Residential Demand Module of the National Energy Modeling System: Model Documentation 2025

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Update Information

This edition of the *Residential Demand Module of the National Energy Modeling System: Model Documentation* reflects changes to the module since the previous iteration of this report. These changes include:

- Incorporating 2020 Residential Energy Consumption Survey (RECS) microdata
- Updating major end-use technology cost and performance assumptions
- Benchmarking major end-use equipment purchase shares to historical shipment data
- Revising new housing heating equipment shares and average new housing square footage based on latest U.S. Census Bureau data
- Incorporating the latest federal minimum efficiency standards for furnaces, room air conditioners, water heaters, clothes washers, clothes dryers, dishwashers, refrigerators, freezers, and miscellaneous refrigeration products
- Revising distributed generation cost and performance assumptions
- Removing estimation of geothermal energy captured from the ground
- Updating historical and projected energy efficiency program impact estimates

You can find additional information regarding annual changes to modeling and assumptions in AEO Residential and Commercial Buildings Working Group materials.

Introduction

Purpose

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

This document serves three purposes. First, this report meets the legal requirement for the U.S. Energy Information Administration (EIA) to provide adequate documentation in support of its reports, according to Public Law 93-275, Section 57(b)(1). Second, it is a reference document with detailed descriptions of our modeling for energy analysts, other users, and the public. Finally, 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 Demand Module is used to develop long-term projections and energy policy analysis during the time horizon beginning with our most recent *Residential Energy Consumption Survey (RECS)* (the module's base year, or RECSyear) through 2050 (the current projection horizon). 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 U.S. census division.

The RDM uses inputs from NEMS, such as energy prices and macroeconomic indicators, to generate energy consumption by fuel type and census division in the residential sector. NEMS uses these projections to compute equilibrium energy prices and quantities.

The RDM is an analytic tool we use 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:

- New end-use technologies
- Changes in fuel prices due to tax policies
- Changes in equipment energy-efficiency standards and building energy codes
- Financial incentives for energy efficiency and distributed generation investments

Documentation

U.S. Energy Information Administration, *Residential Demand Module of the National Energy Modeling System: Model Documentation*, DOE/EIA-M067 (2025) (Washington, DC, August 2025).

Model archival citation

The module, as part of the NEMS system, has been archived for the Reference case published in the *Annual Energy Outlook 2025* (AEO2025), DOE/EIA-0383 (2025).

The latest open-source NEMS code and input files are available at https://github.com/EIAgov/NEMS.

Model contact

Buildings Energy Consumption and Efficiency Modeling
EIAInfoConsumption&EfficiencyOutlooks@eia.gov

Report organization

Chapter 1 of this report discusses the purpose of the RDM and gives specific details on the objectives, primary inputs and outputs, and relationship of the module to other modules in NEMS.

Chapter 2 describes the rationale behind the design, fundamental assumptions regarding consumer behavior, and alternative modeling approaches.

Chapter 3 describes the NEMS RDM structure, including flowcharts and major subroutines.

Appendixes to this report document representative 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 discusses the data quality of the primary data source that informs the module.

Chapter 1: Model Purpose

Module objectives

The NEMS RDM has three fundamental objectives. The module:

- Generates disaggregated projections of energy demand in the residential sector from the RECS base year (RECSyear) through the final projection year (horizon) by housing type, fuel type, census division, and end-use service
- Assesses the impacts of changes in energy markets, building and equipment technologies, and legislative and regulatory initiatives that affect the residential sector
- Serves as an integral component of NEMS, providing projected energy demand to the supply and conversion modules of NEMS and contributing to calculations of overall energy supply and demand balance

The RDM projects residential sector energy demand in six sequential steps, producing information on:

- Housing stocks
- Technology choices
- Appliance stocks
- Building shell efficiency
- Distributed generation
- Energy consumption

The module uses a stock-vintaging approach that monitors equipment stock and equipment efficiency over time.

The module design allows the user to conduct a variety of analyses to assess proposed changes in policy or explore other uncertainties about future residential energy markets. Technological advancement in equipment design and efficiency, as well as incentive programs (such as rebates or tax credits), can be modified for specific equipment types. Housing stock attrition and equipment retirement assumptions can be modified to reflect varying equipment performance over time. Building shell, or envelope, characteristics can be modified to reflect varying policy options, such as building energy codes or the impact of mortgage incentives for energy efficiency.

NEMS uses projected residential fuel demand generated by the RDM when calculating the demand and supply equilibrium. In addition, the supply modules in NEMS 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 equipment lifetimes. The major inputs by module component are:

Housing Stock Component

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

Technology Choice Component

- Equipment retail or replacement cost
- Equipment subsidies
- Equipment energy efficiency
- Equipment penetration level (percentage of households with that equipment)
- Water usage factors
- Fuel- and technology-switching costs
- Fuel costs

Appliance Stock Component

- Expected equipment lifetime parameters
- RECSyear equipment stocks
- Equipment saturation level (number of units per household)

Building Shell Component

- Level of shell efficiency (based on insulation and air tightness)
- Price elasticity of shell efficiency
- Rate of improvement in existing housing shell efficiency
- Cost and efficiency of various building shell measures for new construction

Distributed Generation Component

- Equipment cost
- Equipment subsidies
- Equipment conversion efficiency
- Solar insolation values
- Cross-sector capacity levels
- System penetration parameters
- Wind speeds
- Grid interconnection limitations

Energy Consumption Component

- RECSyear unit energy consumption (UEC)
- Population-weighted heating and cooling degree days
- Population
- Household size
- 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 these types of included equipment:

- Forced-air furnaces (electric, natural gas, propane, and distillate fuel oil)
- Hydronic heating systems/boilers (natural gas, distillate fuel oil/kerosene)
- Heat pumps (electric air-source, ground-source, and natural gas)
- Wood stoves
- Air conditioners (central and room)
- Dishwashers
- Water heaters (electric, natural gas, distillate fuel oil, propane, and solar)
- Cooking ranges (electric, natural gas, and propane)
- Clothes washers
- Clothes dryers (electric and natural gas)
- Refrigerators (with top-, side-, and bottom-mounted freezers)
- Freezers (upright and chest)
- Lighting (general service, linear fluorescent, reflector, and exterior)
- Solar photovoltaic systems
- Natural gas fuel cells
- Small wind turbines

Geographic classification

The NEMS modules provide and use data at the census division level of aggregation, forming nine model regions within the United States. We use census division level of model specificity for two primary reasons. First, the input data available from our RECS and several other key input sources, such as the U.S. Census Bureau, are generally specified for the nine census divisions. Second, the computing system required to run the NEMS model can, within a reasonable turnaround time, experience technical constraints. The need to balance data availability, model runtime, and model output detail is best met at the census division level.

Building type classification

Although RECS and several U.S. Census Bureau products characterize various residential building types (single-family detached, single-family attached, multifamily with 2–4 units, multifamily with 5 or more units, and mobile homes), NEMS uses just three building types: single-family, multifamily, and mobile homes. We include manufactured housing with single-family housing.

The key geographic, building type, and major end-use classifications within the module are often numbered (

Table 1). Fuels are indexed differently depending on where they are referenced within the RDM (Table 2).

Table 1. Categorization of key NEMS Residential Demand Module variables

Dimension	Census division	Housing type	End-use service	
Subscript:	D	B	S	
Index value				Category
1	New England	Single-family	Space heating	Major
2	Middle Atlantic	Multifamily	Space cooling	
3	East North Central	Mobile home	Clothes washing	
4	West North Central		Dishwashing	
5	South Atlantic		Water heating	
6	East South Central		Cooking	
7	West South Central		Clothes drying	
8	Mountain		Refrigeration	
9	Pacific		Freezing	
10			Lighting	
11	U.S. total		Televisions and related equipment	Minor
12			Computers and related equipment	
13			Furnace fans and boiler circulation pumps	
14			Other[1]	

Data source: U.S. Energy Information Administration

[1] Includes miscellaneous electric loads (MELs) and unspecified electricity consumption as seen in Table 4.

Table 2. Mapping of NEMS Residential Demand Module fuel variables

Dimension			
FCON	RTFUEL		
Consumption fuel index	Technology fuel index	Fuel name	Category
1	3	natural gas	Major
2	4	electricity	
3	1	distillate fuel oil/kerosene	
4	2	propane	
5	5	formerly kerosene[a]	
6	1	wood	Minor/renewable
7	4	geothermal	
8	4	solar	

Data source: U.S. Energy Information Administration
Note: Wood is priced to distillate fuel oil when comparing across fuels; geothermal and solar are priced to electricity.
[a] Kerosene is combined with distillate fuel oil as of AEO2019. FCON/ RTFUEL 5 is no longer used.

Relationship to other NEMS models

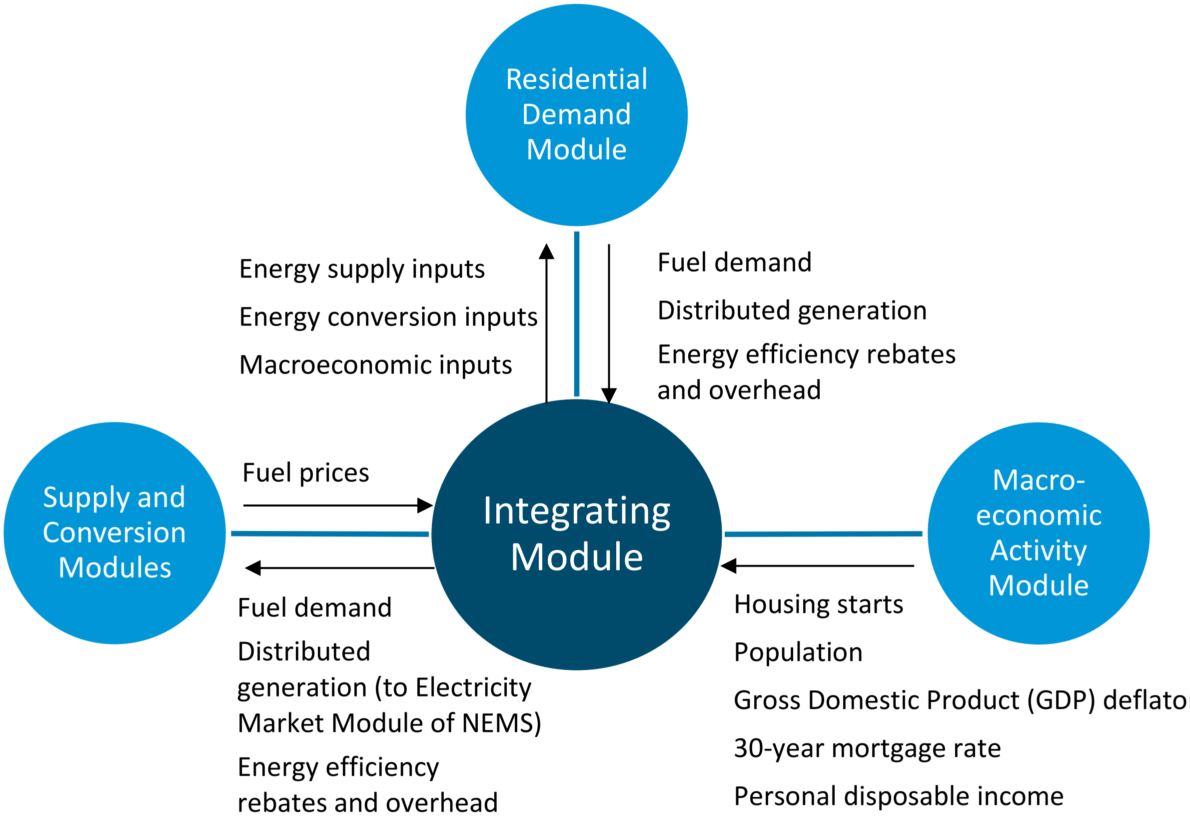
The RDM uses data from the Macroeconomic Activity Module (MAM) of NEMS. The MAM provides projected population, personal disposable income, housing starts by census division and housing type, a gross domestic product price deflator, and a 30-year residential mortgage rate.

The RDM uses fuel price projections generated by the NEMS supply and conversion modules to calculate operating costs for technology selections, existing building shell efficiency 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. The Electricity Market Module (EMM) also receives aggregated utility rebate incentives and efficiency program overhead costs calculated in the RDM to further represent utilities passing these program costs to consumers.

The RDM provides data for distributed generation by some technologies (such as onsite residential systems instead of utility-scale systems) to the EMM for calculating renewable energy credits. Utility subsidies and overhead costs are also provided. Cumulative capacity levels for distributed generation technologies are shared across the residential, commercial, and electricity market modules to facilitate technology-learning algorithms that anticipate cost reductions based on cumulative installations.

Figure 1. Relationship to other NEMS modules



Data source: U.S. Energy Information Administration

Chapter 2: Model Rationale

Theoretical approach

The NEMS RDM is an integrated dynamic modeling system based on accounting principles and a representation of residential consumer economic behavior that generates projections of residential sector energy demand, appliance stocks, and market shares.

The RDM 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 period. The housing stock changes over time as houses are removed from the stock (demolished, retired, or converted) and new construction is added or converted to residential use. Similarly, changes to the equipment stock occur 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 subroutines provide the structure for computing specific elements of the residential sector within the RDM.

RDM base-year information developed from RECS public use microdata forms the foundation of equipment and housing stock. Market share information from RECS is used to estimate the number and type of replacements and additions to the equipment stock. The model weighs both upfront capital cost and first-year operating cost of competing equipment—accounting for fuel prices, expected level of equipment usage, and equipment efficiency characteristics—to determine equipment choice and market share within a given end-use service.

The RDM uses logistic or *logit* functions to estimate the market shares of competing technologies within each end-use service. Market shares are determined for both new construction equipment decisions and replacement equipment decisions. The Technology Choice Component of the RDM considers the relative installed capital and operating costs of each equipment type within the logit function to calculate the market shares of the technology within the service, region, and housing type.

Only major end-use services with technology characterizations (in other words, space heating, space cooling, clothes washing, dishwashing, water heating, cooking, clothes drying, refrigeration, freezing, and lighting) use this approach. Because air-source and ground-source (also known as geothermal) heat pumps are used for both space heating and space cooling, the RDM assigns heat pump market shares for space cooling from the heating choice calculations.

Unlike the major technology services, several miscellaneous electric loads (MELs)—including televisions, computers, and other household devices and equipment as outlined in the RDM assumptions for the AEO—are modeled with a different approach that does not consider investment parameters such as cost or efficiency.

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

For new construction, the RDM also determines the market shares of building shell options using a similar logistic calculation. The shell options are linked to heating and cooling equipment because building codes can be met with a combination of more-efficient equipment and structural options (such as windows and insulation levels). These linked, minimum efficiencies for heating and cooling equipment in new construction can be increased but not decreased.

General model assumptions

The RDM assumes that the residential sector has the following characteristics:

- The sector is bifurcated into two housing vintages: housing that existed in RECSyear and new construction built in years after RECSyear.
- Housing units are removed from the housing stock at a constant rate over time, based on an analysis of each building type's historical stock growth and housing starts.
- Some energy-consuming equipment (such as water heaters and refrigerators) is chosen based on its upfront cost compared with its operating costs, and some appliances are chosen based on factors not related to their energy consumption (such as security systems or coffee makers).
- Equipment lifetime is defined by Weibull shape parameters. These parameters are based on estimated lifetime ranges and are used to refine 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. The RDM assumes zero salvage value for equipment.
- The choice of efficiency level for appliances in the technology menu is made using an implicit discount rate of 6.5%, derived from a ratio of beta parameters that are adjusted *exogenously* such that *endogenous* equipment purchases mimic shares of historical equipment sales.
- Projected new home heating fuel shares are based on the U.S. Census Bureau's new construction data and vary over time as a result of changes in lifecycle cost for each of the heating system types.
- The choice of fuel for water heating and cooking largely depends on the choice of heating fuel.
- The type of fuel used for cooking and water heating when replacing retiring equipment in single-family homes is based on an input percentage of those who may switch and a technology choice-switching algorithm. Replacements are with the same technology in multifamily and mobile homes.
- Space heaters, air conditioners, water heaters, cooking ranges, and clothes dryers may be replaced (up to a user-specified percentage) with competing technologies in single-family homes. Switching is based on retail cost of new equipment and the cost of switching technologies or fuels.
- Building shell efficiency and heating, ventilation, and air-conditioning (HVAC) systems for new housing stock are a function of the lifecycle cost of competing building shell and HVAC packages.

- A constant 1.2% share of existing housing is renovated each year, increasing the square footage of the conditioned (heated and cooled) living area by about one-third.
- The volumetric size of new construction is larger than existing homes, which increases the heating and cooling loads in new construction, all else equal. We base this assumption on a time-series analysis of floorspace from U.S. Census Bureau Survey of Construction data, which shows increased conditioned floorspace per household over time.

Legislation-specific model assumptions

For additional information about legislation and regulations affecting the residential sector, refer to the Residential Demand Module assumptions for the AEO.

Technology-specific modeling assumptions

We base the efficiency choices made for residential equipment on a log-linear function. The function assigns market shares for competing technologies based on the relative weights of capital or installed (first) cost and discounted operating (annual fuel) costs. A time-dependent log-linear function calculates the installed capital cost of equipment in new construction. Although not activated by default in most model runs, the option of a price-induced technological change can be activated. Essentially, with this option, if fuel prices increase markedly and remain high during a multiyear period, more-efficient appliances will be available earlier in the projection period than they would have been otherwise.

Weather and climate adjustment

We adjust space-heating and air-conditioning usage across census divisions by heating and cooling degree day factors to account for potential deviations relative to the temperatures (and their corresponding degree days) during the RECS survey period. We use thirty years of historical heating and cooling degree days for each state to establish a linear trend of heating and cooling degree days at the state level. This 30-year trend informs the projection of state-level degree days, which are exogenously aggregated to the census division level using state-level populations. Projected changes in degree days are intended to reflect projected shifts in population among states as well as continuing changes in historical degree day data.

Technology and fuel switching

Space heaters, air conditioners (heat pumps and central air conditioners), water heaters, cooking ranges, and clothes dryers may be replaced with competing technologies in single-family homes. We generally assume that 20% of the replacement market in single-family homes is eligible to switch fuels in any projection year. The log-linear functional form is flexible to allow the user to specify parameters, such as weighted bias, retail equipment cost, and technology and fuel switching cost. Equipment in multifamily and mobile homes are replaced with the same technology as already present.

Space cooling: room and central air-conditioning units

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

Where room air conditioners are used, RECS also informs the number of room air conditioners per household in new construction.

Water heating: solar water heaters

Market shares for solar water heaters are tabulated from the RECS public use microdata. The module currently assumes that, in solar water heating systems, solar energy provides 50% of the energy needed to satisfy hot water demand and that an electric backup unit satisfies the remaining 50%.

Refrigerators and freezers

The module assumes fixed overall shares for three types of refrigerators based on freezer orientation (top-mounted, side-mounted, or bottom-mounted freezer) and two types of freezers (upright and chest). Market shares were established based on RECS public use microdata.

Clothes dryers

The module currently assumes that clothes dryer market penetration increases during 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 RECS public use microdata.

Clothes washers

The module links clothes washer choice to the water heating service because many efficiency features for clothes washers act to reduce the demand for hot water.

Lighting

The module partitions lighting into four main categories of bulb type: general service, reflector, linear fluorescent, and exterior. 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, exterior, and linear fluorescent categories assume an average hours-of-use value for lamp choice purposes, based on the U.S. Department of Energy's (DOE) *2020 U.S. Lighting Market Characterization* report. Within an application such as general service lighting, the RDM uses a fixed light output level (measured in lumens) so that choices are among bulbs with similar light output. Lighting beta parameters are used to benchmark shares of general service lighting technologies to National Electrical Manufacturers Association (NEMA) lamp shipment indices.

Miscellaneous electric loads

The module uses exogenous expectations of saturation and per-unit consumption to form projections of the miscellaneous electric loads (MELs). Consumption projections for some of these MELs are also affected by projected changes in square footage and disposable income. In some cases, consumption is also multiplied by an income effect index as discussed in (B-150) because certain uses are more likely to be adopted when households have higher disposable income in a given year.

Furnace fans and boiler pumps

The number of housing units that have fossil fuel-fired central forced-air heating or boilers determines furnace fan and boiler pump energy consumption. The relative level of heating and cooling degree days also affects the amount of energy used for this service.

Secondary heating
Consumption of secondary space heating fuels is determined based on the share of total housing that uses a secondary heating fuel multiplied by the UEC, adjusted for the shell efficiency.

Other/unspecified consumption
Even with the consumption information collected in RECS, some consumption is attributed to unspecified uses. Often these unspecified uses are aggregated as *other* uses.

Distributed generation
In single-family housing, adoption of solar photovoltaic systems, natural gas fuel cells, and small wind turbines for onsite electricity generation competes with purchased electricity to satisfy a home’s electricity needs. Penetration is limited by factors outlined in the detailed description of the Distributed Generation Component. The electricity generated from these systems is either used onsite or sold back to the grid. For equipment that qualifies for a federal investment tax credit (ITC), we do not apply any safe harbor provisions. We assume all systems will be installed within the same calendar year as the relevant ITC rate.

Chapter 3: Model Structure

Structural overview

The NEMS Residential 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. This does not include a one-for-one accounting of individual RECS households and the specific equipment used over time but does account for RECS-year equipment stock versus post-RECS-year equipment stocks. The module assesses the shifts of market shares among competing technologies based on fuel prices, equipment costs, and assumptions about the behavior of residential consumers.

The RDM is a sequential structured system of algorithms; succeeding computations use the results from previously executed components as inputs. The module is made up of six components:

- Housing stock projection
- Equipment technology choice
- Appliance stock projection
- Building shell efficiency
- Distributed generation
- Energy consumption

Housing stock projection

The location and type of housing stocks are the primary module drivers. The first component uses data from the NEMS Macroeconomic Activity Module to project new and existing housing for three housing types at the census division level.

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 lifecycle 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 services listed in Table 3. The technologies are distinguished by the end-use service demand they satisfy, the fuel they consume, and their energy efficiency.

Energy efficiency can be defined as the ratio of service demand to energy input. For relatively simple devices such as space heating equipment or light bulbs, service demand is a unit of heat or light, respectively, and so 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).

Due to evolving federal minimum energy efficiency standards and test procedures, efficiency metrics can change over time. For example, heating seasonal performance factor (HSPF), seasonal energy efficiency ratio (SEER), and energy efficiency ratio (EER) are all superseded by HSPF2, SEER2, and EER2, respectively. To maintain consistency across the RDM base year (RECSyear) and projection years, a single metric is used for each equipment type in *all* model years. Conversions and efficiency metric timelines are described in *Updated Buildings Sector Appliance and Equipment Costs and Efficiency*.

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 (UEC). For refrigerators, the primary service demand is the volume of interior space refrigerated but features such as an icemaker or a through-the-door water dispenser can add to the UEC. Televisions are another example where service demand may be described as the area of the visual display, but other factors such as power draw in standby and off modes affect their consumption. For this reason, some equipment is described by a UEC (typically in units of kilowatthours or Million British thermal units per year) rather than an energy-efficiency metric (Table 4).

