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

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Office of Integrated Analysis and Forecasting
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UPDATE INFORMATION

This updated version of the NEMS Residential Module Documentation includes changes made to the residential module for the production of the *Annual Energy Outlook 1995*.

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1. Introduction

Purpose of this Report

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

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

Model Summary

The NEMS Residential Sector Demand Module is currently used for mid-term forecasting purposes and energy policy analysis over the forecast horizon of 1990-2010. The model generates forecasts of energy demand, which is used interchangeably with the concept of energy consumption in this document, for the residential sector by service, fuel, and Census Division. The policy impacts resulting from the introduction of new technologies, market incentives, and regulatory changes can be estimated using the module by defining alternate input and parameter assumptions.

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

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

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

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

Archival Media

At the time of this writing, the module has not yet been archived. The Residential Sector Demand Module will be archived upon completion of the Annual Energy Outlook for 1995 (AEO95) production runs, as part of the National Energy Modeling System on the Energy Information Administration's mainframe computer system.

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NEMS Residential Sector Demand Module Structure

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

Housing Stock Component

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

Technology Choice Component

The Technology Choice Component simulates the behavior of residential consumers based on the relative importance of life-cycle costs, capital costs, and operating costs of competing technologies within a service. New and replacement equipment decisions reflect additional factors beyond the traditional life-cycle cost methodology, including main space heating fuel choice and previous equipment choices. The Technology Choice Component allocates end-use services based upon a defined equipment menu of the various technologies and fuels that compete in the market. The Technology Choice Component also establishes the criteria upon which consumers base equipment choices.

Appliance Stock Component

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

Shell Integrity Component

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

Consumption and Unit Energy Consumption Component

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

Emissions Component

The Emissions Component estimates the amount of airborne pollution attributable to residential sector fuel use. Emissions of interest are those that cause adverse health effects, acid rain, or global climate change. The pollutants explicitly modeled are total carbon, carbon monoxide (CO), carbon dioxide (CO_2), nitrous oxides (NO_x), sulfur oxides (SO_x), and volatile organic compounds (VOC). The fuels for which the emissions are modeled exclude electricity, geothermal, and solar thermal, which are all assumed to have zero emissions.

Report Organization

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

Appendices to this report document the variables and equations contained in the FORTRAN source code. Appendix A catalogues the input data used to generate estimates and forecasts in list and cross-tabular formats. Appendix B provides support to the mathematical representation of the source code equations provided in Chapter 4 of the main text. Appendix C is a bibliography of reference materials used in the development process. Appendix D consists of a model abstract. Appendix E discusses the data quality issues. The mathematical properties of the solution algorithms will be presented in a separate volume to this report.

2. Model Purpose

Module Objectives

The NEMS Residential Sector Demand Module holds three fundamental objectives. First, the module generates disaggregated forecasts of energy demand in the residential sector for the period of 1990-2010 by housing and fuel type, Census Division, and end-use service. Second, it is a policy analysis tool that is capable of assessing the impacts of changes in energy markets, building and equipment technologies, and regulatory initiatives affecting the residential sector. Third, as an integral component of the NEMS system, it provides inputs to the Electricity Market Module, Natural Gas Supply Module, and Petroleum Market Module of NEMS, facilitating the development of an energy supply and demand balance in the system.

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

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

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

Module Input and Output

Inputs

THE PRIMARY MODULE INPUTS INCLUDE FUEL PRICES, HOUSING STOCK CHARACTERISTICS, HOUSING STARTS, POPULATION, AND TECHNOLOGY CHARACTERISTICS. THE TECHNOLOGY CHARACTERISTICS USED IN THE MODULE INCLUDE INSTALLED CAPITAL COSTS, EQUIPMENT EFFICIENCY, AND EXPECTED EQUIPMENT LIFETIMES. THE MAJOR INPUTS BY MODULE COMPONENT ARE AS FOLLOWS:

HOUSING STOCK COMPONENT

- HOUSING STARTS
- EXISTING HOUSING STOCK FOR 1990
- HOUSING STOCK ATTRITION RATES

TECHNOLOGY CHOICE COMPONENT

- EQUIPMENT CAPITAL COST
- EQUIPMENT ENERGY EFFICIENCY
- MARKET SHARE OF NEW APPLIANCES
- EFFICIENCY OF RETIRING EQUIPMENT
- APPLIANCE PENETRATION FACTORS

