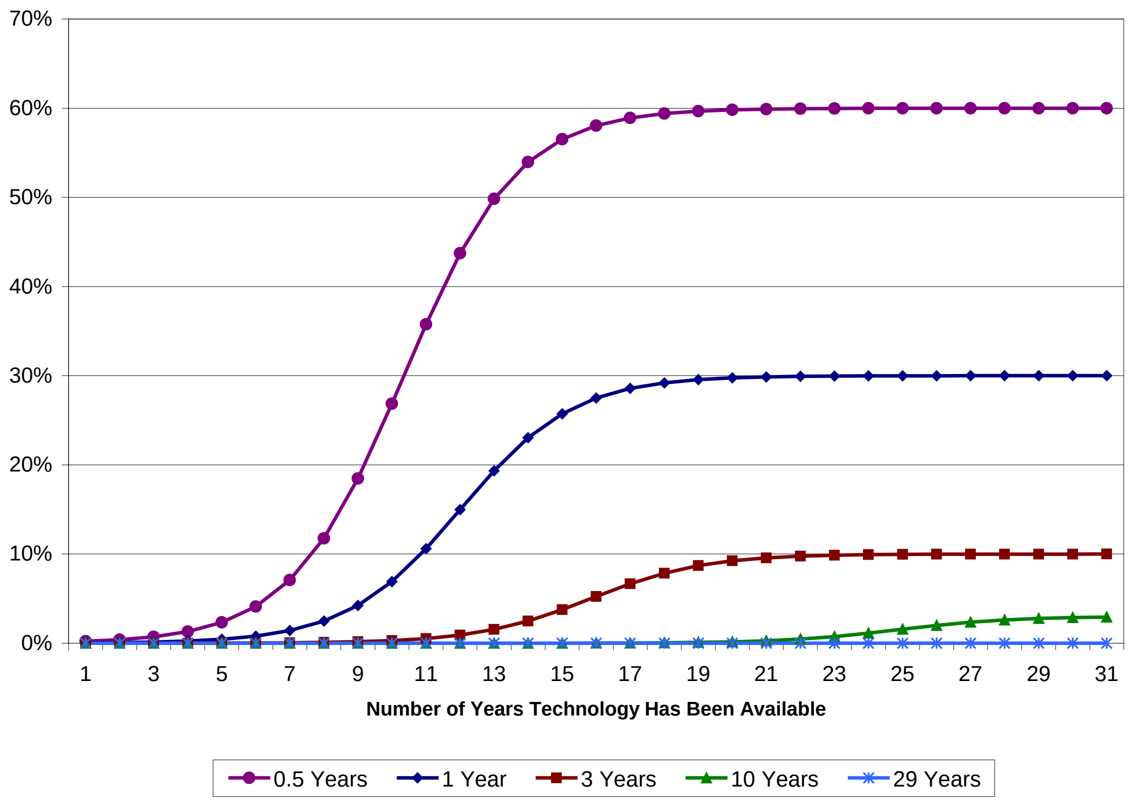
For a given value of $SimplePayBack_{t,n,l,y}$, penetration in NEMS model year "y" is an increasing function of y.

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

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

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

Figure 2: 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. $Units_{y,r,t}$ denotes the accumulated total number of 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 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):

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

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

$$\begin{aligned} Trills_{y,r,t} &= Trills_{y-1,r,t} \\ &+ \sum_{n,l \in r} \begin{bmatrix} \left(ExogPen_{y,r,t} - ExogPen_{y-1,r,t}\right) + \\ \left(Pen_{t,n,l,y} \cdot HSEADD_{r,y} + DeltaPen_{t,n,l,y} \cdot EH_{r,y}\right) \end{bmatrix} \\ &\qquad \cdot xHHShare_{n,l} \cdot AnnualKWH_{t,n,l,y} \cdot 3412 \cdot 10^{-12} \end{aligned} \tag{B-182}$$