Table 3. Major services and equipment in the NEMS Residential Demand Module

End-use equipment	Efficiency metric
Space heating	
Air-source heat pump	Input: Coefficient of performance (COP), input Output: Heating seasonal performance factor (HSPF)
Electric furnace	Annual fuel utilization efficiency (AFUE)
Distillate fuel oil/kerosene boiler	AFUE
Distillate fuel oil/kerosene furnace	AFUE
Ground-source heat pump	COP
Propane furnace	AFUE
Natural gas boiler	AFUE
Natural gas furnace	AFUE
Natural gas heat pump	COP
Wood stove	COP
Air conditioning	
Air-source heat pump	Input: COP Output: Seasonal energy efficiency ratio (SEER)
Central air conditioner	Input: COP Output: SEER
Ground-source heat pump	Energy efficiency ratio (EER)
Natural gas heat pump	COP
Room air conditioner	Input: COP Output: EER
Water heating	
Electricity water heater	Uniform Energy factor (UEF)
Distillate fuel oil/kerosene water heater	UEF
Propane water heater	UEF
Natural gas water heater	UEF
Solar water heater	UEF
Cooking	

Electric cooking range	Kilowatthours per year (kWh / y)
Propane cooking range	Thermal efficiency (Btu out / Btu in)
Natural gas cooking range	Thermal efficiency (Btu out / Btu in)
Clothes drying	
Electric clothes dryer	Combined Energy Factor (CEF)
Natural gas clothes dryer	CEF
Clothes washing	
Top-loading clothes washer	kWh / cycle (machine energy, hot water energy), integrated modified energy factor (IMEF), integrated water factor (IWF)
Front-loading clothes washer	kWh / cycle (machine energy, hot water energy), IMEF, IWF
Dishwashing	
Dishwasher	cycles / kWh, kWh / year, gallons / cycle
Refrigeration[2]	
Refrigerator with top freezer	kWh / y
Refrigerator with side freezer	kWh / y
Refrigerator with bottom freezer	kWh / y
Freezing[2]	
Chest freezer	kWh / y
Upright freezer	kWh / y
Lighting	
General service—incandescent and halogen	Lumens per watt
General service—compact fluorescent lamp (CFL)	Lumens per watt
General service—light-emitting diode (LED)	Lumens per watt
Reflector (incandescent)	Lumens per watt
Reflector (halogen)	Lumens per watt
Reflector (CFL)	Lumens per watt
Reflector (LED)	Lumens per watt
Linear fluorescent (T12)	Lumens per watt
Linear fluorescent (T8)	Lumens per watt
Linear fluorescent (LED)	Lumens per watt
Exterior (incandescent and halogen)	Lumens per watt
Exterior (CFL)	Lumens per watt
Exterior (high-pressure sodium)	Lumens per watt
Exterior (LED)	Lumens per watt

Data source: U.S. Energy Information Administration, National Energy Modeling System (NEMS), Residential Demand Module

[2] Assumptions for typical capacity (nominal total volume) and other features can be seen in https://www.eia.gov/analysis/studies/buildings/equipcosts/

Table 4. Minor services and equipment in the NEMS Residential Demand Module

End-use equipment	Efficiency metric
Televisions and related equipment	
Televisions	MMBtu / y (converted from kWh / y)
Set-top boxes	MMBtu / y (converted from kWh / y)
Video game consoles	MMBtu / y (converted from kWh / y)
Home theater systems	MMBtu / y (converted from kWh / y)
Over-the-top streaming devices	MMBtu / y (converted from kWh / y)
Personal computers and related equipment	
Desktops	MMBtu / y (converted from kWh / y)
Laptops	MMBtu / y (converted from kWh / y)
Monitors	MMBtu / y (converted from kWh / y)
Networking equipment (modems and routers)	MMBtu / y (converted from kWh / y)
Secondary heating[3]	
Natural gas	Million British thermal units per year (MMBtu / y)
Electric	MMBtu / y
Distillate fuel oil/kerosene	MMBtu / y
Propane	MMBtu / y
Wood	MMBtu / y
Furnace fans and boiler circulation pumps	
Furnace fans and boiler circulation pumps	MMBtu / y (converted from kWh / y)
Other	
Ceiling fans	MMBtu / y (converted from kWh / y)
Coffee makers	MMBtu / y (converted from kWh / y)
Dehumidifiers	MMBtu / y (converted from kWh / y)
Microwaves	MMBtu / y (converted from kWh / y)
Pool pumps	MMBtu / y (converted from kWh / y)
Pool heaters	MMBtu / y (converted from kWh / y)
Portable electric spas	MMBtu / y (converted from kWh / y)
Non-PC rechargeable electronics	MMBtu / y (converted from kWh / y)
Smartphones	MMBtu / y (converted from kWh / y)
Tablets	MMBtu / y (converted from kWh / y)
Smart speakers	MMBtu / y (converted from kWh / y)
Home Security systems	MMBtu / y (converted from kWh / y)
Small Kitchen Appliances	MMBtu / y (converted from kWh / y)

[3] Secondary heating consumption is aggregated with space heating consumption by fuel.

Wine coolers and miscellaneous refrigeration	MMBtu / y (converted from kWh / y)
Unspecified: electric	MMBtu / y
Unspecified: natural gas	MMBtu / y
Unspecified: propane	MMBtu / y
Unspecified: distillate fuel oil/kerosene	MMBtu / y

Data source: U.S. Energy Information Administration, National Energy Modeling System (NEMS), Residential Demand Module

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.

Building shell efficiency

Building shell efficiency is modeled for existing and new housing. The existing housing stock responds to rising prices of space-conditioning fuels by improving shell efficiency. Shell efficiency improvements might range from relatively inexpensive measures (such as caulking and weather-stripping) to projects with substantial costs (such as window replacement). These improvements exhibit a one-way price response: more measures are installed as prices increase, but those measures are not undone when prices fall.

New housing stock also incorporates shell efficiency improvements. The shell efficiency 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)
- Meet ENERGY STAR criteria
- Qualify for federal tax credits for efficient shells
- Include the most efficient commercially available building shell components, as well as some non-code-compliant homes

Distributed generation component

The distributed generation component allows adoption of small-scale solar photovoltaic, natural gas fuel cells, and small wind turbine systems for onsite generation to compete with purchased electricity. Penetration rates of these systems are projected based on a ZIP code-level hurdle rate adoption model[4] (solar photovoltaics) and a cash-flow formulation (natural gas fuel cells and wind). Electricity generated from these systems is first deducted from total housing unit use and any excess generation is sold back to the grid, if feasible.

Energy consumption

The energy consumption component calculates end-use consumption for each end-use 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 period, the module performs six steps to develop the projection for energy consumption:

[4] The solar photovoltaic ZIP code-level hurdle rate adoption model was included in NEMS for AEO2016 but not turned on until AEO2017. The cash flow model was used for solar penetration in AEO2016 and has been an option since AEO2017.

1. Generate a projection of housing stock based on the retirement of existing housing stock and new construction, as determined in the Macroeconomic Activity Module
2. Estimate current-year equipment stock, accounting for housing demolitions and additions
3. Determine market shares for equipment types and efficiencies by end-use service
4. Determine the previous year's equipment additions and replacements for both existing homes and new (post-RECSyear) construction vintages, based on the current-year market share
5. Calculate efficiencies weighted by market share
6. Calculate fuel consumption using UEC and the weighted efficiencies
   - Consumption can also vary based on projected heating and cooling shell integrities, fuel prices, personal disposable income, housing unit sizes, and weather, as it applies to specific equipment and end-use services

Fortran subroutine descriptions

The Fortran source code for the NEMS Residential Demand Module consists of more than 60 subroutines sequentially called during the module execution (Table 5). The subroutines can be grouped into 13 categories according to their functions.

Fuel Price Subroutine (1 subroutine)

RDPR reads in fuel prices from NEMS

Initialization Subroutine (1 subroutine)

INTEQT initializes space 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)

RDHTRECQ projects existing vintage equipment by service. In this subroutine, the following operations are performed:

1. Read equipment market share from an input file by equipment type, housing type, and census division.
2. Calculate the RECSyear equipment stock or the existing vintage stock as the product of the share and the number of existing housing units.
3. Project surviving equipment of the existing vintage using the equipment survival rate and the housing demolition rate for every year in the projection period.

Other Input Subroutines (14 subroutines)

These subroutines read other information from input files:

RDSTEFF	reads efficiencies of RECSyear stock equipment
RDEFF	reads efficiencies of retiring equipment
RDRET	reads equipment retirement rates
RDESTARHOMES	reads historical ENERGY STAR home percentages
RTEKREAD	reads the detailed technology data for equipment and building shells
RDSQFOOT	reads home square footage data
RDUECS	reads unit energy consumption data for equipment
BLDBASEREAD	reads baseline electricity consumption for energy efficiency program calculations
RSUECSHLREAD	reads unit energy consumption data for building envelopes
RSMELSREAD	reads miscellaneous electric load data
RSSWITCHREAD	reads fuel and technology switching data
RSMLGTREAD	reads lighting technology data
DEGDAYREAD	reads degree day data
RSMISCREAD	reads miscellaneous variables

Calculation Subroutines (3 subroutines)

The model includes a subroutine **SQFTCALC** to calculate average conditioned home floor area for new and existing houses. The subroutines **PITCINIT** and **RSPITC** calculates the amount of price-induced technology change based on fuel prices.

Technology Choice—TEC Subroutines (10 subroutines)

The code includes 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 lifecycle 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**

Replacements and Additions—ADD Subroutines (9 subroutines)

The code contains end-use-level equipment replacement and additions subroutines (water heaters and cooking 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. Determine new construction vintage equipment additions based on the estimated share (from the MAM) of new houses that demand that service.
2. Compute the surviving new vintage equipment in existing vintage houses.
3. Compute total equipment required for existing vintage houses.
4. Compute the equipment replacements in existing vintage houses by subtracting the sum of surviving existing-vintage equipment and surviving new-vintage equipment in existing-vintage houses from the total equipment demanded for existing-vintage houses. Technology switching is allowed for replacing space heaters, heat pumps and central air conditioners, water heaters, cooking ranges, and clothes dryers in single-family homes.
5. Compute the surviving new-vintage equipment that was purchased as either additions or replacements for new houses.
6. Calculate the current year's replacements of new-vintage equipment in new houses by subtracting the surviving replacements and equipment additions in new houses from the stock of surviving new houses. Technology switching is allowed at replacement for space heaters, heat pumps and central air conditioners, water heaters, cooking ranges, and clothes dryers in single-family homes.

These subroutines are as follows:

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

End-Use Consumption—CON/CNS Subroutines (14 subroutines)

The 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 efficiency 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:

RCONSFL	**RHTRCON**	**RCLCON**	**RWHCON**	**RSTOVCON**
RDRYCON	**RREFCON**	**RFRZCON**	**LTCNS**	**APCNS**
SHTCNS	**APPCNS**	**RCWCON**	**RDWCON**	

Distributed Generation (1 subroutine)

RDISTGEN projects the number of housing units with distributed generation technologies; calculates amount of distributed capacity; and estimates electricity generated both for own use and for sale to the grid (reported to NEMS EMM).

Overall Consumption—CN Subroutines (2 subroutines)

The model includes the following 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 RECSyear consumption

RSBENCH calibrates consumption to historical and near-term forecast consumption

Energy Efficiency Program Impacts (1 subroutine)

CALC111D calculates incremental electricity consumption between an integrated NEMS model run that includes energy efficiency rebates and one in which no rebates are included; aggregates regional subsidies for major end-use and distributed generation equipment; and estimates energy efficiency program overhead costs; all outputs are sent to EMM of NEMS

Report Subroutines (4 subroutines)

RESDRP aggregates consumption by end use for NEMS reports

RESDRP2 provides diagnostic reports for internal use

RESDBOUT output database of detailed model results

NHTSHR prepares new space heating system shares report

Table 5. Primary NEMS Residential Demand Module subroutines

Subroutine name	Description of the subroutine
RTEKREAD	Read technological characterizations for all equipment and building shells
RDSQFOOT	Read annual average conditioned housing floor areas
RSMISCREAD	Read miscellaneous data for the module
RDPR	Populate fuel prices
PITCINIT	Initialize values for price-induced technology change
RSPITC	Compute price-induced technology change
INTEQT	Initialize heating equipment market share
RDHTREQC	Read existing RECSyear equipment stocks and project changes based on equipment retirement and replacement
RDUECS	Initialize equipment unit energy consumption (service aggregates)
RCONSFL	Map end uses to fuel number by type
EXCONS	Calculate RECSyear consumption
RDISTGEN	Project distributed generation penetration
NEWHSE	Calculate new housing
SQFTCALC	Calculate average conditioned floor area of housing
RDSTEFF	Read in efficiency of equipment from RECSyear stock
RDEFF	Read in efficiency of retiring equipment from RECSyear stock
RDRET	Read in proportion of retiring equipment from RECSyear stock
RDESTARHOMES	Read in historical ENERGY STAR home shares
RSUECSHLREAD	Read in unit energy consumption data for building envelopes
RSMELSREAD	Read in miscellaneous electric load data
RSSWITCHREAD	Read in fuel- and technology-switching parameters
RSMLGTREAD	Read in lighting technology data
DEGDAYREAD	Read in degree day data
BLDBASEREAD	Read in baseline electricity consumption for energy efficiency program impact calculations
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
RWHTEC	Choose water heating equipment
REUADD	Calculate new and replacement water heaters and cooking ranges
RWHCON	Calculate consumption for water heating

RSTVTEC	Choose cooking equipment
RSTOVCON	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
NHTSHR	Prepare new home heating system shares report
FUELCN	Calculate fuel consumption
RSBENCH	Calibrate consumption to benchmark values
NEMSCN	Calculate and report NEMS output variables
RESDBOUT	Prepare residential output database file
CALC111D	Calculate energy efficiency program costs and energy savings
RESDRP	Prepare data for reporting
RESDRP2	Report module results

Data source: U.S. Energy Information Administration, National Energy Modeling System (NEMS), Residential Demand Module

Appendix A: Input Parameters

NEMS Residential Demand Module input data files

By convention, all residential input files begin with the letters *rs*, except for KDEGDAY and BLDBASE, which are shared with the Commercial Demand Module. In addition, the following input files were combined into a single Microsoft Excel workbook called RSMESS.XLSX beginning with AEO2019: RSCLASS.TXT, RSMEQP.TXT, and RSMSHL.TXT.

Residential Technology Class Description

File: RSCLASS tab of RSMESS.XLSX

Source: RECS

Units: See discussion of individual variables below.

Comments: This input provides various pointers used throughout the module to coordinate and allocate the number of equipment types within an end use, as well as overarching parameters such as equipment life functions and choice parameters.

Variables:

$RTCLENDU_{eg}$ End use number. Matches $RTTYENDU_{es}$ in the RSMEQP inputs. Equipment classes that have the same end use number compete with one another. The RDM allocates equipment among them in the technology choice process.

1=Space Heating
2=Space Cooling (Air-conditioning)
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 RSMEQP inputs for one or more equipment types; each class in RSCLASS has one or more equipment types in RSMEQP inputs.

$RTCLTYPT_{eg}$ Required pointer from equipment class to a representative equipment type

This is the only pointer from RSCLASS to RSMEQP. This pointer identifies the equipment type used to determine the equipment class for newly constructed housing units and replacement equipment class in single-family houses. Its value is the lowest value of $RTEQTYPE_{es}$ in RSMEQP of the representative equipment (in other words, if an equipment type includes multiple efficiency levels and, therefore, spans multiple

	$RTEQTYPE_{es}$ values in RSMEQP, $RTCLEQCL_{eg}$ represents the first $RTEQTYPE_{es}$ value listed for that equipment type).
$RTCLPNTR_{eg}$	Class pointer. Required for end uses 1, 2, and 5; otherwise, equals 0 If end use ($RTCLENDU_{eg}$) = 1: Required pointer from space heating class to associated water heater class ($RTCLEQCL_{eg}$ for $RTCLENDU_{eg}$ = 5) linking water heater fuel choice to space heater fuel choice for newly constructed housing units If end use ($RTCLENDU_{eg}$) = 2: Required pointer from cooling heat pump class to same class ($RTCLEQCL_{eg}$ for $RTCLENDU_{eg}$ = 1) of space heating heat pump 0 = Not a heat pump (so, room conditioner or central air conditioner) If end use ($RTCLENDU_{eg}$) = 5: Required pointer from water heater class to matching cooking class ($RTCLEQCL_{eg}$ for $RTCLENDU_{eg}$ = 6) linking cooking fuel choice to water heater fuel choice for newly constructed housing units Also, see $RTCLREPL_{eg}$ for end use 5 (water heating) below; only natural gas water heaters may point to two types of cooking ranges
$RTCLREPL_{eg}$	Replacement class Required for end uses 1 and 5; otherwise, equals 0 If end use ($RTCLENDU_{eg}$) = 1: Flag for replacing the existing space heating class with a natural gas forced air space heater at retirement If end use ($RTCLENDU_{eg}$) = 5: Second pointer from natural gas water heater class to matching cooking class The model assumes that 46% of new single-family homes, 46% of new multifamily homes, and 64% of new mobile homes with natural gas water heaters have natural gas cooking ranges and the remainder have electric cooking ranges (*NGNGFACT* as seen in (B-94)).
$RTFUEL_{eg}$	Fuel used by this equipment (Table 2)
$RTFFAN_{eg}$	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 ($RTCLENDU_{eg}$) 1, 2, 4, 5, 7: base efficiency for this equipment class End uses ($RTCLENDU_{eg}$) 3, 6, 8, 9: intensity for this equipment class
$RTLAMBDA_{eg}$	Weibull distribution *scale* parameter alpha (α), which would be the decay length in an exponential distribution; previously lambda (λ)

RTK_{eg}	Weibull distribution *shape* parameter beta (β), which determines the way in which the failure rate changes through time; previously *k*
$RTALPHA_{eg}$	Weibull distribution *delay* parameter theta (θ), which allows for a delay before any failures occur; previously alpha (α) A delay parameter of θ=1 would reflect a typical manufacturer warranty period of 1 year
$RTMINLIF_{eg}$	Minimum life of this equipment class (years) Not used by the model but may be used to exogenously develop Weibull parameters and retained here for informational purposes
$RTMAXLIF_{eg}$	Maximum life of this equipment class (years) Not used by the model but may be used to exogenously develop Weibull parameters and retained here for informational purposes
$RTFCBETA_{eg}$	New home heating technology choice model log-linear parameter beta (β) Used only for end use ($RTCLENDU_{eg}$) 1; zero otherwise
$RTSWFACT_{eg}$	Maximum fraction of single-family homes that may switch away from specified equipment class on replacement
$RTSWBETA_{eg}$	Replacement technology choice model log-linear parameter beta (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

RDM Base-Year Equipment Stock

File: RSSTK.TXT

Sources: RECS; *Analysis and Representation of Miscellaneous Electric Loads in NEMS*

Units: Number of units (for example, number of refrigerators, number of televisions, etc.)

Comments: Each value represents values from RECS public use microdata, aggregated to the census division and building type level

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

Equipment classes include:

Space Heaters: Electric Heating Other Than Heat Pump	Furnace Fans and Boiler Pumps
Space Heaters: Air-Source Heat Pump	Televisions
Space Heaters: Natural Gas Furnace	Set-Top Boxes
Space Heaters: Natural Gas Boiler and Other	Home Theater Systems

Space Heaters: Propane Furnace and Other	Blu-ray/DVD/VHS Players
Space Heaters: Distillate Fuel Oil/Kerosene Furnace	Video Game Consoles
Space Heaters: Distillate Fuel Oil/Kerosene Boiler and Other	PC Desktops
Space Heaters: Wood Stoves and Other	PC Laptops
Space Heaters: Ground-Source Heat Pump	PC Monitors
Space Heaters: Natural Gas Heat Pump	Network Equipment
Space Coolers: Room/Window/Wall Air Conditioner	Rechargeable Devices
Space Coolers: Central Air Conditioner	Ceiling Fans
Space Coolers: Air-Source Heat Pump	Coffee Machines
Space Coolers: Ground-Source Heat Pump	Dehumidifiers
Space Coolers: Natural Gas Heat Pump	Microwaves
Clothes Washers	Pool Heaters and Pumps
Dishwashers	Security Systems
Water Heaters: Natural Gas	Portable Electric Spas
Water Heaters: Electric	Wine Coolers
Water Heaters: Distillate Fuel Oil/Kerosene	Secondary Heaters: Natural Gas
Water Heaters: Propane	Secondary Heaters: Electric
Water Heaters: Solar	Secondary Heaters: Distillate Fuel Oil/Kerosene
Cooking Ranges/Cooktops/Ovens: Natural Gas	Secondary Heaters: Propane
Cooking Ranges/Cooktops/Ovens: Propane	Secondary Heaters: Wood
Cooking Ranges/Cooktops/Ovens: Electric	Appliances: Electric
Clothes Dryers: Natural Gas	Appliances: Natural Gas
Clothes Dryers: Electric	Appliances: Propane
Refrigerators	Appliances: Distillate Fuel Oil
Standalone Freezers	

Data source: U.S. Energy Information Administration, National Energy Modeling System (NEMS), Residential Demand Module

RDM Base-Year Unit Energy Consumption

File: RSUEC.TXT

Sources: RECS; Updated Buildings Sector Appliance and Equipment Costs and Efficiency, Navigant Consulting, Inc.; *Analysis and Representation of Miscellaneous Electric Loads in NEMS*

Units: Per-unit energy consumption (million British thermal units [MMBtu]/unit/year or MMBtu/household/year)

Definition: Unit Energy Consumption (UEC) for all residential equipment classes and building types in each census division

The equipment classes are the same as those listed in the previous section for the stock of existing equipment (RSSTK.TXT).

Comments: For space heating, air-conditioning, and water heating, each value represents per-unit consumption data from RECS public use microdata, aggregated to the census division and building-type level. Other end uses are informed by several sources. The inputs are structured the same as the *RDM Base-Year Equipment Stock* file described above.

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

Equipment classes include: Same as those in the *RDM Base-Year Equipment Stock* described above.

Square Footage

File: RSSQFT.TXT

Source: RECS; U.S. Census Bureau, Survey of Construction (SOC)

Units: Square feet per housing unit

Comments: Average of conditioned floorspace in residential buildings in each housing type, for each census division, from RECSyear to the projection horizon

Values after the last historical data year are based on an exogenous projection derived from census data.

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

Stock Equipment Efficiencies

File: RSSTKEFF.TXT

Source: *Residential End Uses: Historical Efficiency Data and Incremental Installed Costs for Efficiency Upgrades*

Units: Same as RSCLASS

Comments: Values in this file give the average efficiencies of equipment remaining from the RECSyear stock expected to be retired in each year (currently held constant at RECS-year efficiencies).

Variables: $STKEFF_{y,eg}$

Equipment classes include: Same as RSSTK.TXT

Stock Equipment Retired Fraction

File: RSRET01.TXT

Source: Exogenous vintaging models developed based on shipment data

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

Comments: Values in this file give the fraction of RECSyear equipment stocks expected to be retired as of each year. They are based on exogenous calculations that vintage efficiencies from shipment data. Equipment classes included are the same as those described in the *Stock Equipment Efficiencies*.

Variables: $EQCRET_{y,eg}$

Stock Equipment Retired Efficiencies

File: RSEFF01.TXT

Source: Exogenous vintaging models developed based on shipment data

Units: Same as RSCLASS

Comments: Values in this file give the average efficiencies of RECSyear equipment stock expected to be retired as of each year (currently held constant at RECS-year efficiencies).

Variables: $EQCEFF_{y,eg}$

Heating Shares in New Construction

File: RSHTSHR.TXT (also incorporates the former file RSHTSH95.TXT)

Source: U.S. Census Bureau, Survey of Construction (SOC)

Units: Fraction of purchases

Comments: Market share of general space heating equipment for new homes in RECSyear and benchmarked years

This file provides the share of each equipment class by building type and census division. Equipment classes included are the same as those described in the *RDM Base-Year Equipment Stock* file described above, but they are limited to space heating equipment.

Variables:

HtShrYr Final year of historical data available in input file

$HSYSSHR_{y,eg,b,r}$ Share of equipment class by building type and census division

Major end-use technology menu (except lighting)

File: RSMEQP tab of RSMESS.XLSX

Source: RECS; *Updated Buildings Sector Appliance and Equipment Costs and Efficiency*, Guidehouse and Leidos; multiple Technical Support Documents of DOE Appliance Standard Rulemakings; ENERGY STAR product specifications

Units: Discussed for each variable

Comments: Each line 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.

Variables:

EqpRecords Number of technology records in technology menu

RTEKDOLLARYR Dollar year of equipment costs, based on source data

$RTTYENDU_{es}$ End-use number as in RSCLASS and Table 1
Matches *RTCLENDU* in the RSCLASS inputs

$RTTYEQCL_{es}$ Equipment class for this equipment type
Must match a class number, $RTCLEQCL_{eg}$, in the RSCLASS inputs

$RTEQTYPE_{es}$ Equipment type number

It may also refer to the lowest value of RTEQTYPE in RSMEQP (in other words, the first value to look for the next equipment class). Each equipment class may include multiple types. Each equipment type may have up to one record for each year of the projection period (years must not overlap). 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 RSCLASS inputs for heating. If adding heat pump types, add same type to both space heating and air-conditioning 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 RDM base year (RECSyear); 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 year of the projection horizon

RTCENDIV Census division, as numbered in Table 1

HVACPNTR Pointer to identify the unique HVAC system number
For space heating ($RTTYENDU_{es}$ = 1), values are the same as $RTEQTYPE_{es}$; values increase incrementally for all subsequent vintages of space cooling ($RTTYENDU_{es}$ = 2)

$RTTYPNTR_{es}$ 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 for space cooling ($RTTYENDU_{es}$ = 2) only; zero otherwise

Modify as follows only if heat pumps added:

-1 = Room/window/wall air conditioner
0 = Central air conditioner (not heat pump)
Other Integer = Corresponding heating heat pump *HVACPNTR*

$CWMEF_{es}$ Integrated modified energy factor (IMEF); previously characterized as MEF
Used only for clothes washers

$LOADADJ_{es}$ Proportion of water heating load affected by efficiency gains in clothes washing and dishwashing ($RTTYENDU_{es}$ 3 and 4, respectively)

$RTEQEFF_{es}$ Defined differently for different end uses but with the same approach as $RTBASEFF_{eg}$:
If $RTTYENDU_{es}$ = 1, 2, 3, 4, 5, 6 (non-electric), 7: Equipment efficiency (AFUE, COP, etc.)
If $RTTYENDU_{es}$ = 6 (electric), 8, 9: Annual unit energy consumption (kWh per year)

$RTEQCOST_{es}$ Installed capital cost per unit

$RTRECOST_{es}$ Retail capital cost per unit; excludes installation cost; installation assumed to be part of new construction cost

$RTEQSUB_{es}$ Federal subsidy/rebate per installed unit

$RTRESUB_{es}$ Federal subsidy/rebate per replacement unit

$RTEQSUBN_{es}$ Non-federal subsidy/rebate per installed unit

$RTRESUBN_{es}$ Non-federal subsidy/rebate per replacement unit

$RTEQS111D_{es}$ Utility subsidy/rebate per installed unit; was used for Clean Power Plan modeling (prior to repeal); used to estimate impacts of California AB32 in Pacific Census Division

$RTRES111D_{es}$ Utility subsidy/rebate per replacement unit: was used for Clean Power Plan modeling (prior to repeal); used to estimate impacts of California AB32 in Pacific Census Division

$RTMATURE_{es}$ Technology maturity description

MATURE = No further cost reductions expected; uses RTEQCOST and RTRECOST
ADOLESCENT = Main cost reductions occurred before RTCOSTP1; function *EQCOST* reduces installed wholesale and retail capital cost with RTCOSTP1 (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 or operating cost

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

RTECBIAS$_{es}$ Efficiency choice model, consumer preference log-linear parameter

RTTYNAME$_{es}$ Unique name for each equipment type

Lighting technology menu

File: RSMLGT.TXT

Source: RECS; *Updated Buildings Sector Appliance and Equipment Costs and Efficiency*, Guidehouse and Leidos; DOE Lighting Market Characterization; multiple DOE Solid-State Lighting Program reports

Units: Index values; discussed for each variable

Comments: Unlike other end uses and equipment types, characterizing lighting equipment stock and consumption requires time intervals measured in hours rather than years. Furthermore, multiple applications of lighting technologies (general service, reflector, linear fluorescent, and exterior) have different usage profiles.