APPLIANCE STOCK COMPONENT

- EXPECTED EQUIPMENT MINIMUM AND MAXIMUM LIFETIMES
- BASE YEAR APPLIANCE MARKET SHARES

Equipment saturation level

Building Shell Component

Maximum level of shell integrity

Price elasticity of shell integrity

Rate of improvement in new construction shell integrity

Energy Consumption Component

Unit energy consumption (UEC)

Heating and cooling degree days

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

Household size

Emissions Component

Base year airborne emission factors by pollutant

Outputs

Forecasted residential sector energy consumption by fuel type, service, and Census Division is the primary module output. The module also forecasts housing stock, energy consumption per household, and airborne emissions by pollutant for the six pollutant categories listed previously. In addition, the module is capable of producing a disaggregated forecast of appliance stock and efficiency. The types of appliances included in this forecast are:

Heat pumps (electric, natural gas, and geothermal)

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

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

Wood stoves

Central air conditioners

Room air conditioners

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

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

Clothes dryers (electric and natural gas)

Refrigerators

Freezers

Variable Classification

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

Census Divisions

1 New England

2 Middle Atlantic

3 East North Central

4 West North Central

5 South Atlantic

6 East South Central

7 West South Central

8 Mountain

9 Pacific

Housing Types

1 Single-Family

2 Multifamily

3 Mobile Home

End-Use Services

1 Space Heating

2 Space Cooling

3 Water Heating

4 Cooking

5 Clothes Drying

6 Refrigeration

7 Freezing

8 Lighting

9 Other Appliances

10 Secondary Space Heating

Fuels

1 Natural Gas

2 Electricity

3 Distillate

4 LPG

5 Kerosene

6 Geothermal

7 Wood

8 Coal

9 Solar Thermal

Relationship to Other Models

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

3. Model Rationale

Theoretical Approach

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

The Residential Sector Demand Module is a housing and equipment stock model. The stock of households and the corresponding energy consuming equipment are tracked for each year of the forecast. The housing stock changes each forecast year as houses are retired from the stock and new construction is added. The equipment stock changes each forecast year as appliances fail and are replaced, and new technologies enter the market. A logit function is used to estimate the market share of competing technologies within each service category. Market shares are determined for new construction equipment decisions as well as for replacement decisions. The Technology Choice Component of the module weights the relative installed capital and operating costs of each equipment type to allocate the relative market share of the technology within the service, region, and housing type. This approach is implemented for the services of space heating, space cooling, water heating, refrigeration, freezers, cooking, and clothes drying. Lighting and miscellaneous equipment choices are modeled based upon alternate technology assumptions discussed below.

Base year information developed from the 1990 RECS data base forms the foundation of modeling changes to the equipment and housing stock over the forecast period. Market share information from RECS is used to estimate the number and type of replacements and additions to the equipment stock. The choice between the capital cost and the first year's operating cost determines the market share within a given service. Market shares are also modeled as functions of the corresponding fuel prices, expected level of equipment usage, and equipment efficiency characteristics.

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

Fundamental Assumptions

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

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

- With the exception of space heating, equipment types are assumed to be replaced by the same equipment types that were retired.

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

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

- Two housing vintages are assumed: pre-1991 (old housing) and post-1990 (new housing).

- The type of fuel used for cooking and water heating in new housing units is assumed to be a function of the main space heating fuel in most cases. Exceptions to this assumption are included for specific cooking fuel decisions. It is assumed that 63% of new housing units are equipped with natural gas cooking units, while natural gas is the main space heating fuel.

- Housing units are removed from the housing stock at a constant rate over time. The survival rates for housing stock types are assumed to be 99.5% for single-family homes, 99.0% for multi-family homes, and 96.1% for mobile homes.

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

Further Assumptions

Technology Choice

The efficiency choices made for residential equipment are based on a logit function. The functional form is flexible allowing the user to specify parameters as either life-cycle costing, or a weighting of bias, capital and discounted operating costs. Currently, the module calculates choices based on the latter approach.

Climate Adjustment

Space conditioning usage is adjusted across Census Divisions by heating and cooling degree day factors to account for the unusually warm winter during the RECS 1990 survey performance period.

Space Heating Fuel Switching

The space heating algorithm of the module permits fuel switching for replacement decisions for electric, natural gas, LPG, wood, and distillate equipment. The amount of switching depends upon the region and fuel type based on analysis of RECS and the American Gas Association's *Residential Natural Gas Market Survey: 1992*. The module is programmed to shift toward natural gas space heating and away from other fuels as they are replaced.