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

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

$FuelUsage_{y,r,t}$ accumulates $FuelInput_{r,t,y}$ and converts from MMBtu to trillions of Btu:

$$FuelUsage_{y,r,t} = FuelUsage_{y-1,r,t} + \sum_{n,l \in r} \left[\begin{array}{l} \left(ExogPen_{y,r,t} - ExogPen_{y-1,r,t} \right) + \\ \quad \left(Pen_{t,n,l,y} \cdot HSEADD_{r,y} + DeltaPen_{t,n,l,y} \cdot EH_{r,y} \right) \end{array} \right] \cdot xHHShare_{n,l} \cdot FuelInput_{r,t,y} \cdot 10^{-6} \quad \text{(B-184)}$$

$HWBtu_{y,r,t}$ accumulates $WaterHtgMMBtu_{r,t,y}$ and converts it to trillions of Btu:

$$HWBtu_{t,r,y} = HWBtu_{t,r,y-1} + \sum_{n,l \in r} \left[\begin{array}{l} \left(ExogPen_{y,r,t} - ExogPen_{y-1,r,t} \right) + \\ \quad \left(Pen_{t,n,l,y} \cdot HSEADD_{r,y} + DeltaPen_{t,n,l,y} \cdot EH_{r,y} \right) \end{array} \right] \cdot xHHShare_{n,l} \cdot WaterHtgMMBtu_{r,t,y} \cdot 10^{-6} \quad \text{(B-185)}$$

$Invest_{y,r,t}$ is the current year investment in distributed generation resources in millions of 2009 dollars:

$$Invest_{y,r,t} = Invest_{y-1,r,t} + \sum_{n,l \in r} \left[\begin{array}{l} \left(ExogPen_{y,r,t} - ExogPen_{y-1,r,t} \right) + \\ \quad \left(Pen_{t,n,l,y} \cdot HSEADD_{r,y} + DeltaPen_{t,n,l,y} \cdot EH_{r,y} \right) \end{array} \right] \cdot xHHShare_{n,l} \cdot EqCost_{t,y} \cdot kW_t \cdot 10^{-6} \quad \text{(B-186)}$$

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 (ng)

$$RSFLCN_{y,ng,r} = \frac{\left(\begin{array}{l} HTRCON_{y,ng,r} + H2OCON_{y,ng,r} + CKCON_{y,ng,b,r} + GASINPUT_{y,r} + \\ DRYCON_{y,ng,r} + COOLCN_{y,ng,r} + SHTCON_{y,ng,r} + APLCON_{y,ng,r} \end{array} \right)}{1{,}000{,}000} * LEAPYR \tag{B-187}$$

Electricity (el)

$$RSFLCN_{y,el,r} = \frac{\left(\begin{array}{l} HTRCON_{y,el,r} + H2OCON_{y,el,r} + CKCON_{y,el,b,r} + REFCON_{y,r} + \\ DRYCON_{y,el,r} + COOLCN_{y,el,r} + SHTCON_{y,el,r} + APCCON_{y,r} + \\ FRZCON_{y,r} + CSWCON_{y,r} + DSWCON_{y,r} + LTCON_{y,r} + \\ SPACON_{y,r} + CFCON_{y,r} + CMCON_{y,r} + MOCON_{y,r} + \\ RCCON_{y,r} + HACON_{y,r} + SSCON_{y,r} + \\ FANCON_{y,r} + PCCON_{y,r} + TVCON_{y,r} - ANNUALKWH_{y} \end{array} \right)}{1{,}000{,}000} * LEAPYR \tag{B-188}$$

Distillate (ds)

$$RSFLCN_{y,ds,r} = \frac{\left(HTRCON_{y,ds,r} + H2OCON_{y,ds,r} + SHTCON_{y,ds,r} + APLCON_{y,ds,r} \right)}{1{,}000{,}000} * LEAPYR \tag{B-189}$$