Variables:

General lighting control variables:

RLGTDOLLARYR Dollar year of bulb costs, based on source data

NumApps Number of lighting applications modeled

AppID$_{app}$ A three-character variable denoting the application name:
- General service lighting (GSL)
- Reflector (REF)
- Linear fluorescent (LFL)
- Exterior (EXT)

AppIndex$_{app}$ Numerical order of the application (maximum 4 per *MaxApps* parameter in code)

NumTypes$_{app}$ Number of bulb types per application (maximum 4 per *MaxTypes* parameter in code)

NumBins$_{app}$ Number of hour-of-use bins per application (maximum 6 per *MaxBins* parameter in code)

Lighting cost and performance data include one record for each bulb modeled, and each row contains the following variables. The number of data records is allowed to vary (terminated by FirstYear = 9999, with maximum 100 per *NLRec* parameter in code), and each application must include bulbs for all lighting types for that application covering all modeled years from RECSyear through the projection horizon.

FirstYear First year bulb is available

Lastyear Last year bulb is available

BulbCost Cost per bulb

BulbEESub Non-federal subsidy/rebate per bulb. Nine columns correspond to the nine U.S. census divisions shown in Table 1

BulbSub Utility subsidy/rebate per bulb; was used for analysis of Clean Power Plan (repealed)Nine columns correspond to the nine U.S. census divisions shown in Table 1.

LPW Lumens per watt efficacy of bulb

BulbWatts Number of watts bulb consumes

LifeHours Service life in hours-of-use for bulb

BulbCRI Color Rendering Index (CRI) for bulb; 100 for full-spectrum incandescent lighting, lower for other bulb types (for example, an LED may have a CRI value of 80)

LightingApp Three-character variable that matches the AppID for the BulbType characterized

BulbType A three-character variable that defines the bulb type:
- Incandescent/halogen incandescent (INC/HAL)
- Compact fluorescent lamp (CFL)
- Light-emitting diode (LED)
- Linear fluorescent (T12/T-8)
- High pressure sodium (HPS)

LTLBeta1 Choice parameter β that applies to capital cost

LTLBeta2 Choice parameter β that applies to operating cost

Characterization of RECSyear bulb stocks (one record for each application) with stocks for each of the residential housing types (*ht*) modeled (single-family, multifamily, and mobile homes):

$BulbsPerHH_{app,ht}$ Number of bulbs per household

Data characterizing RECSyear bulb usage for each application by hours-of-use bin, grouped by application:

$AppBinHours_{app,bin}$ Daily hours-of-use for application in each hours-of-use bin

$BinShares_{app,bin}$ Shares of bulbs for application by bin (must add to 100%)

$BulbBinShares_{app,e,bin}$ Within bins, initial bulb shares by bulb type *e* for each application

$BaseWattsBulbs_{app,e}$ Watts for each of the bulb types used for this application

Building shell technology menu

File: RSMSHL tab of RSMESS.XLSX

Source: Exogenous modeling of housing units using REM/Design software

Definition: HVAC technology data for new homes

Units: Discussed for each variable

Comments: Each of the lines of this data file gives the important user-modifiable parameters for HVAC equipment in new homes.

Variables:

RSHLDOLLARYR Dollar year of shell costs, based on source data

RSCENDIV Census division number (1–9) per Table 1

RSBTYPE Building-type number (1–3) per Table 1

HVHTEQCL HVAC heating equipment class
Same as the RTCLTYPT pointer in the RSCLASS inputs for heating

HVHTEQTY HVAC heating equipment type
Same as the RTEQTYPE variable in the RSMEQP inputs for heating

HVCLEQCL HVAC cooling equipment class
Same as the RTCLTYPT pointer in the RSCLASS inputs for cooling

HVCLEQTY HVAC cooling equipment type
Same as the RTEQTYPE variable in the RSMEQP inputs for cooling

HVFYEAR Initial calendar year for this model of this equipment type

The first HVFYEAR for a model within a type should be RECSyear; subsequent initial years for a model must be previous HVLYEAR+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 projection horizon

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

HTSHBASE Heating shell base efficiency index for HVAC system type

CLSHBASE Cooling shell base efficiency index for HVAC system type

SHELCOST Installed capital cost for shell measures per housing unit for new homes

SHELLSUBSIDY Federal subsidy/rebate per housing unit

SHELLSUBSIDY111D Non-federal subsidy/rebate per housing unit; was used for analysis of Clean Power Plan (repealed)

HVPACKG HVAC shell efficiency package number

HVPGNAME Unique name for each HVAC shell efficiency package type

Service demand and baseload by new housing type

File: RSUECSHL.TXT

Source: Various

Units: Discussed for each variable

Comments: Contains new-home service demand and baseload inputs by housing type, census division, and technology; used to calculate operating costs for builder choice in new construction

Variables:

$NEWHEATUEC_{es,b,r}$ Service demand for space heating equipment by equipment type (aligns with equipment class name RTCLNAME in RSCLASS inputs), housing type, and census division
Efficiency by equipment type found in Table 3

NEWCOOLUEC$_{b,r}$	Service demand for space cooling equipment by equipment type (aligns with equipment class name RTCLNAME in RSCLASS inputs), housing type, and census division Efficiency by equipment type found in Table 3
BASELOAD$_{es}$	Standard level of efficiency as seen in Table 3 for RTCLEQCL space heating classes 1–11 and space cooling classes 1–5 in the RSCLASS inputs

Miscellaneous Electric Loads (MELs)

File: RSMELS.TXT

Source: *Analysis and Representation of Miscellaneous Electric Loads in NEMS*, Guidehouse, Inc. and Leidos, Inc.; multiple Technical Support Documents of DOE Appliance Standard Rulemakings; ENERGY STAR product specifications

Units: Index, RECSyear = 1.0

Comments: For each end use described in this file, there are two arrays, both indexed to RECSyear. One index modifies the number of units per household (penetration, or PEN), and the other modifies the per-unit energy consumption (efficiency, or EFF). Each end use has two variables associated with it; the variable naming convention uses the first three letters to associate the end use and the last three letters to associate the index type (PEN or EFF).

Variables:

NumMELs Number of MELs characterized in RSMELS.TXT input file

___*PEN*$_y$ Indexed change in equipment stock per household by year for each end use

___*EFF*$_y$ Indexed change in per-unit energy consumption index by year for each end use

Where the first three letters of each variable are associated with the following end uses:

Televisions and related equipment

*TVS*___	Televisions
*STB*___	Set-Top Boxes
*HTS*___	Home Theater Systems
*OTT*___	Over-the-Top Streaming Devices
*VGC*___	Video Game Consoles

Computers and related equipment

*DPC*___	Desktop PCs
*LPC*___	Laptop PCs
*MON*___	Monitors
*NET*___	Modems and Routers (networking equipment)

Other miscellaneous electric loads

BAT___	Non-PC Rechargeable Electronics (battery chargers)
CFN___	Ceiling Fans
COF___	Coffee Machines
DEH___	Dehumidifiers
MCO___	Microwaves
PLP___	Pool Pumps
PHP___	Pool Heaters
SEC___	Security Systems
SPA___	Portable Electric Spas
WCL___	Wine Coolers and Miscellaneous Refrigeration Equipment
SPK___	Smart Speakers
PHN__	Smartphones
TAB___	Tablets
KIT___	Small Kitchen Appliances

MELsIncomeEffect Switch (0 or 1) to apply an income effect to specific MELs end-use projections (as discussed in (B-150)).

Equipment Switching

File: RSSWITCH.TXT

Source: Switching costs based on *Residential End Uses: Historical Efficiency Data and Incremental Installed Costs for Efficiency Upgrades*

Units: Discussed for each variable

Comments: The bias parameters inform the logit function for new home heating equipment choice, and the technology/fuel switching costs describe incremental costs (electrical, plumbing, tank removal, etc.) associated with switching space heating, water heating, cooking, and clothes drying equipment (excluding the equipment cost itself).

Variables:

$RTFCBIAS_{eg,b,r}$ Bias parameters for new home heating fuel choice

$RPINSCOST_{eg,egsw}$ Costs associated with switching from equipment class (*eg*) to equipment class (*egsw*) when replacing select end-use equipment; zero cost when replacing like-with-like

Distributed Generation Technologies

File: RSGENTK.TXT

Source: *Distributed Generation, Battery Storage, and Combined Heat and Power System Characteristics and Costs in the Buildings and Industrial Sectors*, Z Federal and DNV; *Tracking the Sun: The Installed Price of Residential and Non-Residential Photovoltaic Systems in the United States*, Lawrence Berkeley National Laboratory; *Annual Technology Baseline*, National Renewable Energy Laboratory; Interstate Renewable Energy Council; Solar Energy Industry Association; Database of State Incentives for Renewable Energy (DSIRE); RECS

Units: Described for each variable

Comments: This file contains variables used in the distributed generation module calculations, including cost, efficiency, and performance variables for the three modeled technologies (solar photovoltaics, natural gas fuel cells, and small wind turbines); niche variables for modeling within census division (see RDISTGEN section of documentation); and historical capacity installations by census division.

Variables:

LPRINT(2) Controls to output more or fewer details to RDM_DGENOUT.TXT output file

NumTechs Number of distributed generation technologies modeled

NumYears Number of projection years of distributed generation modeled

NumDiv Number of distributed generation census divisions modeled

iGenCapCostYr Dollar year of equipment costs, based on source data

xAlpha Penetration function shape parameter

xPenParm Penetration function used to calculate maximum market share into new construction parameter

$xOperHours_t$ Annual operating hours by technology

GlobalLearn Control to enable global model learning for solar photovoltaic technologies; includes utility-scale systems in learning calculations

$xBeta_t$ Learning *beta* parameter by technology

$xC0_t$ Learning initial cost parameter by technology

iRPSStartYear First year for which renewable portfolios standard (RPS) credits are available for residential photovoltaic generation *iRPSPhaseOutYear* Last year for which RPS credits are available for residential photovoltaic generation

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

xInx Interconnection potential/limitation by census division; assumes that barriers to interconnection are decreasing over time

xInxFY First year of interconnection limitations

xInxLY Last year of interconnection limitations

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

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

xTerm Loan term (currently set at 30 years)

xInflation Inflation assumption for converting constant-dollar fuel costs and fuel-cost savings into current dollars for the cash flow model in order to make the flows correspond to the nominal-dollar loan payments (currently 3% annually)

nVint Number of years of distributed generation technology menu inputs

$aEquipName_{t,v}$ Distributed generation technology equipment name

$iFuelType_{t}$ Fuel used by technology (0 for solar and wind); must coincide with fuels in Table 1

$iFirstYr_{t,v}$ First year technology is available

$iLastYr_{t,v}$ Last year technology is available

$xKW_{t,v}$ Capacity in kilowatts direct current (kW_{DC}) of typical system

$xElEff_{t,v}$ Electrical conversion efficiency (in other words, efficiency of solar panel in converting solar energy into electrical energy) by technology and vintage

$xLossFac_{t,v}$ Conversion losses for systems that are rated *at the unit* rather than per available alternating current wattage (in other words, direct current-to-alternating current [DC-to-AC] inverter conversion efficiency; equivalent to the inverse of inverter loading ratio), if appropriate

$xDegrad_{t,v}$ Annual degradation of conversion efficiency by technology and vintage

$xEqLife_{t,v}$ Equipment lifetime by equipment type and vintage

$xWhHecovery_{t,v}$ Waste heat recovery factor for technologies that burn fuel (that is, not wind or solar photovoltaics)

$xInstCost_{t,v}$ Installation cost in dollars per kW_{DC}

$xCapCost_{t,v}$ Capital cost of the investment in dollars per kW_{DC}

$xMaintCst_{t,v}$ Annual maintenance cost in dollars per kW_{DC}

$xIntervalCst_{t,v}$ DC-to-AC inverter cost

$iIntervalYrs_{t,v}$ DC-to-AC inverter equipment lifetime

$xAvail_{t,v}$ 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 applicable)

$xTxCrMaxPerKW_{t,v}$ Maximum tax credit dollar amount, if any, per kW_{DC} system capacity

$xTxCrMaxPerSys_{t,v}$ Maximum tax credit dollar amount, if any, per distributed generation system

$\mathrm{xTxCrPct\_div}_{t,v,r}$ Subsidy/rebate per system as a percentage of installed capital cost
Nine columns correspond to the nine U.S. census divisions shown in Table 1

xTemp RPS credit availability (1 = yes, 0 = no). Annualized using *xRPS* variable

xTemp1 Number of years before RPS rate adjustment; annualized using *iNumYrsatRPSBaseRate* variable

xTemp2 Total number of RPS credit years; annualized using *iNumRPSCreditYrs* variable

Descriptions for renewable resource and electricity *niche-dimensioned* rate level variables within each census division from RECS:

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

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

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

$xAvgKWH_{r.n,rl}$ RECS average annual electricity consumption in kWh per household within each niche

$xRoofAreaPerHH_{r.n,rl}$ Estimated roof area per household within each niche

$xWindSpeed_{r.n,rl}$ Estimated wind speed within each niche in meters per second

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

Variables representing program-driven and historical distributed generation capacity:

iExogHistYr Last calendar year of historical exogenous capacity data for distributed generation technologies; model builds start after this year

$xExogPen_{t.r,y}$ Exogenous distributed generation capacity by technology, census division, and year

Variables used to estimate the effects of wholesale versus retail electricity rate used to value solar PV generation used onsite or sold back to the electrical grid:

DGrateBlend Control to use blended marginal (wholesale) and retail electricity rates instead of space cooling end-use electricity rate

DGrateYr First year of change from retail net-metered to weighted electricity rates

DGmargWt Census division-level weights for marginal (wholesale) electricity rate
Combined with *DGretWt*, must add up to 1.0 by census division

DGretWt Census division-level weights for retail electricity rate
Combined with *DGmargWt*, must add up to 1.0 by census division

Solar Photovoltaic Hurdle Rate Adoption Model

File: RGENTK.TXT

Source: State solar PV program data from various states; U.S. Census Bureau's American Community Survey (ACS);; solar insolation data from the National Renewable Energy Laboratory; various reports and studies

Units: Described for each variable

Comments: This file has been repurposed from its former use as the residential distributed generation technology menu and now contains ZIP code-level variables used to calculate small-scale residential solar photovoltaic installation penetration via a hurdle rate adoption model.

Variables:

UseZipModel Boolean variable used to activate solar PV hurdle rate adoption model

PVzipcalib Boolean variable used to calibrate hurdle rate adoption model to exogenous PV capacity or to use ZIP code-level hurdle model capacity output starting in EstYear

EstYear First year of data estimated by hurdle rate adoption model

Coefficients for full, urban, and rural models:

CINT	Model intercepts
CHH	Number of households
CPD	Population density
CINC	Income
CINS	Solar insolation
CER	Electricity rate
CCDD	One-year lagged cooling degree days
CPMT	Monthly payment for PV system (30-year)
CIR	Interest rate
CLAG1	Lag1 PV installs (one-year lag)
CLAG2	Lag2 PV installs (two-year lag)
CPVP	PV installed price net of tax credits (if any)
NumZips	Total number of ZIP code records in file

ZIP code-level data:

ZipCodes	Record ZIP code
State	State that includes the record ZIP code
CenDiv	Census division (shown in Table 1) that includes the record ZIP code
Income	Median household income in nominal *EstYear* dollars
Households	Number of households within the ZIP code
PopDensity	Population density in units of households per square mile
Insol	Annual average solar irradiation level, in kilowatthours per square meter per day (assumed to be constant over time)
ElecRate	ZIP code-level electricity rate in cents per kilowatthour, derived from state-level and ZIP code-level rates
LagCDD	One-year lagged cooling degree days
IntRate	Annual average mortgage interest rate for *EstYear*
PVPrice	Installed price of solar PV system in *EstYear*

MonthlyPayment Monthly payment per kW_{DC} of installed system capacity, based on a 30-year (360-month) mortgage

Lag1Installs One-year lagged estimate of number of residential solar PV installations in the ZIP code

Lag2Installs Two-year lagged estimate of number of residential solar PV installations in the ZIP code (not currently used in the models)

PureHurdle Value (0 or 1) indicating whether or not *Lag1Installs* is used in projections for the ZIP code (0 indicates it is used).

RuralZip Value (0 or 1) identifying ZIP code as rural (in other words, having a population density of 10 or fewer households per square mile)

ModelInstalls Projected number of new residential solar PV installations for the ZIP code

Historical ENERGY STAR Home Shares

File: RSESTAR.TXT

Source: ENERGY STAR Certified New Homes Market Indices for States, U.S. Environmental Protection Agency

Units: Share of homes within census division, building type, and shell efficiency level

Comments: This file has been repurposed to use inputs formerly located in RSMSHL (HVBETA1 and HVBETA2) and RSMUECSHL.txt (LEARNFACT). The former shares of ENERGY STAR homes that had been contained in this file were endogenized during AEO2014:

$HVEQWTN_{y,e,s,d}$ Percentage of homes meeting ENERGY STAR Home specification or better by heating technology type, shell level type, and census division

Variables:

ESTARHISTYR Last year of historical ENERGY STAR single-family housing data in file

$HVBETA1_{y,b,s,d}$ HVAC efficiency choice model log-linear parameter β_1, weights capital cost

$HVBETA2_{y,b,s,d}$ HVAC efficiency choice model log-linear parameter β_2, weights fuel cost

$LEARNFACT_{b,d}$ Learning factors (no units) for ENERGY STAR qualified shells by housing type and census division

Weather (Degree Days)

File: KDEGDAY.TXT

Source: Historical and near-term forecast of heating and cooling degree days from the National Oceanic and Atmospheric Administration (NOAA).

We develop projected degree days exogenously, based on a 30-year historical trend. Population weights from detailed inputs to the Macroeconomic Activity Module, which maintains historical and projected state-level populations.

Units: Population-weighted degree days

Comments: This file, which is also used by the Commercial Demand Module (CDM), supplies heating and cooling degree day information for weather adjustments in the RDM.

Variables:

$HDDADJ_{y,r}$ Heating degree days by census division and year

$CDDADJ_{y,r}$ Cooling degree days by census division and year

Miscellaneous Inputs

File: RSMISC.TXT

Units: Discussed for each variable

Source: Discussed for each variable

Comments: This file contains variables and arrays that otherwise did not fit conceptually with the other input files.

Variables:

HDR_b Housing demolition rates by building type

HDRfy, HDRly First and last years of endogenous HDR calculation for integrated runs

ResDiscountRate Consumer discount rate

Tenure Average years spent in a home in RECSyear

$EH_{RECSyear,b,r}$ Existing houses in RECSyear by building type and census division (with totals)

$RACSAT_{b,r}$ New-home room air conditioner penetration level (number of homes with equipment divided by total number of new homes) by building type and census division

$RACUnits_{b,r}$ Number of room air conditioners per new home by building type and census division

$CACSAT_{b,r}$ New-home central air conditioner penetration level by building type and census division

CACPR$_r$ Existing-home central air conditioner average annual penetration rate by census division

DWPR Existing-home average annual dishwasher penetration rate by building type and census division

ELDRYPR$_{b,r}$ Existing-home average annual electric dryer penetration rate by building type and census division

TCW_SHR Share of existing RECSyear clothes washers that are top-loading

FCW_SHR Share of existing RECSyear clothes washers that are front-loading

SMF_SHR Share of existing RECSyear refrigerators with side-mounted freezer

BMF_SHR Share of existing RECSyear refrigerators with bottom-mounted freezer

TMF_SHR Share of existing RECSyear refrigerators with top-mounted freezer

CH_SHR Share of existing RECSyear standalone freezers that are chest-type

UP_SHR Share of existing RECSyear standalone freezers that are upright

FRZSAT$_{b,r}$ Number of freezers per new home by building type and census division

REFSAT$_{b,r}$ Number of refrigerators per new home by building type and census division

DISHNEW$_{b,r}$ New-home dishwasher penetration level by building type and census division

WASHNEW$_{b,r}$ New-home clothes washer penetration level by building type and census division

NEWDRYSAT$_{eg,b,r}$ New-home clothes dryer penetration level by fuel (natural gas, electric), building type, and census division

SHTSHR$_{r,f,b}$ Existing-home secondary space heating penetration level by fuel, building type, and census division

NSHTSHR$_{r,f,b}$ New-home secondary space heating penetration level by fuel, building type, and census division

WTHRZTN$_{y,f,r}$ Changes to existing space heating and space cooling shell indices as a result of weatherization measures, by building type, census division, and projection year

ELASTIC$_{s,r}$ Elasticity of service demand to square footage by end use and census division

MODYEAR First index year for calculating model price elasticities

ENDMODYEAR Last index year for calculating model price elasticities

The following variables are set equal to 1.0 when not performing elasticity runs:

ELFACTOR Electricity scaling factor for calculating model price elasticities

NGFACTOR Natural gas scaling factor for calculating model price elasticities

DSFACTOR Distillate fuel oil scaling factor for calculating model price elasticities

LPGFACTOR Propane scaling factor for calculating model price elasticities

Historical Data and Short-Term Energy Outlook Benchmarking

File: RSSTEO.TXT

Units: Trillion Btu

Source: Three EIA products: State Energy Data System, *Monthly Energy Review*, and *Short-Term Energy Outlook*

Comments: Used to benchmark early RDM projections to annual historical consumption by fuel type and census division

Variables:

STEObenchNG Benchmark multiplicative tweaking factor for natural gas (no units)

STEObenchEL Benchmark multiplicative tweaking factor for electricity (no units)

$STEOCN_{y,f,r}$ Regional consumption by fuel and year for historical years comes from the State Energy Data System for the model's base year (RECSyear) and as many subsequent years as available. Beyond those years, national total energy consumption by fuel and year comes from the *Monthly Energy Review*, and beyond that, the *Short-Term Energy Outlook* (STEO) for near-term forecasts.

Baseline Electricity Consumption for Energy Efficiency Calculations

File: BLDBASE.TXT (also used by the Commercial Demand Module of NEMS)

Source: Integrated NEMS model run in which no energy efficiency rebates or subsidies are included (except for federal tax credits)

Units: Billion kilowatthours

Comments: Used to calculate incremental electricity consumption between an integrated NEMS model run that includes energy efficiency rebates (for example, AEO side cases including and prior to repeal of the U.S. Environmental Protection Agency's Clean Power Plan) and one in which no rebates are included

Variable:

$baselinebkwh_{y,r}$	Baseline electricity consumption, by census division, model index year (starting in 1990), and sector (residential and commercial)

Appendix B: Detailed Mathematical Description

This appendix presents detailed calculations representative of those used in each of the module components. The latest version of open-source NEMS code and input files are available at https://github.com/EIAgov/NEMS. Table B-1 shows the correspondence between each of the subscripts in the documentation and the subscripts in the Fortran source code. The table of subscripts includes all 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 or aggregated nationally) and re-stored under the same variable name (that is, in the same memory location). The equal signs in these statements do not denote equality; they indicate 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 the projection horizon. 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 through the projection horizon.

Some variables are documented with a *y* dimension when, in the Fortran code, they do not have one. 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 model year. Although previous values are overwritten, the variables do have a *y* dimension. The *y* dimension is shown explicitly in the documentation to highlight that the calculations vary by year and to indicate the current model year in formulas to avoid confusion.

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

Table B-1. Definition of subscripts

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 (building) type
Y	CurIYr or CurCalYr	Annual index or calendar year
y-1	CurIYr-1 or CurCalYr-1	Previous year index or calendar year
eg	EQC, RECCL	Index of general equipment class within an end use(for 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

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 housing units use energy. The end uses listed in Table 1 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.

Further, the RDM assumes that several 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 major end uses, as well as stocks, annual unit energy consumption, and projected annual change assumptions for various miscellaneous electric loads. In general, the equipment classes are each used to satisfy a particular end use; however, in a few cases, one class of equipment (for example, heat pumps) satisfies more than one end use, and in other cases, the availability of one class of equipment makes another class more likely (a natural gas furnace is frequently accompanied by a natural gas water heater and cooking equipment).

Each equipment class is made up of a variety of equipment types that each have their own technological characteristics, such as efficiency, cost, and year when the technology is expected to become available or made obsolete. Examples of equipment types include the array of available natural gas furnaces, the more expensive of which tend to have higher efficiencies. The RDM does not attempt to represent all manufacturers' products, but rather, it defines broad types that are like one another in their technological characteristics. The user can define and modify the definitions of these equipment types by modifying the equipment menu inputs.

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

The concept of equipment classes making up a number of different equipment types that each contain several models underlies the entire discussion of this manual. In earlier editions of the documentation, we referred to these two classifications 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. Over time, cost and performance can vary even within a specific equipment type, especially as federal energy-efficiency standards for certain appliances and equipment are introduced.

Other RDM files define the characteristics of the mix of equipment and appliances that are in use in RECSyear, including relative numbers installed (that is, existing stock), efficiencies, and the rates at which they are expected to be replaced.

The Residential Demand Module has 30 defined technology classes across the 9 major end uses shown in Table 1. The list of equipment classes is not exhaustive of all major end-use technologies used in the residential sector; there is, for example, a small percentage of homes in which wood is burned for water heating. Most equipment used to satisfy the major end uses falls into at least one class.