Space Cooling: Room and Central Air Conditioning Units

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

Water Heating: Solar Water Heaters

Market shares for solar water heaters are tabulated from the 1990 RECS data base. The module currently assumes that solar energy provides 55% of the energy needed to satisfy hot water demand, and the remaining 45% is satisfied by an electric back-up unit.

THROUGH-THE-DOOR REFRIGERATION UNITS

A RECENT INNOVATION IN RESIDENTIAL REFRIGERATION UNITS HAS BEEN THE ADVANCEMENT OF THROUGH-THE-DOOR ACCESS PANELS FOR ICE AND WATER. THIS ADDED CONVENIENCE RESULTS IN A GREATER ENERGY USE THAN CONVENTIONAL REFRIGERATOR MODELS. THE RESIDENTIAL SECTOR DEMAND MODULE ASSUMES THAT 22% OF ALL POST-1990 REFRIGERATORS INCORPORATE THE THROUGH-THE-DOOR ACCESS FEATURE, BASED UPON RECENT APPLIANCE SHIPMENT DATA.[1]

CLOTHES DRYER SATURATION

THE MODULE CURRENTLY ASSUMES THAT CLOTHES DRYER MARKET PENETRATION OCCURS OVER THE FORECAST PERIOD, WITH A TERMINAL SATURATION LEVEL THAT IS CONSISTENT WITH THE MARKET PENETRATION OF CLOTHES WASHERS. THIS ASSUMPTION IS BASED UPON ANALYSIS OF THE RECS DATA BASE.

LIGHTING

THREE TYPES OF LIGHTING TECHNOLOGY CHARACTERIZATIONS BASED ON EFFICIENCY ARE INCLUDED IN THE MODULE. MARKET SHARES ARE ASSUMED FOR EACH TYPE OF LIGHTING FOR 1990 (THE BASE YEAR), 2000, AND 2010.

OTHER APPLIANCES

THE CONSUMPTION OF OTHER APPLIANCES BY CENSUS DIVISION IS CALCULATED BY MULTIPLYING THE SUM OF NEW AND EXISTING HOUSING UNITS BY UNIT ENERGY CONSUMPTION (UEC), HOUSING TYPE, AND CENSUS DIVISION.

SECONDARY HEATING

THE CONSUMPTION OF SECONDARY HEATING FUELS IS DETERMINED BY THE SHARE OF TOTAL HOUSING THAT USES A SECONDARY HEATING FUEL MULTIPLIED BY THE UEC ADJUSTED FOR THE SHELL INTEGRITY.

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[1] Association of Home Appliances Manufacturers, "Refrigerators: Energy Efficiency and Consumption Trends," Chicago, IL, August, 1993.

Alternative Approaches

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

Housing Stock

The Residential End-use Energy Planning System (REEPS) model[3] developed by the Electric Power Research Institute (EPRI) and DRI/McGraw-Hill's (DRI) Macroeconomic model[4] also forecast domestic housing stock. The DRI equation for housing stock assumes that 1.6 percent of housing starts per year do not get counted into the housing stock. This assumption attempts to capture completion failures. The Bureau of the Census also predicts household formation based on a complex regression with numerous demographic variables.

Appliance Stock

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

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

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

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

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

REEPS TRACKS THE CAPITAL STOCK OF ENERGY-USING TECHNOLOGIES USING A METHOD SIMILAR TO THE METHOD PROPOSED HERE. THE GRI ENERGY MODEL[6] ALSO TRACKS THE CAPITAL STOCK OF MAJOR RESIDENTIAL APPLIANCES IN ORDER TO FORECAST RESIDENTIAL ENERGY CONSUMPTION.