LPG (lpg)

$$RSFLCN_{y,lpg,r} = \frac{\begin{pmatrix} HTRCON_{y,lpg,r} + H2OCON_{y,lpg,r} + CKCON_{y,lpg,b,r} + \\ SHTCON_{y,lpg,r} + APLCON_{y,lpg,r} \end{pmatrix}}{1{,}000{,}000} * LEAPYR \tag{B-190}$$

Kerosene (ks)

$$RSFLCN_{y,ks,r} = \frac{\left(HTRCON_{y,ks,r} + SHTCON_{y,ks,r}\right)}{1{,}000{,}000} * LEAPYR \tag{B-191}$$

Coal (cl)

$$RSFLCN_{y,cl,r} = \frac{SHTCON_{y,cl,r}}{1{,}000{,}000} * LEAPYR \tag{B-192}$$

Wood (wd)

$$RSFLCN_{y,wd,r} = \frac{\left(HTRCON_{y,wd,r} + SHTCON_{y,wd,r}\right)}{1{,}000{,}000} * LEAPYR \tag{B-193}$$

Geothermal (geo)

$$RSFLCN_{y,geo,r} = \frac{\left(HTRCON_{y,geo,r} + COOLCN_{y,geo,r}\right)}{1{,}000{,}000} * LEAPYR \tag{B-194}$$

National Total (us)

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

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Appendix D: 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, freezing, 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 photovoltaic equipment, fuel cells, and wind turbines.

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 2035. The model facilitates policy analysis of energy markets, technological development, and regulatory development.

Most Recent Model Update:

Residential code completed November 2010.

NEMS Reference case completed February 2011.

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 and Conversion Modules.

Office Model Representative:

Owen Comstock
Buildings Team
Office Energy Consumption and Efficiency Analysis
Office of Energy Analysis
(202) 586-4752

Documentation:

Model Documentation Report: Residential Sector Demand Model of the National Energy Modeling System, July 2011.

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 2011 (AEO2011).

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 2035 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 housing unit. Equipment stock and efficiency.
- Economic Sectors: Domestic residential sector.
- Services: Space heating, space cooling, clothes washing, dishwashing, water heating, cooking, clothes drying, refrigeration, freezing, lighting, 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: 2009," 2010.

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

Navigant Consulting, “EIA – Technology Forecast Updates – Residential and Commercial Buildings Technologies,” 2007 and 2008.

- Residential equipment technical characterization data.
- Expected minimum and maximum appliance lifetimes.

Lawrence Berkeley Laboratory, "Energy Data Sourcebook for the U.S. Residential Sector," 1997

- Expected lifetimes of housing types.

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

DOE Input Sources:

U.S. Department of Energy, Energy Information Administration, *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 C 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 Ronald D. Sands, Batelle Pacific Northwest Laboratory, James E. McMahon, Lawrence Berkeley Laboratory; and Francis X. Johnson, Lawrence Berkeley Laboratory.

Status of Evaluation Efforts by Sponsor:

None.

Appendix E: Data Quality

This Appendix discusses the quality of the Residential Energy Consumption Survey (RECS), from which the majority of the historical housing stock, appliance stock, and technology information that drives the NEMS Residential Sector Demand Module is drawn. 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 data collection procedure relies on two instruments: the housing unit survey and the energy supplier survey. Data are collected from a representative sample of housing units through personal interviews. Billing data are then collected through mail questionnaires from the companies supplying energy to the participating housing units, provided that authorization is obtained from the housing units. The results of the housing unit and energy supplier surveys are presented in the Department of Energy documentation of the RECS 2005 survey[9].

Stage I of RECS consists of a personal interview. The sample for the interviews is drawn from the population of housing units occupied as primary residences 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, housing unit appliances, housing unit vehicles, receipt of government assistance for the cost of space heating, and demographics. Housing unit respondents are also asked to sign authorization forms to allow access to their billing records with energy suppliers.

[9] U.S. Energy Information Administration, Residential Energy Consumption Survey 2005.

Stage II of the survey design consists of a mail questionnaire for energy suppliers of the housing units 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 housing units 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.