Within each of the equipment classes defined in the RSCLASS inputs, the RDM 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 RSMEQP inputs contain 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, it changes the proportions of each type according to its evaluation of the equipment characteristics (that is, a distribution of selections rather than a single selection).

The characteristics of each equipment type can change over time, so the RSMEQP inputs allow more than one set of characteristics for each equipment type.

Housing and equipment stock formation

To calculate the number of existing housing units, the Housing Stock Component adds newly built homes to the inventory and subtracts demolitions. Housing construction starts and mobile home shipments are obtained from regional outputs of the NEMS Macroeconomic Activity Module (MAM). Existing RECSyear housing stock is designated as the *existing* vintage, and new additions to the housing stock are referred to as the *post-RECSyear* vintage. Equipment additions and replacements for both housing vintages are tracked through the projection period.

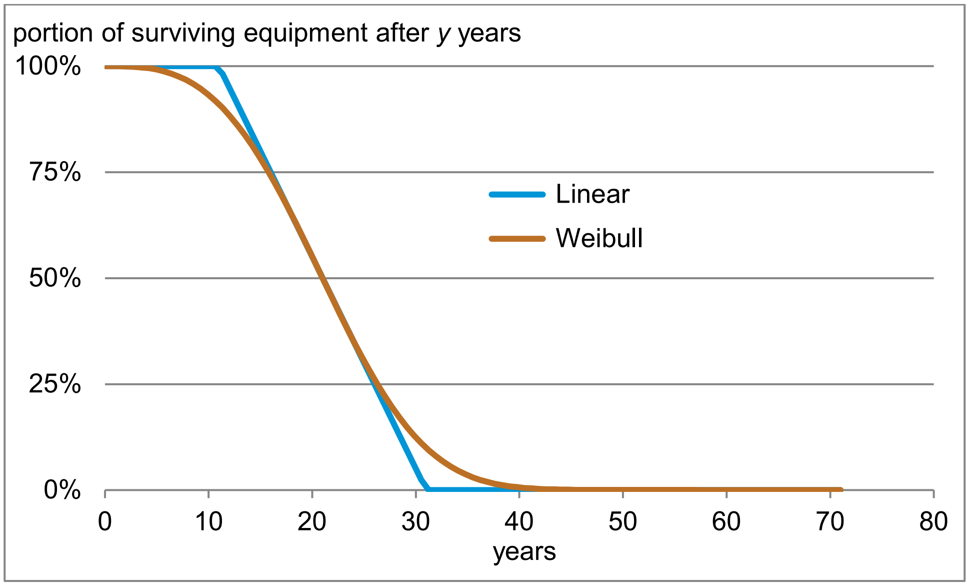
The survival rate function SVRTE can be called with arguments and returns a single value as its result. The function is a Weibull-shaped decline, as shown in Figure 2 below. Its mathematical description is:

$$SVRTE_{y,\theta,k,\lambda} = e^{-({y-\theta}/{\alpha})^{\beta}} \quad \text{(B-1)}$$

where

$SVRTE_{y,k,\lambda}$	is the proportion of surviving equipment after *y* years,
y	is the number of years after purchase,
θ	is the delay parameter,
α	is the scale parameter, and
β	is the shape parameter.

Figure 2. Weibull and linear equipment survival rate functions



Data source: U.S. Energy Information Administration, National Energy Modeling System (NEMS), Residential Demand Module

The Weibull shape and scale parameters were estimated to approximate the median and slopes of the existing linear decay functions that had been used in AEO2012 and previous AEOs. Beginning with AEO2025, Weibull parameters are aligned with definitions and characterizations of delay, scale, and shape parameters as used by DOE energy efficiency standards.

Existing housing evolution rate

The model assumes housing units are removed from stock at a constant rate over time. Housing demolition rates (HDR_b) are intended to reflect all changes to the count of residential units other than additions from new construction. These changes include demolition, decay, and vacancy, as well as additions such as conversion from commercial buildings. They can be thought of as *survival* or *evolution* rates rather than strict demolition or decay factors.

HDR values are determined endogenously. The RDM uses housing starts and housing stock arrays by housing type provided by the MAM to estimate long-term average implicit evolution rates.

The surviving RECSyear housing stock is defined by

$$EH_{y,b,r} = RECS\ data, if\ y = RECSyear$$
$$EH_{y,b,r} = EH_{y-1,b,r} * HDR_b, if\ y > RECSyear \tag{B-2}$$

where

$EH_{y,b,r}$ is the RECSyear housing stock surviving in year y,
HDR_b is the housing evolution rate, with an assumed maximum value of 1.0 (100% of housing stock by building type remaining each year).

New construction

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

$$NH_{y,r} = MC_{HUSPSI_{y,r}} + MC\_HUSPS2A_{y,r} + MC\_HUSMFG_{y,r} \tag{B-3}$$

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, and
$MC\_HUSMFG_{y,r}$	is mobile home shipments added by year and census division.

Square footage

In the calculation of square footage, the model first aggregates 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 housing that existed in RECSyear, and
$NEWHSES_y$	is the national total of remaining post-RECSyear new construction additions.

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

$$SQFTAVG_{y \neq baseyr} = \frac{\sum_{b,r}(SQRFOOT_{RECSyear,b,r} * EH_{RECSyear,b,r} + SQRFOOT_{y,b,r} * NH_{y,b,r})}{OLDHSES_{RECSyear} + NWHSES_y} \tag{B-7}$$

where

$SQFTAVG_y$	is the average conditioned floor area of houses of all types, and
$SQRFOOT_{y,b,r}$	is a table of historical and projected housing floor areas by year, housing type, and census division.

Projecting RECSyear-vintage equipment for all end-use services

Much of the equipment that exists in the RDM base year (RECSyear) survives into subsequent years. For years beyond RECSyear:

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

where

$EQCESE_{y,eg,b,r}$	is the amount of surviving RECSyear-vintage equipment in RECSyear housing by housing type and census division,
HDR_b	is the housing evolution rate by housing type, and
$EQCRET_{y,eg}$	are the annual equipment retirement fractions for the equipment classes.

Technology Choice Component

The Technology Choice Component uses a log-linear function to estimate technology market shares for the major end uses shown in Table 1. The module can calculate market shares based on consumer behavior as a function of bias, capital costs, and operating costs or as a function of lifecycle costs.

All minor end uses are modeled differently and in less detail than the major end-use services.

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. Up to five HVAC/shell packages are 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%, 40%, and 50% 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 efficiency increases for 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:

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

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, region, and projection 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 weather differences between RECSyear and 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, space heating and air conditioning choices are linked and, therefore, operating cost is a function of both the heating and cooling operating costs, accounting for the shell efficiency:

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

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 (for example, high-efficiency versus 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. EQCOST is called if the cost trend switch COSTTRSW = 1 (default setting) in NEMS include file RTEK. The formulation allows three general classifications of equipment. For mature equipment, no further time-dependent cost declines occur. For adolescent equipment and infant equipment, cost 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:

$$EQCOST_{es,y,CAP} = RETEQCOST_{es}, if\ RTMATURE_{es} = MATURE$$

$$EQCOST_{es,y,RET} = RTREQCOST_{es}, if\ RTMATURE_{es} = MATURE \quad \text{(B-11)}$$

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

$$if\ RTMATURE_{es} = ADOLESCENT \quad \text{(B-12)}$$

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

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

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

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

(B-13)

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

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

where

$EQCOST_{es,y,ctype}$ is time-dependent 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,

$RTMATURE_{es}$ is a technology maturity description,

MATURE = no further equipment cost reductions expected,
ADOLESCENT = major cost reductions occurred before RECSyear,
INFANT = all cost reductions expected after first year available,

$RTEQCOST_{es}$ is installed wholesale capital cost in RTEKDOLLARYR dollars per unit for new homes, which remains constant for MATURE technologies only (used when ctype = CAP),

$RTRECOST_{es}$ is retail capital cost in RTEKDOLLARYR dollars per unit for replacements, and remains constant for MATURE technologies only (used when ctype = RET),

y is the current projection calendar year,

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,

γ is the assumed logistic curve shape parameter, $RTCOSTP2_{es}$.

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

The concept of price-induced technology change is also included when formulating equipment costs. Although not activated in most model runs, this concept allows future technologies to have faster diffusion into the marketplace if fuel prices increase markedly and remain high during a multiyear period. First, compare the average fuel price for a given fuel during a three-year period with the price observed in the RDM base year (RECSyear):

$$PRICE\Delta_{y,f} = \frac{0.33333 * (PRICE_{y,f} + PRICE_{y-1,f+}PRICE_{y-2,f})}{PRICE_{RECSyear}} \quad \text{(B-14)}$$

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 will advance forward by, at most, 10 years. For nearer-term technologies, shifts are limited to a lesser number of years by the algorithm to ensure that 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:

$$SHIFTYEARS_f = \frac{(PRICE\Delta_f - 1.0)}{0.10} \quad \text{(B-15)}$$

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

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

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

where

$LFCY_{y,es,b,r,v}$ is the lifecycle cost of an equipment type by projection year, housing type, 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,
Tenure	is the number of years into the future used to compute the present value of future operating cost expenditures based on average years spent in a home, presently set to nine years, and
ResDiscountRate	is the discount rate applied to compute the present value of future operating costs, presently set at 20%.

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

$$HEATSYS_{y,eg,b,r} = LAGFACTOR * HEATSYS_{y-1,eg,b,r} + (1 - LAGFACTOR) * e^{RFTBIAS_{y,eg} + RTFCBETA_{eg} * LFCY_{y,eg,b,r,v}} \quad \text{(B-17)}$$

where

$HEATSYS_{y,eg,b,r}$	is the equipment weight for a space heating equipment class for new housing by year, housing type, and census division,
LAGFACTOR	is the weight given to the previous 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 lifecycle cost for the equipment class by year, housing type, 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:

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

where

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

The equipment class fuel share is computed as

$$HTYSSHR_{y,eg,b,r} = \frac{HEATSYS_{y,eg,b,r}}{SYSTOT_{y,b,r}}, if\ SYSTOT_{y,b,r} > 0 \quad \text{(B-19)}$$

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

where

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

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

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

$$EQWTR_{y,es,b,r} = e^{\left(RTECBTA1_{es}*CAPITAL_{es}+RTECBTA2_{es}*OPCOST_{y,es,b,r,2}\right)} \quad \text{(B-21)}$$

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), and

$RTECBTA1_{es}$
$RTECBTA2_{es}$ these two parameters give relative weights to the capital and operating costs in the equipment choice determination; their ratio forms an implicit discount rate used to value the operating cost savings from more-efficient equipment.

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

$$TOTEWTN_{y,eg,b,r} = \sum_{es\epsilon eg} EQWTN_{y,es,b,r} \quad \text{(B-22)}$$

$$TOTEWTR_{y,eg,b,r} = \sum_{es\epsilon eg} EQWTR_{y,es,b,r} \quad \text{(B-23)}$$

where

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

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

The equipment type share within a general equipment class is computed as:

$$EQFSHRN_{y,es\epsilon eg,b,r} = \frac{EQWTN_{y,es\epsilon eg,b,r}}{TOTEWTN_{y,eg,b,r}}, if\ TOTEWTN_{y,eg,b,r} > 0$$
$$EQFSHRN_{y,es\epsilon eg,b,r} = 0, otherwise \tag{B-24}$$

$$EQFSHRR_{y,es\epsilon eg,b,r} = \frac{EQWTN_{y,es\epsilon eg,b,r}}{TOTEWTR_{y,eg,b,r}}, if\ TOTEWTN_{y,eg,b,r} > 0$$
$$EQFSHRR_{y,es\epsilon eg,b,r} = 0, otherwise \tag{B-25}$$

where

$EQFSHRN_{y,es \in eg,b,r}$ is the new equipment type share by year, building type, and census division, and

$EQFSHRR_{y,es \in eg,b,r}$ 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:

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

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

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 RECSyear 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.

The equipment accounting system partitions equipment into two major categories, depending on the vintage of the housing unit: equipment installed in housing units existing in RECSyear (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-2).

Table B-2. Categorization of tracked equipment by vintage and survival/replacement type

Category	Variable	Definition
Existing housing unit	EQCESE	Surviving equipment stock in RECSyear existing homes (in other words, equipment that was present in RECSyear)
	EQCSR90	Equipment stock in RECSyear existing homes that was added as a replacement after RECSyear and still survives
	EQCRP90	Current-year replacement equipment for RECSyear existing housing
	EQCRP90RP	Current-year replacements for equipment that were previously replaced in EQCRP90 (in other words, replacements of replacements)
Modeled (new construction) Housing unit	EQCSUR	Equipment that was modeled as added and still survives
	EQCREP	Equipment that was modeled as added and needs to be replaced in the current year
	EQCADD	Equipment for housing units added in the current year

Data source: U.S. Energy Information Administration, National Energy Modeling System (NEMS), Residential Demand Module
Note: EQCND90 is the sum of EQCESE, EQCSR90, EQCRP90RP, and EQCRP90.

Table B-3. Categorization of equipment unit energy consumption (UEC) by category of housing unit

Category	Variable	Definition
Existing housing unit	EQCUEC	Average UEC for the original RECSyear equipment in housing units that existed in RECSyear
	EQCSUEC	Average UEC for surviving equipment in existing RECSyear housing units
	EQCAUEC	Average UEC for surviving equipment in existing RECSyear housing units that was replaced in the model run
	EQCRUEC	UEC for all equipment added in the current year to replace existing RECSyear equipment
Modeled (new construction) housing unit	EQCHVUEC	UEC for space heating and air-conditioning equipment in new construction added in the current year
	EQCAHVUEC	Average UEC for space heating and air-conditioning equipment in surviving new construction
	EQCNUEC	UEC for all equipment added in the current year to replace equipment after RECSyear

Data source: U.S. Energy Information Administration, National Energy Modeling System (NEMS), Residential Demand Module

Shell indices are modeled for three categories of housing units:

- EHSHELL is the shell index applicable to housing units that existed in RECSyear.
- AHSHELL is the shell index applicable to housing units added in all but the current year.
- NHSHELL is the shell index for housing units added in the current year.

For example, when accounting for the space heating energy consumption of surviving equipment installed in housing units that existed in RECSyear, the equipment stock (HTESE) is 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 Demand Module. For the example above, the appropriate air conditioning variables would be CLESE, CLUEC, and ECSHELL. The shell indices apply only to space heating and air conditioning; so, refrigeration accounting, for example, requires only RFESE and RFUEC.

The housing demolition rate is used with the equipment survival rate to determine the number of equipment units that survive/retire each year in the projection. The Weibull-shaped function described in (B-1) is used to model the proportion of equipment surviving after *y* years of use.

Equipment in houses constructed in the model run is the product of the number of new houses and the market share of each equipment class, which is expressed as:

$$EQCADD_{y,eg,b,r} = HSEADD_{y,b,r} * SHARESN_{y,eg,b,r} \quad \text{(B-28)}$$

where

$EQCADD_{y,eg,b,r}$ is the number of post-RECSyear-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 projection year by housing type and census division, and
$SHARESN_{y,eg,b,r}$	is the current-year market share for each equipment class by housing type and census division.

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

$$EQCREP_{y,eg,b,r} = \sum_{t=RECSyear+1}^{t=y-1} \left(EQCADD_{t,eg,b,r} * HDR_b{}^{y-t} * \left(1 - SVRTE_{y-t,L_{min},L_{max}}\right)\right) \quad \text{(B-29)}$$

where

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

Post-RECSyear replacement units required in the current year for houses existing in RECSyear are calculated as:

$$EQCRP90_{y,eg,b,r} = EQCESE_{RECSyear,eg,b,r} * \ EQCRET_{y,eg} * HDR_b \quad \text{(B-30)}$$

where

$EQCRP90_{y,eg,b,r}$	is the number of replacement units required for homes existing in RECSyear in year *y*, by housing type and census division,
$EQCRET_{y,eg}$	is the equipment retirement rate for houses existing in RECSyear by projection year,
$EQCESE_{RECSyear,eg,b,r}$	is the vintage stock of equipment in RECSyear in houses existing in RECSyear by housing type and census division.

Within the projection period, some of the EQCRP90 will also need to be replaced. The number of units that need to be replaced is estimated as:

$$EQCRP90RP_{y,eg,b,r} = \sum_{t=RECSyear+1}^{t=y-1} \left(EQCRP90_{t,eg,b,r} + EQCRP90RP_{t,eg,b,r} \right) * (1 - SVRTE_{y-t,L_{min},L_{max}} \quad \text{(B-31)}$$

where

$EQCRP90RP_{y,t,eg,b,r}$	is the number of replacement units required to replace post-RECSyear equipment in houses existing in RECSyear by projection 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):

$$ELIGIBLE_{y,eg,b,r} = \sum_{eg}(EQCRP90_{y,eg,b,r} + EQCRP90RP_{y,eg,b,r} + EQCRP_{y,eg,b,r}) * (SWFACT_{eg}) \quad \text{(B-32)}$$

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 that may switch from equipment class *eg*.

The fuel switching weight for each equipment type is calculated as:

$$RPWEIGHT_{y,egsw,b,r} = e^{RTSWBIAS_{egsw} + \left(RTWSBETA_{egsw} * \left(LFCY_{y,egsw,b,r,v} + RPINSCOST_{eg,egsw}\right)\right)} \quad \text{(B-33)}$$

where

$RTSWBIAS_{eg}$	is a replacement technology choice model bias parameter (used only for single-family homes),
$RTSWBETA_{eg}$	is a replacement technology choice model log-linear parameter β (used only for single-family homes),
$LFCY_{y,eg,b,r,v}$	is a lifecycle cost for the equipment class by year, housing type, census division, and vintage, and
$RPINSCOST_{eg,egsw}$	is the incremental cost associated with switching from equipment class *eg* to equipment class *egsw* when replacing select end-use equipment.

Shares are summed over all equipment types:

$$TOTSH_{y,b,r} = \sum_{egsw=1}^{egsw=11} RPWEIGHT_{y,egsw,b,r} \quad \text{(B-34)}$$

The totals are used to normalize the shares, so that they add to 100%:

$$RPSHARE_{y,egsw,b,r} = \frac{RPWEIGHT_{y,egsw,b,r}}{TOTSH_{y,b,r}}, if\ TOTSH_{y,b,r} > 0 \quad \text{(B-35)}$$

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

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 set of 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, housing type, census division, and vintage,
$RPINSCOST_{eg,egsw}$	is the cost of switching from equipment class *eg* to *egsw* when replacing equipment, and
$TOTSH_{y,b,r}$	is the sum of the fuel switching weights.

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

The surviving post-RECSyear-vintage equipment in houses existing in RECSyear is computed as:

$$EQCSR90_{y,eg,b,r} = \sum_{t=RECSyear+1}^{t=y-1} \left(EQCRP90_{t,eg,b,r} + EQCRP90RP_{t,eg,b,r}\right) * SVRTE_{y-t,L_{min},L_{max}} * HDR_b^{y-t} \quad \text{(B-36)}$$

where

$EQCSR90_{y,eg,b,r}$	is the equipment stock in homes existing in RECSyear that has been replaced after RECSyear and still survives, by housing type and census division,
$EQCRP90_{t,eg,b,r}$	is the number of replacement (post-RECSyear-vintage) equipment units demanded each year in houses existing in RECSyear, 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 evolution rate by housing type, and
y-t	is the age of the equipment.

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

$$EQCSUR_{y,eg,b,r} = \sum_{t=RECSyear+1}^{t=y-1} \left(\left(EQCADD_{t,eg,b,r} + EQCREP_{t,eg,b,r} \right) * SVRTE_{y-t,L_{min},L_{max}} * HDR_b{}^{y-t} \right) \tag{B-37}$$

where

$EQCSUR_{y,eg,b,r}$	is the surviving post-RECSyear equipment purchased as additions or replacements in post-RECSyear houses, by housing type and census division,
$EQCADD_{t,eg,b,r}$	is the quantity of post-RECSyear-vintage equipment added to post-RECSyear houses, by projection 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-RECSyear equipment in post-RECSyear houses, and
$y\text{-}t$	represents the age of the equipment.

Shell efficiency component

The shell efficiency component uses three indices to capture the increases in the energy efficiency of building shells over time. One index corresponds to the existing housing stock, and two indices correspond to the post-RECSyear stock: one for housing constructed in the current year and the other for the average post-RECSyear stock. The existing shell index is adjusted each year to account for fuel price increases and technology improvements. Price *decreases* have no effect on shell efficiency; in other words, shell efficiency only *increases* in response to fuel price changes. 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, and an increase in energy efficiency decreases the value of the index.

The existing housing heating shell index is calculated as:

$$\begin{aligned} &EHSHELL_{y,f,r,b} = EHSHELL_{y-1,f,r,b}\, , if\ EHSHELL_{y,f,r,b} > EHSHELL_{y-1,f,r,b} \\ &EHSHELL_{y,f,r,b} = LIMIT, if\ EHSHELL_{y,f,r,b} < LIMIT \\ &EHSHELL_{y,f,r,b} = EHSHELL_{RECSyear,f,r,b} * RSELAST_{y,f,r,\alpha,ef1,ef2,ef3,RECSyear} * TECHG_{e,r,b}, otherwise \end{aligned} \tag{B-38}$$

where

$EHSHELL_{y,f,r,b}$	is the shell efficiency index for existing housing by year, fuel, census division, and housing type,
$LIMIT$	is the maximum shell index efficiency index of 0.3 (in other words, maximum shell efficiency is limited to a 70% improvement on the RECSyear value),

$TECHG_{1,d,b}$ is a parameter that represents the annual increase in existing shell efficiency resulting from technology improvements, and

RSELAST is the short-term price elasticity function that distributes the price effect to the current year (EF1) and the prices in the two preceding 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.

$$RSELAST_{y,f,r,\alpha,ef1,ef2,ef3,baseyr} = \left(\frac{PRICES_{f,r,y}}{PRICES_{f,r,RECSyear}}\right)^{EF1*\alpha} * \left(\frac{PRICES_{f,r,y-1}}{PRICES_{f,r,RECSyear}}\right)^{EF2*\alpha} * \left(\frac{PRICES_{f,r,y-2}}{PRICES_{f,r,RECSyear}}\right)^{EF3*\alpha} \quad \text{(B-39)}$$

The new housing heating shell index is calculated as:

$$NHSHELL_{y,f,r,b} = \sum_{t=RECSyear+1}^{t=y-1} \left(EQFSHRN_{t,es,b,r} * SHELLEFF_{t,es,b,r}\right) \quad \text{(B-40)}$$

where

$NHSHELL_{y,f,r,b}$ is the new housing units shell efficiency index by year, fuel, census division, and housing type, and

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

The average post-RECSyear housing heating shell index is calculated as:

$$AHSHELL_{y,f,r,b} = \frac{\sum_{eg\epsilon f}\left[NHSHELL_{y,f,r,b} * EQCADD_{y,eg,b,r} + AHSHELL_{y-1,f,r,b} * \left(EQCREP_{y,eg,b,r} + EQC\right.\right.}{\sum_{eg\epsilon f}\left[EQCADD_{y,eg,b,r} + EQCREP_{y,eg,b,r} + EQCSUR_{y,eg,b,r}\right]} \quad \text{(B-41)}$$

where

$AHSHELL_{y,f,r,b}$ is the average post-RECSyear heating shell index by year, fuel, census division, and housing type, equal to NHSHELL in the first year after RECSyear,

$NHSHELL_{y,f,r,b}$ is the new housing units shell efficiency index by year, fuel, census division, and housing type,

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

$EQCREPy_{,eg,b,r}$ is the number of equipment replacements of post-RECSyear equipment in post-RECSyear houses, and

$EQCSUR_{y,eg,b,r}$	is the surviving post-RECSyear equipment purchased as additions or replacement in post-RECSyear houses by projection year, housing type, and census division.

In addition to the calculation shown above, the module places two additional restrictions on $AHSHELL_{y,f,r,b}$: it may never increase, and it must not fall lower than LIMIT. If $AHSHELL_{y,r,r,b}$ is ever calculated to increase, its value is set to the previous year's value; if it falls lower than LIMIT, it is set equal to LIMIT.

Consumption and UEC component

The fuels demanded by the equipment that provide housing units with the demanded services determine final end-use fuel consumption. For each equipment class, the UEC for new equipment, replacement equipment, and the average of all equipment is computed. New equipment UEC values are calculated as:

$$EQCNUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * WTEQCEFFN_{y,eg,b,r} * RTBASEFF_{RECSyear,eg} * HDDFACT_{y,r} * EXSQFTADJ_{y,b,r} \quad \text{(B-42)}$$

where

$EQCNUEC_{y,eg,b,r}$	is the unit energy consumption for new equipment by projection 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,
$RTBASEFF_{RECSyear,eg}$	is the RECSyear stock-average efficiency of the equipment class,
$EQCUEC_{r,eg,b}$	is unit energy consumption for original RECSyear 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
$EXSQFTADJ_{y,b,r}$	is the adjustment for increasing conditioned floor area of new houses.

Replacement equipment UEC values are calculated as:

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * WTEQCEFFR_{y,eg,b,r} * RTBASEFF_{RECSyear,eg} * HDDFACT_{y,r} \quad \text{(B-43)}$$

where

$EQCRUEC_{y,eg,b,r}$	is the unit energy consumption for replacement equipment by housing type and census division,
$RTBASEFF_{RECSyear,eg}$	is the efficiency of the weighted average of retiring units from the RECSyear 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.