TECHNOLOGY CHOICE

THE TECHNOLOGY CHOICE COMPONENT OF THE NEMS RESIDENTIAL SECTOR DEMAND MODULE REQUIRES EXTENSIVE DATA DESCRIBING END-USE TECHNOLOGIES. EQUIPMENT COSTS, EFFICIENCY LEVELS, AND OTHER CHARACTERISTICS MUST BE SPECIFIED FOR ALL TECHNOLOGIES MODELED. THESE DATA ARE AVAILABLE FROM DEPARTMENT OF ENERGY SOURCES[7], LAWRENCE BERKELEY LABORATORY (LBL)[8] STUDIES, ENGINEERING ANALYSES PERFORMED BY ARTHUR D. LITTLE (ADL)[9], GAS RESEARCH INSTITUTE (GRI)[10] RESEARCH, ELECTRIC POWER RESEARCH INSTITUTE (EPRI)[11], GAS APPLIANCE MANUFACTURING ASSOCIATION (GAMA)[12], ASSOCIATION OF HOME APPLIANCE MANUFACTURERS (AHAM), THE AIR CONDITIONING AND REFRIGERATION INSTITUTE

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

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

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

[9] Arthur D. Little, "Technical Memorandum for Technology Advances and Forecasts-Residential/Commercial End-Use Equipment," Cambridge, MA, 1990.

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

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

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

(ARI)[13], AND NUMEROUS TRADE PUBLICATIONS.

REEPS SIMULATES CONSUMER CHOICE BASED ON THE CONSUMER'S EVALUATION OF CERTAIN EQUIPMENT ATTRIBUTES (SUCH AS CAPITAL COST AND ENERGY EFFICIENCY), WITH THE CHOICE OF A PARTICULAR UNIT EXPRESSED AS A PROBABILITY OF THE CONSUMER CHOOSING THAT UNIT. THIS PROBABILITY IS BASED ON EMPIRICAL ESTIMATION REFLECTING OBSERVED TRENDS IN THE HOME APPLIANCE MARKET DESCRIBED IN HOME APPLIANCE TRADE PUBLICATIONS.

SHELL INTEGRITY

THE EPRI, LBL, AND GRI MODELS ACCOUNT FOR ENERGY CONSERVATION THROUGH SHELL RETROFIT. EPRI'S REEPS AND LBL'S REM MODELS BOTH USE A SOPHISTICATED APPROACH TO ACCOUNT FOR SHELL RETROFITS. THE REEPS MODEL GROUPS DIFFERENT RETROFITS INTO SEVERAL LEVELS, WITH EACH LEVEL ASSIGNED A DIFFERENT COST AND ENERGY SAVINGS. OVER TIME, HOUSING STRUCTURES CHOOSE BETTER COMBINATIONS OF SHELL ATTRIBUTES, CAUSING A SAVINGS IN ENERGY CONSUMPTION. THE DECISION PROCESS IS SIMULATED BY A LOGIT FUNCTION THAT WEIGHS PARAMETERS SUCH AS FIRST COST, ENERGY SAVINGS, AND DISCOUNT RATE. THE LBL MODEL USES CONSERVATION SUPPLY CURVES TO DESCRIBE THE TRADE-OFF BETWEEN INVESTMENT IN DIFFERENT SHELL MEASURES AND THE ENERGY SAVINGS ASSOCIATED WITH THEM. THE CHOICE TO RETROFIT DEPENDS ON THE COST OF CONSERVED ENERGY. IF THE RETROFIT OPTION SAVES MORE MONEY THAN IT COSTS, THE OPTION IS SELECTED. THE GRI MODEL ASSUMES AN EXOGENOUS RATE OF ANNUAL IMPROVEMENT.

REASONS FOR SELECTING THE NEMS RESIDENTIAL SECTOR DEMAND MODULE APPROACH

Execution time and memory requirements established in the design stage of the NEMS model development effort contribute to the ultimate design of the Residential Sector Demand Module. The component approaches for modeling housing stock, appliance stock, technology choice, and

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

shell integrity are designed in a modular fashion to facilitate enhancements to each component design. The module design draws upon aspects of the REEPS, DRI, and GRI models discussed above, attempting to enhance previous modeling methodologies but retaining as much simplicity as possible in the modeling approach. The current module design is flexible enough to lend itself to further enhancement in all components.

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

1) Inability to track appliances through time,
2) Projections were generated for only four Census regions (Northeast, South, Midwest, and West),
3) Only six fuel types and six services were considered,
4) Did not incorporate consumer choice parameters in the technology choice module,
5) Technology choice methodology was limited to a life-cycle cost approach,
6) Did not produce energy consumption forecasts for each service by fuel type,
7) Did not forecast airborne emissions,
8) Did not explicitly include dispersed renewable technologies, and
9) Did not account for weather effects.