The UEC for the surviving stock must be adjusted, according to

$$EQSUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * HDDFACT_{y,r} * \frac{RTBASEFF_{RECSyear,eg}}{RTBASEFF_{y,eg}} \tag{B-44}$$

where

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

The average UEC for all equipment in the existing stock is calculated as:

$$EQCAUEC_{y,eg,b,r} = EQCNUEC_{y,eg,b,r}, if\ y = RECSyear + 1$$

$$otherwise, EQCAUEC_{y,eg,b,r} = \frac{\left(\begin{array}{c}(EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP90RP_{y,eg,b,r}) * EQCNUEC_{y,eg,b,r} + \\ (EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r}) * EQCAUEC_{y-1,eg,b,r} + \\ EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r}\end{array}\right)}{\begin{array}{c}(EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP90RP_{y,eg,b,r} + \\ EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r} + EQCRP90_{y,eg,b,r})\end{array}} \tag{B-45}$$

where

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

The final step of this algorithm is to calculate consumption for the end-use service category. The consumption during the first year of the projection is computed initially as:

$$HTRCON_{y=RECSyear,f,r} = \sum_{b}\sum_{eg}\left[\begin{array}{c}\left(\begin{array}{c}EQCESE_{y,eg,b,r} * ECQCUEC_{eg,b,r} * EHSHELL_{y,f,r,b} + \\ EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * NHSHELL_{y,f,r,b} + \\ EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} * EHSHELL_{y,f,r,b}\end{array}\right) \\ * RSELAST_{f,r,\alpha,EF1,EF2,EF2,RECSyear}\end{array}\right] \tag{B-46}$$

Subsequent annual consumption (for $y \geq$ RECSyear+2) is computed as:

$$HTRCON_{y,f,r} = \sum_{b}\sum_{eg}\left[\begin{pmatrix} EQCESE_{y,eg,b,r} * ECQCUEC_{eg,b,r} * EHSHELL_{y,f,r,b} \\ +EQCADD_{y,eg,b,r} * EQCHVUEC_{y,eg,b,r} * NHSHELL_{y,f,r,b} * RBN_{y,eg,b,r} \\ +EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} * EHSHELL_{y,f,r,b} * RBR_{y,eg,b,r} \\ +EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * EHSHELL_{y,f,r,b} * RBN_{y,eg,b,r} \\ +EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} * EHSHELL_{y,f,r,b} * RBA_{y,eg,b,r} \\ +EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * AHSHELL_{y,f,r,b} * RBN_{y,eg,b,r} \\ +EQCSUR_{y,eg,b,r} * EQCAHVUEC_{y,eg,b,r} * AHSHELL_{y,f,r,b} * RBA_{y,eg,b,r} \end{pmatrix} \\ * RSELAST_{f,r,\alpha,EF1,EF2,EF3,RECSyear}\right] \tag{B-47}$$

where

$HTRCON_{y,f,r}$	is heating energy consumption by year, fuel type, and region,
RSELAST	is the short-term price elasticity function with distributed lag weights EF1, EF2, and EF3 and the total short-term price elasticity, α, described in (B-39), 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

$$RBN_{r,eg,b,r} = WTEQCEFFN_{y,eg,b,r} * RTBASEFF_{RECSyear,eg}{}^{\alpha_1} \tag{B-48}$$

$$RBR_{r,eg,b,r} = WTEQCEFFR_{y,eg,b,r} * RTBASEFF_{RECSyear,eg}{}^{\alpha_1} \tag{B-49}$$

$$RBA_{r,eg,b,r} = WTEQCEFFA_{y,eg,b,r} * RTBASEFF_{RECSyear,eg}{}^{\alpha_1} \tag{B-50}$$

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

RCLTEC (Air-conditioning equipment choice component)

Air-conditioning equipment choice begins with calculating a factor that adjusts for differences in temperatures between RECSyear and the year under consideration. For each region *r*,

$$CDDFACT_{y,r} = \left(\frac{CDDADJ_{y,r}}{CDDADJ_{RECSyear,r}}\right)^{1.50} \tag{B-51}$$

where

$CDDFACT_{y,r}$	is an adjustment factor for weather differences between RECSyear and the current year; it is computed as the ratio of the numbers of cooling degree days in the current (numerator) and base (denominator) years,
$CDDADJ_{y,r}$	are regional population-adjusted cooling degree days by census division and historical year, with projection years, from the KDEGDAY.TXT file, and
1.50	is an exponent that best adjusted values to recent historical data.

Operating costs for air-conditioning equipment are calculated like those for heating equipment, except for the degree-day factor:

$$OPCOST_{y,es,b,r,v} = PRICES_{f,r,y} * EQCUEC_{y,eg,b} * CDDFACT_{r,y} * RTEFFAC_{eg,v} * CSHELL_{y-1,r,v} \quad \text{(B-52)}$$

where

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

The following variables are computed as indicated:

$LFCY_{y,es,b,r,v}$	is the air conditioner type's lifecycle 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 type weights for the new equipment class. It is computed as in (B-22) above.
$TOTEWTR_{y,eg,b,r}$	is the sum of equipment type weights for the replacement equipment class. It is computed as in (B-23) above.

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

$$NEQTSJR_{y,es,b,r} = NEQTSHR_{y,RTTYPNTR_{es},b,r}$$
$$REQTSJR_{y,es,b,r} = REQTSHR_{y,RTTYPNTR_{es},b,r} \quad \text{(B-53)}$$

and for other air-conditioning equipment:

$$NEQTSHR_{y,es,b,r} = \frac{EQWTN_{y,es,b,r}}{TOTEWTN_{y,eg,b,r}} \quad \text{(B-54)}$$

$$REQTSHR_{y,es,b,r} = \frac{EQWTR_{y,es,b,r}}{TOTEWTR_{y,eg,b,r}} \quad \text{(B-55)}$$

where

$NEQTSHR_{y,es,b,r}$	is the new market share for the new air-conditioning equipment type by year, housing type, and census division,
$REQTSHR_{y,es,b,r}$	is the new market share for the replacement air-conditioning 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 air-conditioning 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-26).
$WTEQCEFFR_{y,eg,b,r}$	is the weighted average inverse efficiency of replacement equipment types within each equipment class by year, housing type, and census division, computed as in).

RCLADD (Additions and replacements of air-conditioning equipment component)

Given the complex dependencies between choices of space heating and air-conditioning 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:

$$EQCADD_{y,CAC,b,r} = HSEADD_{y,b,r} * CACSAT_{b,r} \quad \text{(B-56)}$$

where

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

For room air conditioners, there are similar saturation levels:

$$EQCADD_{y,RAC,b,r} = HSEADD_{y,b,r} * RACSAT_{b,r} * RACUNTS_{b,r} \quad \text{(B-57)}$$

where

$EQCADD_{y,RAC,b,r}$	is the number of room air conditioners (RAC) added to new (post-RECSyear) housing units by year, housing type, and census division,
$HSEADD_{y,b,r}$	is the number of housing additions by year, housing type, and census division,
$RACSAT_{b,r}$	is the market penetration level or saturation of the market for room air-conditioning equipment by housing type and census division, and
$RACUnits_{b,r}$	is the number of room air conditioners per housing unit 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:

$$EQCADD_{y,HP,b,r} = EQCADD_{y,RTCLPNTY_{eg},b,r} \quad \text{(B-58)}$$

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 air-conditioning equipment class.

The number of new homes with central air conditioners 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, 10% of central air conditioners are left in the additions:

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

where

$EQCADD_{y,t,eg,b,r}$	is the number of central air conditioners in each equipment class added to new (post-RECSyear) housing units by year, housing type, and census division, and
eg	is the space cooling equipment class.

Surviving equipment follows the same dichotomy as the other calculations, but a different method determines the number of surviving heat pumps than the one used for calculating the surviving stock for other types of air-conditioning equipment. For heat pumps, the stock is equated to the stock calculated in the space heating subroutines:

$$EQCSR90_{y,eg,b,r} = EQCSR90_{y,RTCLPNTR_{eg},b,r} \quad \text{(B-60)}$$

where

$EQCSR90_{y,eg,b,r}$	is the surviving post-RECSyear air-conditioning equipment in existing 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 space heating subroutine into the correct heat pump stock in the space cooling subroutine.

For single-family houses with central air conditioning, the following penetration rate describes new units added in existing houses:

$$EQCND90_{y,eg,b,r} = EQCND90_{y,eg,b,r} * CACPR_r * HDR_b \quad \text{(B-61)}$$

where

$EQCND90_{y,eg,b,r}$	is the number of air-conditioning units needed in existing RECS 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 RSMISC.TXT file.

The replacement equipment types, EQCREP, EQCRP90, and EQCRP90RP are computed as in (B-29), (B-30), and (B-31), respectively. The surviving new additions, EQCSUR, is computed as in (B-37) above.

Because replacements for heat pumps in the cooling end use equal replacements for heat pumps in the heating end use and switching was allowed when replacing heat pumps used for heating, switching when replacing heat pumps in the cooling end use occurred in RHTRADD (the subroutine for replacing heating equipment types). No switching when replacing central or room air conditioners is allowed because 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. Air-conditioning equipment consumption begins with calculating a factor that adjusts for differences in temperatures between RECSyear and the year under consideration, in each region, as computed in (B-51) above.

Unit energy consumption is calculated for each of the vintages of homes. For surviving equipment in existing vintage homes:

$$EQCSUEC_{y,eg,b,r} = EQCUEC_{y,eg,b} * CDDFACT_{y,r} * \frac{RTBASEFF_{RECSyear,eg}}{RTBASEFF_{y,eg}} \quad \text{(B-62)}$$

where

$EQCSUEC_{y,eg,b,r}$	is the unit energy efficiency of surviving equipment in existing 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 RECSyear, by census division, equipment class, and housing type,
$CDDFACT_{y,r}$	are the regional cooling degree day adjustment factors, and
$RTBASEFF_{y,eg}$	are the annual average efficiencies for the equipment classes.

For new equipment:

$$EQCNUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * WTEQCEFFN_{y,eg,b,r} * RTBASEFF_{RECSyear,eg} * CDDFACT_{y,r} * EXSQFTADJ_{y,b,r} \quad \text{(B-63)}$$

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 existing 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
$EXSQFTADJ_{y,b,r}$	adjusts for the increasing average conditioned 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:

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * WTEQCEFFR_{y,eg,b,r} * RTBASEFF_{RECSyear,eg} * CDDFACT_{y,r} \quad \text{(B-64)}$$

where

$EQCRUEC_{y,eg,b,r}$	is the unit energy consumption for replacement equipment by housing type and census division,
$RTBASEFF_{RECSyear,eg}$	is the efficiency of the weighted average of retiring units from the 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 technology choice component) by housing type and census division.

The average UEC, EQCAUEC, for all air-conditioning equipment is calculated as in (B-45) above.

Cooling shell efficiency is calculated similarly to heating shell efficiency computed in equations (B-38) through (B-41).

The final step of this component is to calculate consumption for the service category. This calculation is accomplished in two steps. The first year of the projection is computed as:

$$COOLCN_{y=RECSyear+1,f,r} = \sum_{b}\sum_{eg}\left[\begin{pmatrix} EQCESE_{RECSyear+1,eg,b,r} * ECQCUEC_{eg,b,r} * ECSHELL_{RECSyear+1,r,b} + \\ EQCADD_{RECSyear+1,eg,b,r} * EQCNUEC_{RECSyear+1,eg,b,r} * NCSHELL_{RECSyear+1,} \\ EQCRP90_{RECSyear+1,eg,b,r} * EQCRUEC_{RECSyear+1,eg,b,r} * ECSHELL_{RECSyear+} \end{pmatrix} \\ * RSELAST_{f,r,\alpha,EF1,EF2,EF2,RECSyear}\right. \qquad \text{(B-65)}$$

Subsequent consumption is computed as:

$$COOLCN_{y,f,r} = \sum_{b}\sum_{eg}\left[\begin{pmatrix} EQCESE_{y,eg,b,r} * ECQCUEC_{eg,b,r} * ECSHELL_{yr} \\ +EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * NCSHELL_{y,r,b} * RBN_{y,eg,b,r} \\ +EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} * ECSHELL_{y,r,b} * RBR_{y,eg,b,r} \\ +EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * ECSHELL_{y,r,b} * RBN_{y,eg,b,r} \\ +EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} * ECSHELL_{y,r,b} * RBA_{y,eg,b,r} \\ +EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} * ACSHELL_{y,r,b} * RBN_{y,eg,b,r} \\ +EQCSUR_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} * ACSHELL_{y,r,b} * RBA_{y,eg,b,r} \end{pmatrix} \\ * RSELAST_{f,r,\alpha,EF1,EF2,EF3,RECSyear}\right] \qquad \text{(B-66)}$$

where

RSELAST is the short-term price elasticity function with distributed lag weights EF1, EF2, and EF3, and the total short-term price elasticity, α, described in (B-39).

The *rebound effect* that was introduced in the space heating section in equations (B-48) through (B-50) is also represented in the space cooling consumption equation.

RCWTEC (Clothes washing technology choice component)

Clothes washing is modeled somewhat differently than most other end uses. It has two general equipment configurations: top-loading or front-loading. RECS includes only a single UEC; therefore, rather than modeling these different general configurations as classes (for example, clothes dryers that have multiple classes and UECs), the configurations are treated as just another clothes washer type but with further special treatment. For clothes washing, the denotation for equipment class *eg* is always defined as 1 and is not needed as a subscript as for other end uses.

The special treatment of the two configurations takes the form of an assumed share of the market, whereas market shares for the other end use equipment types are determined based on model-endogenous logistic equipment choice based on the relationship between operating cost and capital cost. Front-loading clothes washers are generally more costly and more efficient. They can also be stacked, which may not be an option for top-loading clothes washers. Assumed market shares are needed because, if modeled *competitively* as just another clothes washer type (denoted *es*), they may not receive a significant market share that reflects their actual adoption. In the equations that follow, the subscript *es* refers to variables accounting for shares of top- or front-loading clothes washers.

We compute current-year operating costs for clothes washers:

$$OPCOST_{y,es,b,r,v} = PRICES_{f,r,y} * EQCUEC_{y,eg,b} * \frac{RTBASEFF_{RECSyear,eg}}{RTEQEFF_{es}} \quad \text{(B-67)}$$

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 price for the equipment from NEMS, by fuel, by region and projection year,
$EQCUEC_{r,eg,b}$ is the unit energy consumption by census division, equipment class, and housing type,
$RTEQEFF_{es}$ is the equipment efficiency, and
$RTBASEFF_{RECSyear,eg}$ is the RECSyear stock-average efficiency.

The following variables are computed as indicated:

$LFCY_{y,es,b,r,v}$ is the clothes washer's lifecycle 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 derived by:

$$NEQTSHR_{y,es,b,r} = \frac{EQWT_{y,es,b,r}}{TCWSHR_{b,r}} * (TCW\_SHR) \quad \text{(B-68)}$$

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, and
$EQWT_{es}$ is the equipment weight for new equipment.

$TCWSHR_{b,y}$,	is the model-calculated market share of top-loading clothes washers (versus *FCWSHR* for front-loading) in the current year by housing type, and
TCW_SHR	is the assumed overall share of top-loading clothes washers (versus *FCW_SHR* for front-loading).

Because 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 associated with installing more efficient clothes washers is calculated as:

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

$$NCWLOAD_{y,eg,b,r} = \sum_{es \epsilon eg} \frac{EQWT_{y,es,b,r} * LOADADJ_{es}}{TEMP}, if\ TEMP > 0 \qquad \text{(B-69)}$$

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

where

$NCWLOAD_{y,eg,b,r}$	is the weighted average load adjustment of new clothes washers with respect to water heating load in the current year by housing type and census division,
$EQWT_{y,es,b,r}$	is the equipment weight for each type of new equipment, and
$LOADADJ_{es}$	is the fraction of hot water needed to provide the same level of service, relative to the RECSyear average.

RCWADD (Clothes washing additions component)

New clothes washing equipment is calculated using a saturation level for newly purchased equipment:

$$EQCADD_{y,eg,b,r} = HSEADD_{y,b,r} * \frac{WASHNEW_{b,r}}{100} \qquad \text{(B-70)}$$

where

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

$EQCSR90_{y,eg,b,r}$	is the surviving post-RECSyear-vintage equipment in existing housing units in the current year by housing type and census division. It is computed as in (B-36) above.

$EQCSUR_{y,eg,b,r}$	is the surviving new (post-RECSyear-vintage) equipment in the current year by housing type and census division. It is computed as in (B-37) above.
$EQCREP_{y,eg,b,r}$	is the number of replacement units (post-RECSyear-vintage) equipment demanded in post-RECSyear-vintage housing units by housing type and census division. It is computed as in (B-29) above.
$EQCRP90_{y,eg,b,r}$	is the number of replacement units demanded in existing housing units each year by housing type and census division. It is computed as in (B-30) 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-31) 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-42) through (B-45).

$EQCNUEC_{y,eg,b,r}$	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,
$EQCSUEC_{y,eg,b,r}$	is the UEC for surviving RECSyear equipment in each equipment class 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:

$$CSWCON_{y,r} = \sum_{b,eg} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} + \\ EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} + \\ EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} + \\ EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \end{pmatrix}, if\ y = RECSyear + 1 \qquad \text{(B-71)}$$

$$CSWCON_{y,r} = \sum_{b,eg} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} + \\ EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} + \\ EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} + \\ EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} + \\ EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} + \\ EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} + \\ EQCSUR_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \end{pmatrix}, if > \ RECSyear + 1 \qquad \text{(B-72)}$$

RDWTEC (Dishwashing technology choice component)

The following variables are computed as 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-67) above.

$LFCY_{y,es,b,r,v}$ is the dishwasher's lifecycle 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 year, housing type, and census division. It is computed as in (B-20) above.

$EQWTR_{y,es,b,r}$ is the equipment weight for replacement equipment by year, housing type, and census division. 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 as follows:

$$NEQTSHR_{y,es,b,r} = \frac{EQWT_{y,es,b,r}}{TOTEWT_{y,eg,b,r}} \quad \text{(B-73)}$$

where

$NEQTSHR_{y,es,b,r}$ is the new market share of dishwasher equipment types by housing type and census division in the current year,

$TOTEWT_{eg,b,r}$ is the sum of equipment weights for the new equipment class by housing type and census division, and

$EQWT_{y,es,b,r}$ is the equipment weight for new equipment by year, housing type, and census region.

RDWADD (Dishwashing additions component)

New dishwashing equipment is calculated using a saturation level for newly purchased equipment:

$$EQCADD_{y,eg,b,r} = HSEADD_{y,b,r} * DISHNEW_{b,r} \quad \text{(B-74)}$$

where

$EQCADD_{y,eg,b,r}$ is the amount of new (post-RECSyear-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. Note that dishwashers have a single equipment class eliminating the need for an *eg* subscript.

The next step is to calculate the numbers of dishwashers in each vintage category. The following variables were computed as indicated:

$EQCSR90_{y,eg,b,r}$	is the surviving post-RECSyear-vintage equipment in existing housing units in the current year by housing type and census division. It is computed as in (B-36) above.
$EQCSUR_{y,eg,b,r}$	is the surviving new (post-RECSyear-vintage) equipment in the current year by housing type and census division. It is computed as in (B-37) above.
$EQCREP_{y,eg,b,r}$	is the number of replacement units (post-RECSyear-vintage) equipment demanded in post-RECSyear-vintage housing units by housing type and census division. It is computed as in (B-29) above.
$EQCRP90_{y,eg,b,r}$	is the number of replacement units demanded in existing housing units each year by housing type and census division. It is computed as in (B-30) 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-31) 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-42) through (B-45).

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

$$DSWCON_{y,r} = \sum_{b,eg} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} + \\ EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} + \\ EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \end{pmatrix}, \; if \; y = RECSyear + 1 \qquad \text{(B-75)}$$

$$\boldsymbol{DSWCON_{y,r}} = \sum_{b,eg} \begin{pmatrix} \boldsymbol{EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r}} + \\ \boldsymbol{EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r}} + \\ \boldsymbol{EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r}} + \\ \boldsymbol{EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r}} + \\ \boldsymbol{EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r}} + \\ \boldsymbol{EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r}} + \\ \boldsymbol{EQCSUR_{y,eg,b,r} * EQCAUEC_{y,eg,b,r}} \end{pmatrix}, \boldsymbol{if\ y > RECSyear + 1} \tag{B-76}$$

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 RSCLASS inputs. Replacement water heaters are not so constrained in single-family housing. There are five equipment classes for water heaters: natural gas, electric, distillate fuel oil, propane, and solar thermal. Within the electric water heater class, heat pump water heaters are modeled alongside electric resistance storage water heaters, reflecting their differences in efficiency.

The component first adds up the market shares of all space heating equipment:

$$TOTN_{b,r} = \sum_{eg} HSYSSHR_{y,eg,b,r} \tag{B-77}$$

where

$TOTN_{b,r}$	is the sum of the current-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:

$$NH2OSH_{y,b,r} = \frac{\sum_{eg} HSYSSHR_{y,RTCLEQCL_{SH}=RTCLPNTR_{WH,b,r}}}{TOTN_{b,r}} \tag{B-78}$$

where

$NH2OSH_{y,b,r}$	is the market share of each new water heater class by housing type and census division,
$TOTN_{b,r}$	is the sum of the current-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 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-67).
$LFCY_{y,es,b,r,v}$ is the water heater type's lifecycle cost by year, housing type, census division, and vintage. It is computed as in (B-16).
$EQWTN_{y,es,b,r}$ is the equipment weight for new equipment types by housing type, census division, and year. It is computed as in (B-20).
$EQWTR_{y,es,b,r}$ is the equipment weight for replacement equipment types by housing type, census division, and year. It is computed as in (B-21).
$TOTEWTN_{y,eg,b,r}$ is the sum of the equipment types' weights for the new equipment class. It is computed as in (B-22).
$TOTEWTR_{y,eg,b,r}$ is the sum of the equipment types' weights for the replacement equipment class. It is computed as in (B-23).
$EQFSHRN_{y,f,b,r}$ is the fuel share of new equipment type by year, housing type, and census division. It is computed as in (B-24).
$EQFSHRR_{y,f,b,r}$ is the fuel share of replacement equipment type by year, housing type, and census division. It is computed as in (B-25).

The fuel shares are finally defined:

$$NEQTSHR_{y,f,b,r} = EQFSHRN_{y,es,b,r} \quad \text{(B-79)}$$

$$REQTSHR_{y,f,b,r} = EQFSHRR_{y,es,b,r} \quad \text{(B-80)}$$

where

$NEQTSHR_{y,f,b,r}$ is the fuel share of new water heaters by fuel, housing type, and census division, and
$REQTSHR_{y,f,b,r}$ is the fuel share 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-26) and :

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

The RDM has only one component for adding and replacing water heating equipment and cooking equipment.

The first operation is to calculate the total equipment in existing housing:

$$EQCND90_{y,eg,b,r} = EQCESE_{RECSyear,eg,b,r} * HDR_b, if\ y = RECSyear + 1$$

(B-81)

$$EQCND90_{y,eg,b,r} = EQCESE_{y-1,eg,b,r} * HDR_b, if >\ RECSyear + 1$$

where

$EQCND90_{y,eg,b,r}$ is the total equipment in existing housing each year by housing type and census division,

$EQCESE_{RECSyear,eg,b,r}$ is the existing equipment stock in existing housing units in RECSyear by housing type and census division, and

HDR_b is the housing demolition rate by housing type.

Next, purchases are calculated for new housing:

$$EQCADD_{y,eg,b,r} = HSEADD_{y,b,r} * SHARE_{y,eg,b,r} \quad \text{(B-82)}$$

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, and

$NCKSH_{y,eg,b,r}$ is the market penetration level or saturation of the market for cooking ranges by housing type and census division.

The following variables are computed as indicated:

$EQCSR90_{y,eg,b,r}$ is the surviving post-RECSyear-vintage equipment in existing housing units in the current year by housing type and census division. It is computed as in (B-36) above.

$EQCSUR_{y,eg,b,r}$ is the surviving new (post-RECSyear-vintage) equipment in the current year by housing type and census division. It is computed as in (B-37) above.

$EQCREP_{y,eg,b,r}$ is the number of replacement units (post-RECSyear-vintage) equipment demanded in post-RECSyear-vintage housing units by housing type and census division. It is computed as in (B-29) above.

$EQCRP90_{y,eg,b,r}$	is the number of replacement units demanded in existing housing units each year by housing type and census division. It is computed as in (B-30) 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-31) 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 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 household size that will be used with an elasticity to account for this determinant:

$$HHSIZE_{y,r} = \frac{MC\_NP16A_{r,y}}{\sum_b EH_{y,b,r} + NH_{y,b,r}} \tag{B-83}$$

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 Activity Module,
$EH_{y,b,r}$	is the number of existing vintage homes existing in year *y*, from the RSMISC.TXT file, and
$NH_{y,b,r}$	is the number of post-RECSyear-vintage homes remaining in year *y*, from the NEMS Macroeconomic Activity Module, as shown in equation (B-3).

Unit energy consumption is calculated for housing vintages. First, for the surviving RECSyear homes:

$$EQCSUEC_{r,eg,b,r} = EQCUEC_{r,eg,b} * \left(\frac{HHSIZE_{y,r}}{HHSIZE_{RECSyear,r}}\right)^{HHSELAS} * \frac{RTBASEFF_{RECSyear,eg}}{RTBASEFF_{y,eg}} \tag{B-84}$$

where

$EQCSUEC_{y,eg,b,r}$	is the unit energy efficiency of surviving water heating equipment in existing-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 RECSyear, by census division, equipment class, and housing type,
$HHSIZE_{y,r}$	is the average number of persons over age 16 per housing unit by year and region,
$HHSELAS$	is an elasticity parameter for the increase in hot water intensity as a result of increases in the average number of people over age 16 per housing unit, and
$RTBASEFF_{y,eg}$	are the annual average efficiencies for the equipment classes.

For new purchases:

$$EQCNUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * WTEQCEFFN_{y,eg,b,r} * RTBASEFF_{RECSyear,eg} * \left(\frac{HHSIZE_{y,r}}{HHSIZE_{RECSyear,r}}\right)^{HHSELAS} \quad \text{(B-85)}$$

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 number of persons over age 16 per housing unit by year and region,
$HHSELAS$	is an elasticity parameter for the increase in hot water intensity as a result of increases in the average number of people over age 16 per housing unit, and
$RTBASEFF_{y,eg}$	is the efficiency of the water heating equipment classes.

For replacements in all years:

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

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,
$EQCUEC_{r,eg,b}$	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 RECSyear stock by year.

The average UEC for all equipment is calculated as:

$$EQCAUEC_{y,eg,b,r} = EQCNUEC_{y,eg,b,r}, if y = baseyr + 1 \quad \text{(B-87)}$$

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

$$if\ y > RECSyear + 1$$

where

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

Water heater efficiency is calculated next. If y = RECSyear+1,

$$WTEQCEFFA_{y=RECSyear+1,eg,b,r} = WTEQCEFFN_{y=RECSyear+1,eg,b} \tag{B-88}$$

$$WTEQCEFFA_{y,eg,b,r} = \frac{\left(\begin{array}{c}\left(EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP90RP_{y,eg,b,r}\right) \\ * WTEQCEFFM_{y,eg,b,r} \\ +\left(EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r}\right) * WTEQCEFFA_{y-1,eg,b,r} \\ +EQCRP90_{y,eg,b,r} * WTEQEFFR_{y,eg,b,r}\end{array}\right)}{\left(\begin{array}{c}EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP90RP_{y,eg,b,r} \\ +EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r} + EQCRP90_{y,eg,b,r}\end{array}\right)} \tag{B-89}$$

$$if\ y > RECSyear + 1$$

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:

$$H20SHRCW_{y,f,b,r,v} = H20SHR_{y,f,b,r,v} * NUMCW_{y,b,r,v} \tag{B-90}$$

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, and
$NUMCW_{y,b,r,v}$	is the number of clothes washers by census division and building type for all vintages of equipment.

Next, the consumption of water heating for homes with clothes washers is computed as:

$$H2OCONCW_{y,f,b,r,v} = H2OSHRCW_{y,f,b,r,v} * H2OUEC_{y,f,b,r,v} * LDADJCW_{y,b,r} \quad \text{(B-91)}$$

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 = RECSyear+1,

$$H2OCON_{y,f,r} = \sum_b \left[\left(\begin{pmatrix} EQCESE_{y,eg,b,r} * ECQCUEC_{eg,b,r} \\ +EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ +EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ +EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \end{pmatrix} + \sum_v H2OCONCW_{y,f,b,r} \right. \right. \\ \left. * RSELAST_{f,r,\alpha,EF1,EF2,EF2,RECSyear} \right] \quad \text{(B-92)}$$

If y > RECSyear+1,

$$H2OCON_{y,r} = \sum_b \left[\left(\begin{pmatrix} EQCESE_{y,eg,b,r} * ECQCUEC_{eg,b,r} \\ +EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ +EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ +EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ + EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \\ +EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ +EQCSUR_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \end{pmatrix} + \sum_v H2OCONCW_{y,f,b,r,v} \right) \\ * RSELAST_{f,r,\alpha,EF1,EF2,EF2,RECSyear} \right] \quad \text{(B-93)}$$

where

$H2OCON_{y,f,r}$	is consumption for water heating by fuel, and
$RSELAST$	is the short-term price elasticity function with distributed lag weights EF1, EF2, and EF3, and the total short-term price elasticity, α, described in (B-39).

RSTVTEC (Cooking technology choice component)

Throughout this document, cooking equipment is characterized as a *cooking range*, a unit that contains both an oven and a cooktop/stovetop. Electric cooking ranges may have either an electric resistance cooktop or induction cooktop, modeled as appliance options with different annual energy consumption and cost characteristics.

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 natural gas or electric cooking ranges; homes that heat with propane cook with propane; homes that heat water with distillate fuel oil cook with electricity. Replacement cooking 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:

$$NCKSH_{y,eg,b,r} = NH2OSH_{y,eg,b,r} * NGNGFACT_b, if\ eg = natural\ gas\ range$$
$$NCKSH_{y,eg,b,r} = NH2OSH_{y,eg,b,r}, if\ eg = propane\ range$$
$$NCKSH_{y,eg,b,r} = \sum\left(NH2OSH_{y,eg,b,r}\right) + NH2OSH_{y,eg,b,r} * (1 - NGNGFACT_b)$$
$$if\ eg = other \qquad \text{(B-94)}$$

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
$NGNGFACT_b$	is a constant that defines the fraction of new homes having natural gas water heaters that have natural gas cooking 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 propane: homes that heat water with any other equipment class than these, depending on which are defined in the RSCLASS inputs, are assumed to cook with electricity.

The following variables are computed as 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-67) above.
$LFCY_{y,es,b,r,v}$	is the cooking equipment's lifecycle cost by year, housing type, census division, and vintage. It is computed as in (B-16) above.
$EQWTN_{y,es,b,r}$	is the equipment weight for new equipment types by housing type, census division, and year. It is computed as in (B-20) above.
$EQWTR_{y,es,b,r}$	is the equipment weight for replacement equipment types by housing type, census division, and year. It is computed as in (B-21) above.
$TOTEWTN_{y,eg,b,r}$	is the sum of the equipment types' weights for the new equipment class. It is computed as in (B-22) above.
$TOTEWTR_{y,eg,b,r}$	is the sum of the equipment types' weights for the replacement equipment class. It is computed as in (B-23) above.

$EQFSHRN_{y,f,b,r}$ is the fuel share of new equipment type by year, housing type, and census division. It is computed as in (B-24) above.
$EQFSHRR_{y,f,b,r}$ is the fuel share of replacement equipment type by year, housing type, and census division. It is computed as in (B-25) above.

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

$$NEQTSHRD_{y,eg,b,r} = NCKSH_{y,eg,b,r} * EQFSHRN_{y,es,b,r}$$
$$REQTSHRD_{y,eg,b,r} = NCKSH_{y,eg,b,r} * EQFSHRR_{y,es,b,r} \quad \text{(B-95)}$$

where

$NEQTSHRD_{y,es,b,r}$ is the new equipment type share for cooking ranges by equipment type, housing type, and census division,
$REQTSHRD_{y,es,b,r}$ is the replacement equipment type share for cooking 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 cooking ranges by equipment type, housing type, and census division, and
$EQFSHRR_{y,es,b,r}$ is the replacement market share for cooking ranges by equipment type, housing type, and census division.

REUADD (Water heating and cooking additions and replacements component)

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.

RSTOVCON (Cooking energy consumption component)

For cooking, the unit energy consumption for surviving equipment is calculated differently from the other end uses because the RSCLASS input metric for $RTBASEFF_{es}$ is the annual energy usage, measured in kWh or MMBtu per year, of the equipment in each class:

$$EQCSUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * \frac{RTBASEFF_{RECSyear,eg}}{RTBASEFF_{y,eg}} \quad \text{(B-96)}$$

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:

$$EQCNUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * \frac{WTEQCEFFN_{y,eg,b,r}}{RTBASEFF_{RECSyear,eg}} \quad \text{(B-97)}$$

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

For replacement equipment:

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

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

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

If y = RECSyear+1,

$$EQCAUEC_{y,eg,b,r} = EQCNUEC_{r,eg,b} \quad \text{(B-99)}$$

If y > RECSyear+1,

$$EQCAUEC_{y,eg,b,r} = \frac{\begin{pmatrix} \left(EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP90RP_{y,eg,b,r}\right) \\ * EQCNUEC_{y,eg,b,r} \\ +\left(EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r}\right) * EQCAUEC_{y-1,eg,b,r} \\ +EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \end{pmatrix}}{\begin{pmatrix} EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP90RP_{y,eg,b,r} \\ +EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r} + EQCRP90_{y,eg,b,r} \end{pmatrix}} \quad \text{(B-100)}$$

And energy consumption is defined as:

$$CKCON_{y,r} = \sum_{b,eg} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} + \\ EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} + \\ EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \end{pmatrix}, \ if\ y = RECSyear + 1 \quad \text{(B-101)}$$

$$CKCON_{y,r} = \sum_{b,eg} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} + \\ EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} + \\ EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} + \\ EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} + \\ EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} + \\ EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} + \\ EQCSURE_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \end{pmatrix}, \ if\ y > RECSyear + 1 \quad \text{(B-102)}$$

RDRYTEC (Clothes drying technology choice component)

The following variables are computed as 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-67) above.
$LFCY_{y,es,b,r,v}$	is the clothes dryer's lifecycle 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 year, housing type, and census division. It is computed as in (B-20) above.
$EQWTR_{y,es,b,r}$	is the equipment weight for replacement equipment by year, housing type, and census division. 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 dryers are computed next:

$$NEQTSHR_{y,es,b,r} = \frac{EQWT_{y,es,b,r}}{TOTEWT_{y,eg,b,r}} \quad \text{(B-103)}$$

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, and
$EQWT_{es}$	is the equipment weight for new equipment.

DRYADD (Clothes drying additions component)

New clothes drying equipment is calculated using a saturation level for newly purchased equipment:

$$EQCADD_{y,eg,b,r} = \sum_{es} \left(HSEADD_{y,b,r} * NEQTSHR_{y,es,b,r} * \frac{NEWDRYSAT_{b,r}}{100} \right) \quad \text{(B-104)}$$

where

$EQCADD_{y,eg,b,r}$	is the amount of new (post-RECSyear-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 percentage, from the RSMISC.TXT file.

The next step is to calculate the numbers of dryers of each vintage category. The following variables were computed as indicated:

$EQCSR90_{y,eg,b,r}$	is the surviving post-RECSyear-vintage equipment in existing housing units in the current year by housing type and census division. It is computed as in (B-36) above.
$EQCSUR_{y,eg,b,r}$	is the surviving new (post-RECSyear-vintage) equipment in the current year by housing type and census division. It is computed as in (B-37) above.
$EQCREP_{y,eg,b,r}$	is the number of replacement units (post-RECSyear-vintage) equipment demanded in post-RECSyear-vintage housing units by housing type and census division. It is computed as in (B-29) above.
$EQCRP90_{y,eg,b,r}$	is the number of replacement units demanded in existing housing units each year by housing type and census division. It is computed as in (B-30) 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-31) above.

RDRYCON (Clothes drying energy consumption component)

The unit energy consumption for surviving equipment is calculated as:

$$EQCSUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * \frac{RTBASEFF_{RECSyear,eff}}{RTBASEFF_{y,eg}} \quad \text{(B-105)}$$

where

$EQCSUEC_{y,eg,b,r}$	is the UEC for surviving RECSyear 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 RECSyear housing by census division, equipment class, and housing type.

For new equipment:

$$EQCNUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * WTEQCEFFN_{y,eg,b,r} * RTBASEFF_{y,eg} \quad \text{(B-106)}$$

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 RECSyear efficiency of the equipment class, and
$EQCUEC_{r,eg,b}$	is unit energy consumption for equipment in RECSyear housing by census division, equipment class, and housing type.

For replacement equipment:

$$EQCRUEC_{y,eg,b,r} = EQCUEC_{r,eg,b} * WTEQCEFFR_{y,eg,b,r} * RTBASEFF_{y,eg} \quad \text{(B-107)}$$

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 RECSyear efficiency of the equipment class, and
$EQCUEC_{r,eg,b}$	is unit energy consumption for equipment in RECSyear housing by census division, equipment class, and housing type.

The average of the two unit energy consumption variables is computed as:

If y = RECSyear+1,

$$EQCAUEC_{y,eg,b,r} = EQCNUEC_{r,eg,b} \quad \text{(B-108)}$$

If y > RECSyear+1,

$$EQCAUEC_{y,eg,b,r} = \frac{\begin{pmatrix} \left(EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP90RP_{y,eg,b,r}\right) \\ * EQCNUEC_{y,eg,b,r} \\ +\left(EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r}\right) * EQCAUEC_{y-1,eg,b,r} \\ +EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \end{pmatrix}}{\begin{pmatrix} EQCREP_{y,eg,b,r} + EQCADD_{y,eg,b,r} + EQCRP90RP_{y,eg,b,r} \\ +EQCSR90_{y,eg,b,r} + EQCSUR_{y,eg,b,r} + EQCRP90_{y,eg,b,r} \end{pmatrix}} \quad \text{(B-109)}$$

The class averages of equipment type efficiencies for clothes drying equipment are calculated as for other end uses:

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

$$WTEQCEFFA_{y,eg,b,r} = \frac{\sum_{es}\left(EQWT_{y,es,b,r} * RTEQEFF_{es}\right)}{TEMP}, if\ TEMP > 0 \quad \text{(B-110)}$$

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

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.

And energy consumption is defined as:

$$DRYCON_{y,r} = \sum_{b,eg} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} \\ +EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ +EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ +EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \end{pmatrix}, if\ y = RECSyear + 1 \quad \text{(B-111)}$$

$$DRYCON_{y,r} = \sum_{b,eg} \begin{pmatrix} EQCESE_{y,eg,b,r} * EQCUEC_{eg,b,r} \\ +EQCADD_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ +EQCRP90_{y,eg,b,r} * EQCRUEC_{y,eg,b,r} \\ +EQCRP90RP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ +EQCSR90_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \\ +EQCREP_{y,eg,b,r} * EQCNUEC_{y,eg,b,r} \\ +EQCSURE_{y,eg,b,r} * EQCAUEC_{y,eg,b,r} \end{pmatrix}, if\ y > RECSyear +\ 1 \quad \text{(B-112)}$$

RREFTEC (Refrigeration technology choice component)

Refrigeration is modeled somewhat differently than most other end uses (with some similarities to clothes washing). It has three general equipment configurations, depending on the freezer location: top-mounted, side-mounted, or bottom-mounted. RECS includes only a single UEC; therefore, rather than modeling these different general configurations as classes (for example, electric dryers that have multiple classes and UECs), the configurations are treated as just another refrigerator type but with further special treatment. For refrigeration, the denotation for equipment class *eg* is always defined as 1 and is not needed as a subscript as for other end uses.

The special treatment of the various types takes the form of an assumed share of the market, whereas market shares for the other end use equipment types are determined based on model-endogenous logistic equipment choice based on the relationship between operating cost and capital cost. Refrigerators with side- and bottom-mounted freezers are generally more costly and tend to be less efficient. Thus, the assumed market share for these types is needed because, if modeled *competitively* as just another refrigerator type (denoted *es*), they would not receive a significant market share, even though in practice they are popular. In the equations that follow, the subscript *es* refers variables accounting for shares of side- or bottom-mounted freezer refrigerators versus other types when the distinction is necessary.

Equipment operating cost for top-mounted freezer refrigerators is:

$$OPCOST_{y,es,b,r,v} = PRICES_{f,r,y} * RTEQEFF_{es} * \mathrm{FACTOR} \quad \text{(B-113)}$$

where

$OPCOST_{y,es,b,r,v}$ is the operating cost of the equipment type by housing type, census division, and vintage in the current year,

$PRICES_{f,r,y}$ is the fuel price in the current year by census division from the NEMS Integrating Module,

$RTEQEFF_{es}$ is the efficiency (represented as unit energy consumption for this service) of the refrigerator type, and

FACTOR is a factor (0.003412 MMBtu/kWh) that converts the units of $RTEQEFF_{es}$, expressed in kWh for refrigerators and freezers.

The following variables are computed as indicated:

$LFCY_{y,es,b,r,v}$ is the refrigerator's lifecycle 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 year, housing type, and census division. It is computed as in (B-20) above.

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

The general types of refrigerators have market shares as:

$$NEQTSHR_{y,es=TMF,b,r} = \frac{EQWTN_{es,b,r}}{TMFSHR_{b,r}} * (TMF\_SHR) \quad \text{(B-114)}$$

$$REQTSHR_{y,es=TMF,b,r} = \frac{EQWTR_{es,b,r}}{TMFSHR_{b,r}} * (TMF\_SHR) \quad \text{(B-115)}$$

where

$NEQTSHR_{y,es,b,r}$	is the market share for new refrigerators of the equipment type in the current year by housing type and census division,
$REQTSHR_{y,es,b,r}$	is the market share for the replacements of equipment type in the current year by housing type and census division,
$TMFSHR_{b,r}$	is the model-calculated market share of refrigerators with top-mounted freezers by housing type and census division, and
TMF_SHR	is the assumed overall share of refrigerators with top-mounted freezers.

Market shares are defined similarly for refrigerators with side-mounted freezers (SMF) and bottom-mounted freezers (BMF) instead of TMF. For refrigerators with modeled market shares, their calculated market shares are *deflated* by the assumed share of the different types, ensuring that the market shares sum to unity.

$$WTEQCEFFN_{y,b,r} = \frac{\sum_{es}\left(NEQTSHR_{y,es,b,r} * RTEQEFF_{es}\right)}{\sum_{es} NEQTSHR_{y,es,b,r}} \quad \text{(B-116)}$$

$$WTEQCEFFR_{y,b,r} = \frac{\sum_{es}\left(REQTSHR_{y,es,b,r} * RTEQEFF_{es}\right)}{\sum_{es} REQTSHR_{y,es,b,r}} \quad \text{(B-117)}$$

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 RSMEQP inputs,
$NEQTSHR_{y,es,b,r}$	is the new market share for the equipment types in the current year by housing type and census division, and
$REQTSHR_{y,es,b,r}$	is the market share for the replacements of equipment 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. The additions are calculated as:

$$EQCADD_{y,b,r} = HSEADD_{y,b,r} * RFADDFAC, if\ b = 1$$
$$EQCADD_{y,b,r} = HSEADD_{y,b,r}, otherwise \quad \text{(B-118)}$$

where

$EQCADD_{y,b,r}$	is the amount of new (post-RECSyear-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 percentage of new single-family housing units with two refrigerators.

The following variables are computed as indicated:

$EQCSR90_{y,eg,b,r}$	is the surviving post-RECSyear-vintage equipment in existing housing units in the current year by housing type and census division. It is computed as in (B-36) above.
$EQCSUR_{y,eg,b,r}$	is the surviving new (post-RECSyear-vintage) equipment in the current year by housing type and census division. It is computed as in (B-37) above.
$EQCREP_{y,eg,b,r}$	is the number of replacement units (post-RECSyear-vintage) equipment demanded in post-RECSyear-vintage housing units by housing type and census division. It is computed as in (B-29) above.
$EQCRP90_{y,eg,b,r}$	is the number of replacement units demanded in existing housing units each year by housing type and census division. It is computed as in (B-30) 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-31) above.

RREFCON (Refrigeration energy consumption component)

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

$$EQCSUEC_{y,b,r} = EQCUEC_{r,b} * \frac{RTBASEFF_y}{RTBASEFF_{RECSyear}} \quad \text{(B-119)}$$

where

$EQCSUEC_{y,b,r}$	is the UEC for surviving RECSyear equipment in each equipment class by housing type and census division,
$EQCUEC_{r,b}$	is the UEC for the original RECSyear 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:

$$EQCNUEC_{y,b,r} = EQCUEC_{r,b} * \frac{WTEQCEFFN_{y,b,r}}{RTBASEFF_{RECSyear}} \tag{B-120}$$

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

For replacement refrigerators:

$$EQCRUEC_{y,b,r} = EQCUEC_{r,b} * \frac{WTEQCEFFR_{y,b,r}}{RTBASEFF_{RECSyear}} \tag{B-121}$$

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

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

If y = RECSyear+1,

$$EQCAUEC_{y,b,r} = EQCNUEC_{y,b,r} \tag{B-122}$$

If y > RECSyear+1,

$$EQCAUEC_{y,b,r} = \frac{\begin{pmatrix} \left(EQCREP_{y,b,r} + EQCADD_{y,b,r} + EQCRP90RP_{y,b,r}\right) \\ * EQCNUEC_{y,b,r} \\ +\left(EQCSR90_{y,b,r} + EQCSUR_{y,b,r}\right) * EQCAUEC_{y-1,b,r} \\ +EQCRP90_{y,b,r} * EQCRUEC_{y,b,r} \end{pmatrix}}{\begin{pmatrix} EQCREP_{y,b,r} + EQCADD_{y,b,r} + EQCRP90RP_{y,b,r} \\ +EQCSR90_{y,b,r} + EQCSUR_{y,b,r} + EQCRP90_{y,b,r} \end{pmatrix}} \tag{B-123}$$

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 as:

$$WTEQCEFFA_{y,b,r} = WTREFFN_{y,b,r} \; if \; y = RECSyear + 1$$

$$WTEQCEFFA_{y,b,r} = \frac{\begin{pmatrix} (EQCREP_{y,b,r} + EQCADD_{y,b,r} + EQCRP90RP_{y,b,r}) \\ * WTEQCEFFN_{y,b,r} \\ +(EQCSR90_{y,b,r} + EQCSUR_{y,b,r}) * WTEQCEFFA_{y-1,b,r} \\ +EQCRP90_{y,b,r} * EQCRUEC_{y,b,r} \\ +EQCADD_{y,b,r} * RTBASEFF_{RECSyear,eg} \end{pmatrix}}{\begin{pmatrix} EQCREP_{y,b,r} + EQCADD_{y,b,r} + EQCRP90RP_{y,b,r} \\ +EQCSR90_{y,b,r} + EQCSUR_{y,b,r} + EQCRP90_{y,b,r} \end{pmatrix}} \; otherwise \tag{B-124}$$

And energy consumption is estimated as:

$$REFCON_{y=RECSyear+1,r} = \sum_b \begin{pmatrix} EQCESE_{y,b,r} * EQCUEC_{b,r} \\ +EQCADD_{y,b,r} * EQCNUEC_{y,b,r} \\ +EQCADD_{y,b,r} * EQCUEC_{y,b,r} \\ +EQCRP90_{y,b,r} * EQCRUEC_{y,b,r} \\ +EQCRP90RP_{y,b,r} * EQCNUEC_{y,b,r} \end{pmatrix}, \tag{B-125}$$

$$if \; y = RECSyear + 1$$

$$REFCON_{y,r} = \sum_b \begin{pmatrix} EQCESE_{y,b,r} * EQCUEC_{b,r} \\ +EQCADD_{y,b,r} * EQCNUEC_{y,b,r} \\ +EQCADD_{y,b,r} * EQCUEC_{b,r} \\ +EQCRP90_{y,b,r} * EQCRUEC_{y,b,r} \\ +EQCRP90RP_{y,b,r} * EQCNUEC_{y,b,r} \\ +EQCSR90_{y,b,r} * EQCAUEC_{y,b,r} \\ +EQCREP_{y,b,r} * EQCNUEC_{y,b,r} \\ +EQCSUR_{y,b,r} * EQCAUEC_{y,b,r} \end{pmatrix}, \; if \; y > RECSyear + 1 \tag{B-126}$$

where

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

$EQCESE_{y,b,r}$ is the surviving old (existing-vintage) equipment in old (existing vintage) housing units in the current year by housing type and census division,

$EQCADD_{y,b,r}$ is the amount of new (post-RECSyear-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-RECSyear-vintage) equipment in existing 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,

$EQCNUEC_{y,b,r}$ is the efficiency-weighted unit energy consumption for new refrigerators in the current year by housing type and census division, and

$EQCUEC_{r,b}$ is the unit energy consumption for refrigerators by housing type and census division.

RFRZTEC (Freezing technology choice component)

Freezing is parallel to refrigeration (so, it is also modeled without reference to the equipment class *eg*, which is implicitly 1). Upright and horizontal chest freezers (with *es* instead denoted as *UP* and *CH*) conceptually take the place of refrigerator door configurations and each receive an assumed market share. Processing the market share weights is similar to refrigeration. The following variables are computed as 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-67) above.

$LFCY_{y,es,b,r,v}$ is the freezer's lifecycle 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 year, housing type, and census division. It is computed as in (B-20) above.

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

Shares for equipment types, in normalized form, are calculated by a method similar to the method used for other equipment types:

$$NEQTSHR_{y,es,b,r} = \frac{EQWTN_{es,b,r}}{UPSHR_{b,r}} * (UP\_SHR), \qquad if\ es = upright\ freezer$$

(B-127)

$$NEQTSHR_{y,es,b,r} = \frac{EQWTN_{es,b,r}}{CHSHR_{b,r}} * (CH\_SHR), \quad if\ es = chest\ freezer$$

$$REQTSHR_{y,es,b,r} = NEQTSHR_{y,es,b,r} \qquad \text{(B-128)}$$

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,
$UPSHR_{b,r}$	is the model-calculated market share of upright freezers by housing type and census division,
$CHSHR_{b,r}$	is the model-calculated market share of chest freezers by housing type and census division,
UP_SHR	is the market share for upright freezers, and
CH_SHR	is the market share for chest freezers.

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

$$WTEQCEFFN_{y,b,r} = \frac{\sum_{es}\left(NEQTSHR_{y,es,b,r} * RTEQEFF_{es}\right)}{\sum_{es} NEQTSHR_{y,es,b,r}} \quad \text{(B-129)}$$

$$WTEQCEFFR_{y,b,r} = \frac{\sum_{es}\left(REQTSHR_{y,es,b,r} * RTEQEFF_{es}\right)}{\sum_{es} REQTSHR_{y,es,b,r}} \quad \text{(B-130)}$$

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 in 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 all vintage categories. For additions after the RECSyear+1:

$$EQCADD_{y,b,r} = HSEADD_{y,b,r} * FRZSAT_{b,r} \quad \text{(B-131)}$$

where

$EQCADD_{y,b,r}$	is the amount of new (post-RECSyear-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 RSMISC.TXT file, expressed as percentages.

The following variables are computed as indicated:

$EQCSR90_{y,eg,b,r}$	is the surviving post-RECSyear-vintage equipment in existing housing units in the current year by housing type and census division. It is computed as in (B-36) above.

$EQCSUR_{y,eg,b,r}$	is the surviving new (post-RECSyear-vintage) equipment in the current year by housing type and census division. It is computed as in (B-37) above.
$EQCREP_{y,eg,b,r}$	is the number of replacement units (post-RECSyear-vintage) equipment demanded in post-RECSyear-vintage housing units by housing type and census division. It is computed as in (B-29) above.
$EQCRP90_{y,eg,b,r}$	is the number of replacement units demanded in existing housing units each year by housing type and census division. It is computed as in (B-30) 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-31) 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 RECSyear equipment in each equipment class, by housing type and census division, calculated as in equation (B-119),
$EQCNUEC_{y,b,r}$	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-120), and
$EQCRUEC_{y,b,r}$	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-121).

Weighted average usages are calculated:

$$WTEQCEFFA_{y,b,r} = WTREFFN_{y,b,r}, if\ y = RECSyear + 1$$

$$WTEQCEFFA_{y,b,r} = \frac{\begin{pmatrix} (EQCREP_{y,b,r} + EQCADD_{y,b,r} + EQCRP90RP_{y,b,r}) \\ * WTEQCEFFN_{y,b,r} \\ +(EQCSR90_{y,b,r} + EQCSUR_{y,b,r}) * WTEQCEFFA_{y-1,b,r} \\ +EQCRP90_{y,b,r} * WTEQCEFFR_{y,b,r} \end{pmatrix}}{\begin{pmatrix} EQCREP_{y,b,r} + EQCADD_{y,b,r} + EQCRP90RP_{y,b,r} \\ +EQCSR90_{y,b,r} + EQCSUR_{y,b,r} + EQCRP90_{y,b,r} \end{pmatrix}} \quad \text{(B-132)}$$

And regional energy consumption is estimated as

$$FRZCON_{y,r} = \sum_{b} \begin{pmatrix} EQCESE_{y,b,r} * EQCSUEC_{b,r} + \\ EQCADD_{y,b,r} * EQCNUEC_{y,b,r} + \\ EQCRP90_{y,b,r} * EQCRUEC_{y,b,r} \\ EQCRP90RP_{y,b,r} * EQCNUEC_{y,b,r} \end{pmatrix}, if\ y = RECSyear + 1 \quad \text{(B-133)}$$

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.

LTCNS (Lighting choice, stock, and energy consumption component)

The lighting end use is separated into distinct applications grouped by usage or lamp characteristics, referred to as lighting *applications*: general service lighting, reflector lamps, linear fluorescent lamps, and exterior lighting. General service lighting represents *Edison-type* sockets—the typical screw-base bulbs found on incandescent, compact fluorescent, and LED bulbs. General service lighting is most important in terms of energy consumption for the residential sector; therefore, it also has the most detailed characterization and accounting in the lighting module. The equations below are generalized to represent any of the four applications—the only difference among them is that the general service category is further partitioned into hours-of-use bins, which affect the relationship between operating and capital costs, as documented below. Currently reflector lamps, linear fluorescent lamps, and exterior lighting are characterized with only a single hours-of-use bin; however, this characterization is controlled by the dimensions set in the input file so that up to six hours-of-use bins could be characterized, data permitting.

Operating costs are developed using the same general framework for each lighting application. Note that operating costs receive a regional dimension because of the regional variation in electricity prices. The capital costs below do not have a regional dimension, although subsidies are available by census division to represent regional energy efficiency program expenditures.

$$OPCOST_{y,app,bin,e,r} = PRICES_{y,r} * BULBWATTS_{app,e,y} * FACTOR * APPBINHOURS_{app,bin} * 365 \quad \text{(B-134)}$$

where

$OPCOST_{y,app,bin,e,r}$	are the annual operating costs for year, application, bin, bulb type, *e*, and census division, *r*,
$PRICES_{y,r}$	are lighting end-use electricity prices by year and census division,
$BULBWATTS_{app,e,y}$	are the watts for application, bulb type, and year,
FACTOR	is a value (3.412/10^6) that converts watts to Btu per hour,
$APPBINHOURS_{app,bin}$	are the number of hours of use per day for this application and bin, and
365	converts daily hours to annual hours.

Capital costs are merely the cost of the bulb with two potential adjustments. When multiple bulb replacements per year must be made as a result of high hours-of-use bins (affecting incandescent lights especially), bulb costs are scaled up by the number of annual replacements required, representing the annual purchase costs. Also, for non-incandescent bulbs, an adjustment is made based on the color rendering index (CRI) that normalizes to a CRI-adjusted cost and ultimately reduces the market share in the choice equation below for bulbs with less-desirable light spectra.

$$LTLCAP_{y,app,bin,e} = \frac{BULBCOST_{app,e,y} \Big/ BULBBINLIFE_{app,e,bin,y}}{\left(BULBCRI_{app,e,y} \big/ 100\right)^2} \qquad \text{(B-135)}$$

where

$LTLCAP_{y,app,bin,e}$	is the total annual bulb costs by year, application bin, bulb type, and census division,
$BULBCOST_{app,e,y}$	is the cost per bulb,
$BULBBINLIFE_{app,e,bin,y}$	is the life in years for a bulb within an hours-of-use bin (if life in years is greater than one year, the capital cost is not adjusted because the choice is based on first-year total costs), and
$BULBCRI_{app,e,y}$	is the color rendering index for an application and bin (dividing by 100, then squaring the result, increases LTLCAP, thus *penalizing* bulbs with lower-quality light).

Market shares for purchases of the various types of bulbs available for a particular application are computed separately for each application as:

$$LTMSHR_{y,app,bin,e,b,r} = \frac{exp^{LTLBeta1*LTLCAP_{y,app,bin,e}+LTLBeta2*OPCOST_{y,app,bin,e,b,r}}}{\sum_e exp^{LTLBeta1*LTLCAP_{y,app,bin,e}+LTLBeta2*OPCOST_{y,app,bin,e,b,r}}} \qquad \text{(B-136)}$$

where

$LTMSHR_{y,app,bin,e,b,r}$	is the market share by year, application, bin, bulb type, housing type, and census division, and
LTLBeta1 and LTLBeta2	are the choice weights for capital and operating costs, respectively.

After computing market shares for each application by bin, bulb type, housing type, and census division, overall purchases of bulbs, *LTREPTOT* (B-141), are determined. First, bulb purchases needed for each projection year's floorspace additions for new construction, *HSEADD*, plus newly added floorspace in existing homes are developed. The required number of bulb purchases for this element of the residential stock includes floorspace area adjustments for both new construction and added floorspace in the existing stock of households.

$$\begin{aligned} LTNEEDED_{y,app,bin,e,b,r} &= [HSEADD_{y,b,r} * SQRFOOT_{y,b,r} \,/\, SQRFOOT_{RECSYR,b,r} + EH_{y,b,r} \\ &* (EXSQRFOOT_{y,b,r} \,/\, EXSQRFOOT_{y-1,b,r} - 1)] \;\; * BULBSPERHH_{app,b} \\ &* BULBBINSHARES_{app,bin} * LTMSHR_{y,app,bin,e,b,r} \end{aligned} \qquad \text{(B-137)}$$

where

$HSEADD_{y,b,r}$	is the number of new housing units constructed in the projection year by housing type and census division,
$SQRFOOT_{y,b,r}$	is an input table of historical and projected average conditioned floorspace areas by year, housing type, and census division,

$EH_{y,b,r}$	is the RECSyear housing stock surviving in year *y*,
$EXSQRFOOT_{y,b,r}$	is the projected average conditioned floorspace areas by year, housing type, and census division,
$BULBSPERHH_{app,b}$	bulbs per household in the RECSyear for each lighting application and housing type, and
$BULBBINSHARES_{app,bin}$	is the bulb shares by bulb type *e* within hours-of-use bins for each application.

The remaining stocks of bulbs for the RECS-year housing stock account for the year-to-year decay of the existing housing stock from the RECS year by housing type. Until the remaining stocks become zero, they are calculated as the difference between the bulb stock from the previous year less the number that expire in the remaining (surviving) housing stock this year. Bulbs in this stock existed in the RECS year and, as they expire, are added to *LTREPTOT*, (B-141).

$$LTSTOCKEX_{app,y,e,bin,b,r} = LTSTOCKEX_{app,y-1,e,b,r,bin} - LTSTOCKEX_{app,RECSyear,e,b,r,bin} * HDR_b^{(y-RECSyear)} / BULBBINLIFE_{app,e,bin} \quad \text{(B-138)}$$

where

$LTSTOCKEX_{app,RECSyear,e,b,r,bin}$	is the stock of bulbs in RECSyear for each application, bulb type, housing type, census division, and hours-of-use bin,
HDR_b	is the percentage of the housing stock by housing type that survives from one year to the next as in (B-2), and
$BULBBINLIFE_{app,e,bin}$	is the life in years by bulb and hours-of-use bin.

Another component of bulb purchases is replacement bulbs in existing homes. *LTREPFUT* represents the stock of bulbs that will need to be replaced each projection year for all bulbs purchased from the RECS year up to, but not including, the current model projection year. It is denoted as *LTREPFUT* because it represents replacements in future years after a bulb's initial purchase. For any given purchase, future replacements generally decline toward zero as more housing units decay from stock and as fractions get repurchased every year (and get replaced with a new purchase that again generates its own stream of future replacement requirements). The exception is purchases made toward the end of the modeling horizon, which would not come up for replacement by the last modeled year of NEMS. Current-year replacements are based on the previous year's lighting stock, adjusted for the decay of the housing stock. For bulbs purchased in a particular year, replacements continue each future year until the number of replacements equals the total in the original purchase, adjusted for the housing stock that has retired:

$$LTREPFUT_{app,y,e,b,r,bin} = P_{app,y-1,e,b,r,bin} / BULBBINLIFE_{e,bin} * HDR_b$$

$$LTREPFUT_{app,y+1,e,b,r,bin} = P_{app,y-1,e,b,r,bin} / BULBBINLIFE_{e,bin} * {HDR_b}^2 \quad \text{(B-139)}$$

$$LTREPFUT_{app,y+2,e,b,r,bin} = P_{app,y-1,e,b,r,bin} / BULBBINLIFE_{e,bin} * {HDR_b}^3, etc \ldots$$

LTREPSTK represents the remaining purchased bulbs still in the lighting stock that accumulate from year to year as purchases are made.

$$LTREPSTK_{app,y,e,b,r,bin} = LTREPSTK_{app,y-1,e,b,r,bin} - LTREPFUT_{app,y,e,b,r,bin} \quad \text{(B-140)}$$

For each application, all of the required replacement bulbs are aggregated by bulb type because the purchases will ultimately be reallocated based on purchase market shares, *LTMSHR* (B-136). These consist of replacements that may still be required from the original stock of RECS-year bulbs, replacements for bulbs purchased during the modeling horizon, and bulbs needed for new construction and floorspace additions.

$$LTREPTOT_{app,y,bin,b,r} = \sum_{e} [LTSTOCKEX_{app,y-1,e,b,r,bin} * HDR_b - LTSTOCKEX_{app,y,e,b,r,bin} + LTREPFUT_{app,y,e,b,r,bin} + LTNEEDED_{app,y,e,b,r,bin} \quad \text{(B-141)}$$

Distributing the replacements to bulb types using *LTMSHR*:

$$LTREPSTK_{y,app,e,bin,b,r} = LTREPTOT_{app,y,b,r,bin} * LTMSHR_{app,y,e,b,r,bin} \quad \text{(B-142)}$$

Consumption for the still-existing remaining RECS-year lighting stock is calculated as:

$$LSTOCKEXCONS_{y,app,e,bin,b,r} = LSTKEX_{app,y,e,b,r,bin} * APPBINHOUR_{app,bin} * 365 * BASEWATTSBULBS_{app,e} * FACTOR \quad \text{(B-143)}$$

where

$APPBINHOURS_{app,bin}$	is the number of hours of use per day for this application and bin,
$BASEWATTSBULBS_{app,e}$	is the RECS-year watts for each of the bulb types used for this application, and
FACTOR	converts watts to Btu per hour as in (B-134).

Consumption for replacement bulbs is computed directly from BULBWATTS and stock:

$$LTREPCONS_{y,app,e,bin,b,r} = LREPSTK_{app,y,e,b,r,bin} * APPVINHOURS_{app,bin} * 365 * BULBWATTS_{app,e,y} * FACTOR \quad \text{(B-144)}$$

where

$BULBWATTS_{app,e}$	is the current-year watts for each of the bulb types used by application.

Total lighting consumption before adjustments for the price elasticity and rebound effects is the sum of consumption from the surviving bulbs from the RECS year stock, LTSTOCKEXCONS, plus the consumption from all surviving purchases and replacements, LTREPCONS.

WTLEFF represents the average consumption per bulb and is used to calculate the efficiency rebound effect.

$$WTLEFF_{app,y,b,r,bin} = \frac{\sum_e \begin{pmatrix} LREPSTK_{app,y,e,b,r,bin} * BULBWATTS_{app,e,y} \\ +LTSTKEX_{app,y,e,b,r,bin} * BASEWATTSBULBS_{app,e} \end{pmatrix}}{\sum_e (LREPSTK_{app,y,e,b,r,bin} + LTSTKEX_{app,y,e,b,r,bin})} \qquad \text{(B-145)}$$

LTNUEC is the efficiency- and rebound-adjusted energy consumption by application, year, housing type, and census division.

$$LTNUEC_{app,y,b,r} = \sum_{bin} LTBINSHARE_{app,bin} * LTUEC_{app,r,b} * \left(\frac{WTLEFF_{app,y,b,r,bin}}{BASEWATTSBINS_{app,bin}}\right)^{(1+\alpha)} \qquad \text{(B-146)}$$

where

$LTUEC_{app,r,b}$	is RECS-year unit energy consumption by application, census division, and housing type,
$BASEWATTSBINS_{app,bin}$	is computed directly from lighting inputs for the RECS year and defined below, and
α	is the efficiency-rebound effect elasticity, currently valued at -0.15.

$$BASEWATTBIN_{app,bin} = \sum_{e} BULBBINSHARES_{app,e,bin} * BASEWATTBULBS_{app,e} \qquad \text{(B-147)}$$

LTEQCN adjusts for leap year and price elasticity and aggregates over bulb types and lighting bins:

$$LTEQCN_{y,app,b,r} = LEAPYR * \sum_{e,bin} \left(LREPSTK_{app,y,e,b,r,bin} + LTSTKEX_{app,y,e,b,r,bin}\right) * LTNUEC_{app,y,b,r} * RSELAST \qquad \text{(B-148)}$$

where

$LTSTOCK_{y,b,r}$	is the number of general service 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, and
RSELAST	is the short-term price elasticity function applied to electricity prices with distributed lag weights EF1, EF2, and EF3, and the total short-term price elasticity, α, as described in (B-39).

Finally, $LTCON_{y,r}$ is the reporting variable for NEMS and is merely the aggregation of $LTEQCN_{y,app,b,r}$ over all applications and all housing types.

APCNS (Miscellaneous Electric Loads/appliance consumption component)

For these miscellaneous electric loads (MELs), two input arrays, based on metrics from contracted report data and other sources, provide a penetration rate (number of units per household) and usage trend (kilowatthours per unit per year).

Throughout this section, the end use will be generalized as *MEL*. In the code, those three letters are replaced with three letters associated with each end use, such as *TVS* for televisions, *STB* for set-top boxes, *LPC* for laptop personal computers, and so on. The abbreviations associated with each end use are described in the RSMELS.TXT description in Appendix A: Input Parameters.

To form the projection of usage, the usage index is multiplied by the RECSyear UEC. Specifically,

$$MELNUEC_{y,r,b} = MELUEC_{r,b} * MELEFF_y \tag{B-149}$$

where

$MELNUEC_{y,r,b}$	is the unit energy consumption for a MEL by year, census division, and housing type,
$MELUEC_{r,b}$	is RECSyear unit energy consumption for a MEL by census division and housing type,
$MELEFF_y$	is the usage index for a MEL in year *y*.

In some cases, this array is also multiplied by an income effect index—the ratio of model-year and RECSyear real disposable income—because certain uses are more likely to be adopted when households have higher disposable income in a given year:

$$MELNUEC_{y,r,b} = MELUEC_{r,b} * MELEFF_y * \left(MELsIncomeEffect * \left(\frac{MC\_YPDR_{r,y}}{MC\_YPDR_{r,RECSyear}} \right)^{0.05} \right) \tag{B-150}$$

where

MELsIncomeEffect	is the switch that enables the income effect for specific MELs,

$MC\_YPDR_{r,y}$	is the personal disposable income variable from the Macroeconomic Activity Module, and
0.05	is an exponent that estimates the correlation between changes in disposable income and changes in adoption of specific MELs.

The income effect described above is applied to the following MELs: TVS, STB, HTS, VGC, DPC, LPC, MON, NET, BAT, DEH, PLP, PHP, SEC, SPA, WCL, and PHN.

Similarly, the projection of stock is formed by multiplying the equipment stock index by RECSyear stock:

$$MELEQP_{y,r,b} = \left(\frac{MELEQP_{r,b}}{EH_{y=baseyr,r,b}}\right) * MELPEN_y * \left(EH_{y,b,r} + NH_{y,b,r}\right) \qquad \text{(B-151)}$$

where

$MELEQP_{y,r,b}$	is the number of each MEL in the housing stock by year, census division, and housing type,
$MELEQP_{r,b}$	is the RECSyear equipment stock for each MEL
$MELPEN_y$	is the estimated penetration of each MEL for year *y*,
$EH_{y,r,b}$	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 each MEL:

$$MELCON_{y,r} = \sum_b \left(\begin{array}{c} \left(MELEQP_{y,b,r} * MELNUEC_{y,b,r}\right) \\ * RSELAST(f, r, \alpha, EF1, EF2, EF3, RECSyear) \end{array} \right) \qquad \text{(B-152)}$$

where

$MELCON_{y,r}$	is the energy consumption of each MEL by year and census division, and
RSELAST	is the short-term price elasticity function with distributed lag weights EF1, EF2, and EF3, and the total short-term price elasticity, α, described in (B-39).

The remaining electricity consumption is captured in a catch-all category that includes—but is not limited to—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 consumption components described above. 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.

Electric appliance energy consumption is computed as:

$$APCON_{y,r} = \sum_b \left(EAUEC_{y,r} * EAPEN_{y,r}\right) * \left(EH_{y,r,b} + NG_{y,r,b}\right) * (RSELAST(f, r, \alpha, EF1, EF2, EF3, RECSyear) \qquad \text{(B-153)}$$

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,
$RSELAST$	is the short-term price elasticity function with distributed lag weights EF1, EF2, and EF3, and the total short-term price elasticity, α, described in (B-39),
$EH_{y,r,b}$	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.

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:

$$SHTCON_{y,f,r} = \sum_{b} \begin{pmatrix} SHTSHR_{r,f} * \left(NH_{y,b,r} + EH_{y,b,r}\right) * SHTUEC_{r,f,b} \\ * AHSHELL_{y,f,r,b} * RSELAST(f, r, \alpha, EF1, EF2, EF3, RECSyear) \end{pmatrix} \quad \text{(B-154)}$$

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 (existing) housing units in the current year by housing type and census division,
$NH_{y,b,r}$	is the number of new (post-RECSyear) housing units in the current year by housing type and census division,
$SHTUEC_{r,f,b}$	is RECSyear unit energy consumption for secondary heating by census division, fuel, and housing type,
$AHSHELL_{y,f,r,b}$	is the average post-RECSyear heating shell index by year, fuel, census division, and building type, and
$RSELAST$	is the short-term price elasticity function with distributed lag weights EF1, EF2, and EF3, and the total short-term price elasticity, α, described in (B-39).

APPCNS (Non-electric miscellaneous appliance energy consumption component)

Other appliances refers to small appliances not covered in the other categories that do not use electricity as their primary fuel. Consumption alone is calculated.

The formula is a simple calculation from housing stock and unit energy consumption:

$$APLCON_{y,f,r} = \sum_{b} \begin{pmatrix} \left(NH_{y,b,r} + EH_{y,b,r}\right) * APPUEC_{y,b,r} \\ RSELAST(f, r, \alpha, EF1, EF2, EF3, RECSyear) \end{pmatrix} \quad \text{(B-155)}$$

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 (existing RECSyear) housing units in the current year by housing type and census division,
$NH_{y,b,r}$	is the number of new (post-RECSyear) housing units in the current year by housing type and census division,
$APPUEC_{r,f,b}$	are unit energy consumption estimates from the RSUEC.TXT file by year, housing type, and census division, and
RSELAST	is the short-term price elasticity function with distributed lag weights EF1, EF2, and EF3, and the total short-term price elasticity, α, described in (B-39).

RDISTGEN (distributed generation component)

The Residential Demand Module includes a subroutine 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 solar photovoltaics, natural gas fuel cells, and small distributed wind turbines.

The technology input file contains several general categories of input data:

- Cost and performance of specific technologies (system capacity, cost per kW_{DC}, efficiencies, etc.)
- Tax credits and regional subsidies, if any, apply to a particular technology (this functionality allows tax credit policies and subsidies to be included in the economic considerations)
- Technology window of availability, 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 to readily model proposed legislation; for extended NEMS time frames, however, multiyear time intervals beyond the projection horizon can be added for simplicity.
- Economic assumptions, including tax rates, inflation rates for projecting results in the cash flow model, and financing assumptions such as down payment percentages and loan terms.
- Program-driven penetrations of technologies by census division
- These program-driven penetrations are viewed as non-economic, supplemental to any economic penetrations.
- Market niche variables developed from RECS 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. 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 relative electricity prices, the market 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). The solar niches are cross-classified by three levels of electricity prices, yielding nearly 300 market niche categories that are modeled separately.

- Utility interconnection limitations for each census division
- These limitations are intended to reflect state laws, regulations, and policies that encourage or limit distributed generation integration. State scores on a scale of zero (closed to interconnection) to one (open to interconnection) are aggregated to the census division level by population. The scores are based on information from the Database of State Incentives for Renewables & Efficiency (DSIRE) and on updates on state legislative and public utility commission websites. Components include state-level renewable portfolio standards or goals, public benefit funds that support renewable resources, the existence of net-metering and interconnection standards and rules, whether fuel cells or CHP are eligible RPS technologies, and the existence of solar or wind access laws.

For solar photovoltaic equipment, a hurdle rate adoption model uses ZIP code-level input data, as discussed later in this section. Otherwise, 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 small wind, natural gas fuel cell, and as an alternative for solar photovoltaic distributed generation technologies. Cash flow analysis simulations are carried out by market niche for single-family homes. System characteristics, financial variables, solar insolation, and program-driven systems (for example, the California solar program) are supplied to the subroutine via the RSGENTK.TXT input file.

The *payback* concept used in the residential Distributed Generation Component 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 (for example, inverter replacement for solar PV systems), inflation-related 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 NEMS Macroeconomic Activity Module supplies residential mortgage rates. 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 that represents 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 cash flow 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 paid, but hot water savings are also realized through the capture and use of waste heat. Loan interest is separately tracked and leads to 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 applied. Based on current legislation, solar PV receives a 30% credit on installed capital costs through 2019, dropping to 26% in 2020, 22% in 2021, and discontinuing after 2021. These credits are modeled as one-time payments back to the consumer and, given the time value of money, such payments can have a major effect on increasing the cumulative net cash flow because 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 recover 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. We assume the penetration function to follow a logistic functional form, as shown in equation (B-184) (Figure 3). 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 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=49), times the number of electricity price niches (*l*=3). An uppercase *Y* is used to denote years internal to the cash-flow analysis to distinguish cash-flow simulation years from NEMS model years (denoted with a lowercase *y*). The annual technology vintages will also be denoted with lowercase *y* because 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 is adjusted for learning effects on equipment cost for emerging technologies:

$$AdjCost_{t,y} = MIN\langle CapCost_{t,y}, C_{0,t} * CumShip_{t,y}{}^{-\beta_t} \rangle \qquad \text{(B-156)}$$

where $CapCost_{t,y}$ is the tentative maximum cost from the distributed generation input file, $C_{0,t}$ 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 residential and commercial buildings and utility installations combined (supplied by the global interface). Learning effects are modeled for solar photovoltaic systems, natural gas fuel cell technologies, and small wind turbines.

Calculated maximum kW_{DC} for photovoltaic systems

The calculated maximum capacity (in kW_{DC}) for photovoltaic systems, $xCalcKW_{t=1,n,l,y}$, is allowed to vary from the menu capacity in the RSGENTK.TXT input file. The capacity is niche-dependent. The target maximum size is enough to serve the residence's annual electricity requirements, subject to maximum and minimum size constraints for the technology being evaluated. For solar photovoltaics, only 90% of the properly oriented half of a home's roof area is considered suitable for solar PV installation. Available roof area per house is developed from conditioned floorspace and the number of floors estimated from RECS and is provided as part of the niche inputs in RSGENTK.TXT. We also assume the modules to be placed at *latitude tilt*, which requires about twice the roof area for minimum rack spacing when installed on flat roofs. We assume that, on sloped roofs, solar modules are close enough to being *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 is required to mount a one-square-foot module. Based on these constraints, the kW_{DC} capacity of the maximum module area is calculated as:

$$xCalcKW_{t=1,n,l,y} = \frac{RoofAreaPerHH_{n,l}}{1.25 * 90\% * 50\% / xSqftperkW_y} \quad \text{(B-157)}$$

The equation (B-166) below is the calculation of $xSqftperKW_y$, 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 input from the distributed generation technology menu times the system capacity:

$$EqCost_{t,y} = \left(AdkCost_{t,y} + InstCost_{t,y}\right) * kW_{t,y} \quad \text{(B-158)}$$

For solar photovoltaics, $kW_{t,y}$ is replaced by $xCalcKW_{t,n,l,y}$ from (B-157).

Initial outlay cost

$$DownPay_{t,y} = \left(EqCost_{t,y} * DownPayPct\right) \quad \text{(B-159)}$$

Annual levelized payment calculation

$$Payment_{t,y} = \left[EqCost_{t,y} - DownPay_{t,y}\right] * \frac{IntRate}{1 - (1 + IntRate)^{-Term}} \quad \text{(B-160)}$$

where the term in brackets is the amount financed:

IntRate	is the interest rate for the loan and
Term	is the number of years over which the loan payments are amortized.

Outlays for capital relating to down payments and borrowing costs

$$Outlay_{t,y,Y=1} = DownPay_{t,y} \quad \text{(B-161)}$$

$$Outlay_{t,y,1<Y\leq Term} = Payment_{t,y}$$
$$Outlay_{t,y,Y>Term} = 0$$

Calculations of loan interest paid and the value of tax credits

$$Prin_{t,y,Y} = Payment_{t,y} - IntAmt_{t,y,Y}$$
$$where\ IntAmt_{t,y,Y} = IntRate * LoanBal_{t,y,Y-1}, and\ 1 < Y \leq Term \quad \text{(B-162)}$$

$Prin_{t,y,Y}$ 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:

$$LoanBal_{t,y,Y} = LoanBal_{t,y,Y-1} - Prin_{t,y,Y} \quad \text{(B-163)}$$

$TaxCredit_{t,y,Y}$ is the allowed tax credit and can vary both by technology and vintage for distributed generation investments favored by the tax code. We assume that the credit is collected in Year 3 of the cash-flow analysis.

$$TaxCredit_{t,y,Y} \equiv MIN\langle EqCost_{t,y} * TaxCreditPct_{t,y}, TxCreditMax_{t,y}\rangle,$$
$$if\ Y = 3 \quad \text{(B-164)}$$
$$0, if\ Y \neq 3$$

Annual kWh generated by technology

$AnnualKWH_{t,n,y}$ represents the base level of annual system kWh generation for a new system for the specific technology and vintage being analyzed.

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

$$AnnualKWH_{t,n,y} = \begin{pmatrix} ElEff_{t,y} * SolarIns_n * 365.25 * \\ xSqftperKW_y/10.8 * LossFac_{t,y} \end{pmatrix} * xCalcKW_{t,n,y} \quad \text{(B-165)}$$

The parenthetical expression represents the kWh generated by a 1-kW_{DC} system, so this amount is multiplied by system kW_{DC} 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-167). 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 subroutine assumes that a typical solar PV module in 2020 has a system efficiency of 20.3% and requires an area of 77 square feet for a 1-kW_{DC} system. The variable for the estimated photovoltaic array square footage for a 1-kW_{DC} system, $xSqftperKW_y$, depends inversely on the electrical efficiency of the system, $ElEff_{1,y}$:

$$xSqftperKW_y = 77 * \frac{0.203}{ElEff_{1,y}} \tag{B-166}$$

The higher the efficiency, the smaller the square footage that will be required for a given system capacity. Because system size is allowed to vary, higher-efficiency modules lead to higher-capacity systems as potential selections.

For natural gas fuel cells (t=2), annual system generation for a 1-kW_{DC} 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_{DC} system by system capacity:

$$AnnualKWH_{t,y} = \left(OperHours_t * Avail_{t,y} * LossFac_{t,y}\right) * kW_{t,y} \tag{B-167}$$

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

$$AnnualKWH_{t,n,y} = \left(\frac{ElEff_{t,y}}{ElEff_{t,y}} * \left(\begin{matrix} .0645 - .0670 * xMpS_n \\ +.0210 * xMpS_n{}^2 - .0011 * xMpS_n{}^3 \end{matrix}\right)\right) * LossFac_{t,y} * kW_{t,y} \tag{B-168}$$

$xMpS_n$ denotes average wind speed in meters per second for niche *n*. Distributed wind turbine penetration is also assumed appropriate and suitable for only rural residences (developed from RECS and input in RSGENTK.TXT) because of 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—based on *Distributed Generation, Battery Storage, and Combined Heat and Power System Characteristics and Costs in the Buildings and Industrial Sectors*—to account for output loss as modules age. Degradation begins in the year after the system is fully in use, which, in the cash-flow model assumptions, is year 3.

$$KWH_{t,y,Y} = AnnualKWH_{t,[n],y} * \left(1 - Degradation_{t,y}\right)^{(Y-2)} \tag{B-169}$$

Fuel consumption for fuel-using distributed generation technologies

Fuel consumption for natural gas 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:

$$FuelInput_{t,y} = \frac{0.003412 * OperHours_t * Avail_{t,y}}{ElEff_{t,y}} * kW_{t,y} \tag{B-170}$$

Calculation of waste heat available for water heating use

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

$$BTUWasteHeat_{t,y} = \left(FuelInput_{t,y} - 0.003412 * AnnualKWH_{t,y}\right) * WhRecoveryEff_{t,y} \quad \text{(B-171)}$$

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

$$WaterHeatingMMBtu_{t,y} = MIN\langle BTUWasteHeat_{t,y}, AvgWaterHtgMMBtu\rangle \quad \text{(B-172)}$$

Any amount of waste heat generated beyond the average water heating requirements is not assumed 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 constant/real dollars as the technology capital costs.

$$BaseYrFuelCost_{t,y} = \left(FuelInput_{t,y} - WaterHtgMMBtu_{t,y}\right) * FuelPrice_{r,y} \quad \text{(B-173)}$$

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

$$FuelCost_{t,y,Y} = BaseYrFuelCost_{t,y} * (1 + inflation)^{(Y-2)} \quad \text{(B-174)}$$

Value of electricity savings calculations

$VALESAVEBASE_{t,n,l,y}$ 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 (in other words, $AnnualKWH_{t,y}$ <= $AvgKWH$), then savings are valued at the air-conditioning price, $PELRSOUT_{r,y,AC}$ (because photovoltaic generation tends to correlate with the need for air conditioning):

$$VALESAVEBASE_{t=1,n,l,y} = \begin{bmatrix} PELRSOUT_{r,y,AC} * xRateScalar_{n,l} * 0.003412 \\ +EPRPSPR/1000 * xScaleRPS_t \end{bmatrix} * AnnualKWH_{t,[n],y} \quad \text{(B-175)}$$

The factor 0.003412 converts prices in dollars per million Btu to dollars per kWh. The potential to model renewable portfolio standard 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 1,000 because it is provided in mills per kWh[5]. If the credit is received, the scalar is set to a value greater than zero (for example, for triple credits, the scalar is 3). Because RPS credits often have a last year or *sunset* year, the cash-flow simulation also tracks the calendar year of each of the simulated years and zeroes out the credit if the calendar year exceeds the sunset year. If generation exceeds average usage, then the excess kWh generation is sold to the grid at the marginal price for utility purchases ($PELME_{r,y}$) and the value is:

$$VALESAVEBASE_{t,n,l,y} = 0.003412 * \begin{bmatrix} PELRSOUT_{r,y,AC} * xRateScalar_{n,l} * AvgKWH \\ +PELME_{r,y} * \left(AnnualKWH_{t,y} - AvgKWH\right) \end{bmatrix} + EPRPSPR_y/1000 * xScaleRPS_t * AnnualKWH_{t,y} \quad \text{(B-176)}$$

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 nonrenewable technologies. Therefore, when RPS credits are modeled, scalars for nonrenewable technologies are set to zero.

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

$$VALESAVE_{t,n,l,y,Y} = VALESAVEBASE_{t,n,l,y} * (1 + inflation)^{(Y-2)} * \left(1 - Degradation_{t,y}\right)^{(Y-2)} \quad \text{(B-177)}$$

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_{DC}, and $xIntervalCst_{t=1,y}$ is the *interval* maintenance cost for inverter replacement per kW_{DC} if the technology being evaluated is a photovoltaic system (that is, 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 solar photovoltaic system vintage, *y*.

$$MaintCost_{t,y,Y} = kW_{t,y} * \left(MaintCostBase_{t,y} + xIntervalCst_{t=1,y}\right) * (1 + inflation)^{(Y-2)} \quad \text{(B-178)}$$

Deductible expenses for personal income taxes

$$TaxDeduct_{t,y,Y} = \begin{pmatrix} IntAmt_{t,y,Y-1} - MaintCost_{t,y,Y-1} \\ +FuelCost_{t,y,Y-1} - ValElecSave_{t,y,Y-1} \end{pmatrix} * TaxRate + TaxCredit_{t,y,Y} \quad \text{(B-179)}$$

[5] A mill is equal to 1/1000 of a U.S. dollar, or 1/10 of one cent. Mills per kilowatthour (kWh) equals dollars per megawatthour (mWh). To convert mills per kWh to cents per kWh, divide mills per kWh by 10.

Cash flow and investment payback years

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

$$NetCashFlow_{t,n,l,y,Y} = ValElecSave_{t,n,l,y,Y} + TaxDeduct_{t,y,Y} - OutLay_{t,y,Y} - FuelCost_{t,y,Y} - MaintCost_{t,y,Y} \quad \text{(B-180)}$$

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

Simple Payback Years

$SimplePayback_{t,n,l,y}$ is the first year in the cash-flow stream for which an investment has a positive $CumCashFlow_{t,n,l,y,Y}$ (in other words, 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 factor 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:

$$SimplePayback_{t,n,l,y} = IntSimplePayback_{t,n,l,y} - \frac{\left(CumCashFlow_{t,n,l,y,Y'-1} + NetCashFlow_{t,n,l,y,Y'}\right)}{NetCashFlow_{t,n,l,y,Y'}} \quad \text{(B-181)}$$

Because *Y'* is the first year for which $CumCashFlow_{t,n,l,y,Y}$ is greater than or equal to zero, its previous-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:

$$MaxPen_{t,n,l,y} = \frac{PenParm_t}{SimplePayback_{t,n,l,y}} \quad \text{(B-182)}$$

$PenParm_t$ is set to 0.3 for all technologies. So, the asymptotically approached $MaxPen_{t,n,l,y}$ for these technologies with a one-year payback will be 30%. Because $SimplePayback_{tn,l,,y}$ 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 interconnection limitations

$$Inxdecay_{r,y} = MIN\left\langle 1.0, Inx_r + (1.0 - Inx_r) * \frac{y - Inxfy}{Inxly - Inxfy} \right\rangle \quad \text{(B-183)}$$

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 and are determined by EIA analyst judgment.

Penetration function formula for new construction

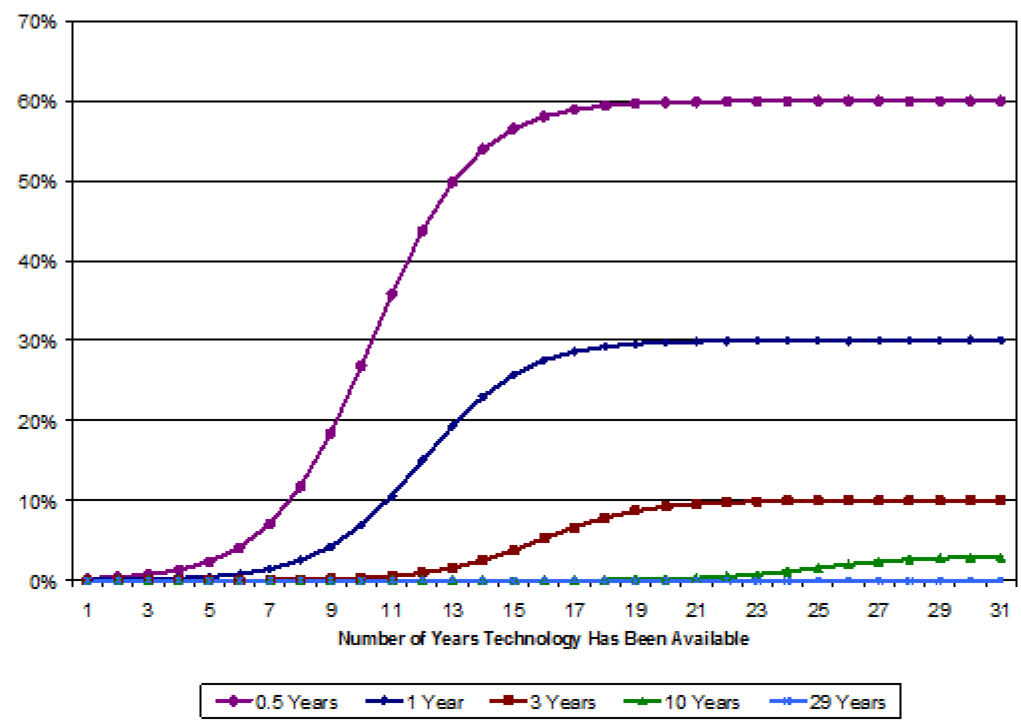
For a given value of $SimplePayBack_{t,n,l,y}$, penetration in NEMS model year *y* is an increasing function of y.

$$Pen_{t,n,l,y} = Inxdecay_{r,y} * \left[MaxPen_{t,n,l,y} - \frac{1}{\frac{1}{MaxPen_{t,n,l,y}} + e^{[\alpha_t * (y - RECSyear + 1 - SimplePayBack_{[t],[y]})]}} \right] \quad \text{(B-184)}$$

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

Figure 3 shows the logistic-shaped penetration function for a variety of years to achieve positive cumulative net cash flow:

Figure 3. 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 Demand Module and NEMS

Explicit recognition of the census-division dimension begins here. Refer to the variable descriptions in the *Distributed Generation Technologies* section of Appendix A: Input Parameters for variables not explicitly defined 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 (*ExogPen*) representing 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*) for the share of households in each niche (*xHHShare*):

$$Units_{y,r,t} = Units_{y-1,r,t} + \sum_{n,l \in r} \begin{bmatrix} \left(ExogPen_{y,r,t} - ExogPen_{y-1,r,t}\right) \\ +\left(Pen_{t,n,l,y} * HSEADD_{r,y} + DeltaPen_{t,n,l,y} * EH_{r,y}\right) \\ * xHHShare_{n,l} \end{bmatrix} \quad \text{(B-185)}$$

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

$$Trills_{y,r,t} = Trills_{y-1,r,t} + \sum_{n,l \in r} \begin{bmatrix} \left(ExogPen_{y,r,t} - ExogPen_{y-1,r,t}\right) \\ +\left(Pen_{t,n,l,y} * HSEADD_{r,y} + DeltaPen_{t,n,l,y} * EH_{r,y}\right) \end{bmatrix} * xHHShare_{n,l} * AnnualKWH_{t,n,l,y} * 3412 * 10^{12} \quad \text{(B-186)}$$

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

$$\begin{aligned} &TrillsOwnUse_{y,r,t} \\ &= TrillsOwnUse_{y-1,r,t} \\ &+ \begin{bmatrix} \sum_{n,l \in r} \begin{bmatrix} \left(ExogPen_{y,r,t} - ExogPen_{y-1,r,t}\right) \\ +\left(Pen_{t,n,l,y} * HSEADD_{r,y} + DeltaPen_{t,n,l,y} * EH_{r,y}\right) \end{bmatrix} \\ * xHHShare_{n,l} * MIN\langle AnnualKWH_{t,n,l,y}, RECSAvgKwh_{n,l}\rangle * 3412 * 10^{2} \end{bmatrix} \end{aligned} \quad \text{(B-187)}$$

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

$$\begin{aligned} FuelUsage_{y,r,t} &= FuelUsage_{y-1,r,t} \\ &+ \begin{bmatrix} \sum_{n,l \in r} \begin{bmatrix} \left(ExogPen_{y,r,t} - ExogPen_{y-1,r,t}\right) \\ +\left(Pen_{t,n,l,y} * HSEADD_{r,y} + DeltaPen_{t,n,l,y} * EH_{r,y}\right) \end{bmatrix} \\ * xHHShare_{n,l} * FuelInput_{r,t,y} * 10^{6} \end{bmatrix} \end{aligned} \quad \text{(B-188)}$$

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

$$HWBtu_{y,r,t} = HWBtu_{y-1,r,t} + \left[\sum_{n,l \in r} \left[\begin{array}{c} \left(ExogPen_{y,r,t} - ExogPen_{y-1,r,t}\right) \\ + \left(Pen_{t,n,l,y} * HSEADD_{r,y} + DeltaPen_{t,n,l,y} * EH_{r,y}\right) \end{array} \right] * xHHShare_{n,l} * WaterHtgMMBtu_{r,t,y} * 10^6 \right] \quad \text{(B-189)}$$

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

$$Invest_{y,r,t} = Invest_{y-1,r,t} + \left[\sum_{n,l \in r} \left[\begin{array}{c} \left(ExogPen_{y,r,t} - ExogPen_{y-1,r,t}\right) \\ + \left(Pen_{t,n,l,y} * HSEADD_{r,y} + DeltaPen_{t,n,l,y} * EH_{r,y}\right) \end{array} \right] * xHHShare_{n,l} * EqCost_{r,t,y} * kW_t * 10^6 \right] \quad \text{(B-190)}$$

Beginning with AEO2017, the cash-flow analysis for residential solar photovoltaic penetration has been superseded by an econometric hurdle rate adoption model using ZIP code-level input data. The *UseZipModel* variable in the RGENTK.TXT input file is used to switch between the hurdle rate adoption model and the cash-flow model for PV; the cash-flow model continues to be used for non-PV distributed generation technologies. Detailed information on how the econometric model was developed, the data it incorporates, and its functional forms is available in *Using Hurdle Models for Long-term Projections of Residential Solar Photovoltaic Systems Installations*.

The hurdle rate adoption model uses various ZIP code-level covariate data:

- Median household income, based on the U.S. Census Bureau's *American Community Survey* (ACS) and decennial census data
- Annual average solar irradiation (kWh per square meter per day), as estimated by NREL
- Retail electricity rate (cents per kWh)
- Number of households, based on the ACS and decennial census data
- Monthly payment per kW_{DC} of installed PV capacity, estimated based on the installed price of solar PV panels and the annual average mortgage interest rate in year *t*
- Population density (households per square mile), estimated by dividing the number of households in ZIP code *z* by the land area in ZIP code *z*
- Social spillover, which is represented as the lagged number of new installations observed in the previous year. This covariate is only used to model whether at least one solar installation will be observed; it is not used in modeling the number of installations

The model estimates the number of residential solar PV systems to be installed for each of the ZIP codes characterized in the RGENTK.TXT input file, starting in *EstYear,* as determined by ACS data availability. From RECSyear through *EstYear*, an additive factor, $ExogPVMistie_{r,y}$, is used as in (B-191) to calibrate total capacity by census division to historical exogenous PV capacity, $xexogpen_{t.r,y}$. $ExogPVMistie_{r,y}$ capacity is held constant from *EstYear* onward. The number of PV systems associated with

ExogPVMistie$_{r,y}$ is added to *Units*$_{y,r,t}$, and generation associated with *ExogPVMistie*$_{r,y}$ is shared out to *Trills*$_{y,r,t}$ and *TrillsOwnUse*$_{y,r,t}$.

$$ExogPVMistie_{r,y} = ExogPen_{r,y} - Capacity_{r,y} \quad \text{(B-191)}$$

where

ExogPVMistie$_{r,y}$ is the adjustment factor used to calibrate solar PV capacity,
ExogPen represents program-driven or historical capacity from RSGENTK.TXT, and
Capacity is the calculated capacity from the hurdle rate adoption model.

$$Capacity_{r,y} = Capacity_{r,y} + ExogPVMistie_{r,y} \quad \text{(B-192)}$$

$$Units_{y,r,t} = Units_{y,r,t} + \left(\frac{ExogPVMistie_{r,r}}{kW_{t,y}}\right) \quad \text{(B-193)}$$

where

kW$_{t,y}$ is the average solar PV system capacity from RSGENTK.TXT.

$$Trills_{y,r,t} = Trills_{y,r,t} + \left(\frac{ExogPVMistie_{r,y}}{kW_{t,y}}\right) * AnnualKWH_{t,z,l,y} * 3412 * 10^{12} \quad \text{(B-194)}$$

$$TrillsOwnUse_{y,r,t} = TrillsOwnUse_{y,r,t} + \left(\frac{TrillsOwnUse_{y,r,t}}{Trills_{y,r,t}}\right) * \left(\frac{ExogPVMistie_{r,t}}{kW_{t,y}}\right) * AnnualKWH_{t,z,l,y} * 3412 * 10^{12} \quad \text{(B-195)}$$

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. Division by 1,000,000 converts units from million Btu per year to trillion Btu per year. The factor *LEAPYR* in each equation takes on the value of 366/365 in near-term years (in other words, history and years up through the STEO benchmarking period); otherwise, it has the value of 1.

Natural gas (ng)

$$RSFLCN_{y,ng,r} = \frac{\begin{pmatrix} HTRCON_{y,ng,r} + H2OCON_{y,ng,r} + CKCON_{y,ng,b,r} + GASINPUT_{y,r} \\ +DRYCON_{y,ng,r} + COOLCN_{y,ng,r} + SHTCON_{y,ng,r} + APLCON_{y,ng,r} \end{pmatrix}}{1{,}000{,}000} * LEAPYR \quad \text{(B-196)}$$

Electricity (el)

$$RSFLCN_{y,el,r} = \frac{\begin{pmatrix} HTRCON_{y,el,r} + H2OCON_{y,el,r} + CKCON_{y,el,b,r} + REFCON_{y,r} \\ +DRYCON_{y,el,r} + COOLCN_{y,el,r} + SHTCON_{y,el,r} + APCCON_{y,r} \\ +FRZCON_{y,r} + CSWCON_{y,r} + DSWCON_{y,r} + LTCON_{y,r} \\ +SPACON_{y,r} + CFCON_{y,r} + CMCON_{y,r} + MOCON_{y,r} \\ +RCCON_{y,r} + HACON_{y,r} + SSCON_{y,r} + FANCON_{y,r} \\ +PCCON_{y,r} + TVCON_{y,r} - ANNUALKWH_{y} \end{pmatrix}}{1{,}000{,}000} * LEAPYR \tag{B-197}$$

Distillate fuel oil and kerosene (ds)

$$RSFLCN_{y,ds,r} = \frac{\left(HTRCON_{y,ds,r} + H2OCON_{y,ds,r} + SHTCON_{y,ds,r} + APLCON_{y,ds,r}\right)}{1{,}000{,}000} * LEAPYR \tag{B-198}$$

Propane (lpg)

$$RSFLCN_{y,lpg,r} = \frac{\begin{pmatrix} HTRCON_{y,lpg,r} + H2OCON_{y,lpg,r} + CKCON_{y,lpg,b,r} \\ +SHTCON_{y,lpg,r} + APLCON_{y,lpg,r} \end{pmatrix}}{1{,}000{,}0000} * LEAPYR \tag{B-199}$$

Wood (wd)

$$RSFLCN_{y,wd,r} = \frac{\left(HTRCON_{y,wd,r} + SHTCON_{y,wd,r}\right)}{1{,}000{,}000} * LEAPYR \tag{B-200}$$

National total (U.S.)

$$RSFLCN_{y,US} = \sum_{r,f} \left(RSFLCN_{y,f,r}\right) \tag{B-201}$$

RSBENCH (Benchmarking fuel consumption totals)

For historical years, the present year, and near-term future (through the current *Short-Term Energy Outlook* [STEO] horizon), fuel consumption totals are benchmarked to maintain consistency across EIA products. These products include the State Energy Data System (SEDS), which provides state totals (then aggregated to the census division level), and the *Monthly Energy Review* (MER), which provides national totals distributed to the census division levels based on the previous year's SEDS distribution. Fuel consumption levels in the Residential Demand Module are benchmarked to the specific values in these historical publications.

For near-term future years, national fuel consumption totals are intended to be within a reasonable percentage of the STEO values. Currently, 2% is considered reasonable, but occasionally a larger difference may be accepted for a specific fuel if warranted by inherent differences in modeling structures. Beyond the benchmarked period (that is, beyond the STEO horizon), the RDM provides an option to maintain these benchmark factors throughout the projection period. Benchmark factors may be additive, meaning the difference between the modeled fuel total and benchmarked fuel total is maintained throughout, or multiplicative, meaning the ratio is maintained throughout. Currently, all major residential fuels (electricity, natural gas, propane, and distillate fuel oil/kerosene) use additive benchmarking.

Because benchmarking factors must be attributed to certain end uses, the benchmark factors for natural gas, distillate fuel oil/kerosene, and propane are attributed to space heating. For electricity, the benchmark is applied to miscellaneous uses not specifically modeled, also known as *electric other*.

Appendix C: Bibliography

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Appendix D: Data Quality

The Residential Energy Consumption Survey (RECS) forms the basis of the historical housing stock, appliance stock, and technology information that drives the NEMS Residential Demand Module. Information about RECS methodology, data quality (including the kinds of errors associated with sample surveys), estimation of standard errors, and end-use consumption estimation are available on the EIA website. Data quality information pertinent to additional sources used in the module development is not available for this report.