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

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

4. Model Structure

Structural Overview

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

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

Housing Stock Forecast

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

- Single-Family Homes
- Multifamily Homes
- Mobile Homes

Technology (Equipment) Choice

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

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

Appliance Stock Forecast

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

- Space Heating
- Water Heating
- Freezers
- Cooking
- Space Cooling
- Refrigeration
- Clothes Dryers

Building Shell Integrity

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

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

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

Space Heating Equipment
Electric Furnace
Electric Heat Pump
Natural Gas Furnace
Natural Gas Other (Hydronic)
Kerosene Furnace
LPG Furnace
Distillate Furnace
Distillate Other (Hydronic)
Wood Stove
Geothermal Heat Pump
Natural Gas Heat Pump

Space Cooling Equipment
Electric Room Air Conditioner
Central Air Conditioner
Electric Heat Pump
Geothermal Heat Pump
Gas Heat Pump

Hot Water Heaters
Solar Thermal
Natural Gas
Electric Resistance
Distillate
LPG

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

Freezers
Chest Manual Defrost
Upright Manual Defrost

Lighting
Incandescent

Energy Consumption

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

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

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

2. Pre-1991 vintage equipment stock is estimated, accounting for housing demolitions and additions.

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

4. The previous year's equipment additions and replacements for both pre-1991 and post-1990 vintage are determined based on the current year market share.

5. Efficiencies weighted by market share are calculated.

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

Flow Diagrams

This section includes flow diagrams representing the structure of the NEMS Residential Sector Demand Module. Figure 1 presents the overall sequential structure. Figure 2 illustrates the Housing Stock Component flow. Figure 3 provides the flow of the Appliance Stock

Component. The Technology Choice Component flow is represented in Figure 4, and the Consumption and UEC Component flow is provided in Figure 5.

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

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

Figure 3 illustrates the Appliance Stock Component of the module. The base year existing stock of major household appliances is derived from analysis of the RECS 1990 data. Appliance retirements are determined based upon the minimum and maximum equipment lifetime assumptions discussed in the Fundamental Assumptions section of this report. Additions to the appliance stock are calculated in this component, as is the surviving stock of equipment.

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

Figure 5 illustrates the Consumption and UEC Component of the module. This component utilizes the base year UEC information developed from the RECS data, the technology selection information developed previously, building shell integrity, household size, and heating- and cooling-degree day effects to determine end-use consumption.

Figure 1. NEMS Residential Sector Demand Module Basic Structure

Figure 2. Housing Stock Component Flow

Figure 3. Appliance Stock Component Flow

Figure 4. Technology Choice Component Flow

Figure 5. Consumption and UEC Component Flow

FORTRAN Code Subroutine Process Description

The NEMS Residential Sector Demand Module FORTRAN source code consists of more than 50 subroutines sequentially called during the execution of the module. Table 2 lists the major subroutines and their corresponding descriptions. The subroutines can be grouped into the following 12 categories according to their functions:

1) Fuel Price Subroutines (2)

The code includes the following two subroutines for reading and printing fuel prices:

RDPR reads in fuel prices from the NEMS system.

PRTPR print fuel prices

2) Initialization Subroutines (2)

The code includes the following two subroutines for initialization purposes:

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

ISHLEFF initializes the housing shell integrities for new and existing housing.

3) Housing Subroutines (2)

The code includes the following two subroutines to assess housing stocks:

EXHSE initializes the existing housing or the pre-1991 vintage of housing. It then applies the housing decay function to these values to compute the surviving stock of housing of the pre-1991 vintage in every year in the forecast.

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

4) Existing Equipment - RD Subroutines (10)

The code includes eight subroutines that read and project pre-1991 (existing) vintage equipment by service. In each of these subroutines, the following operations are performed:

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

2. The base year equipment stock or the pre-1991 vintage stock is determined by multiplying the share by the amount of existing housing.

3. Surviving equipment of the pre-1991 vintage is forecasted using the equipment survival rate and the housing decay rate for every year in the forecast.

These subroutines are as follows:

RDHTEQT
RDTEQT
RDHWEQ
RDCKEQ
RDDRYEQ
RDRFEQ
RDFZEQT
RDCLEQT
RDEFF

RDRET

5) Technology Choice - TEC Subroutines (8)

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

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

These subroutines are as follows:

HTRTEC

RACTEC

CACTEC

H2OTEC

CKTEC

DRYTEC

REFTEC

FRZTEC

In addition to the TEC subroutines, the LTCNS subroutine assigns market shares to the different lighting technologies.

6) Replacements and Additions - ADD Subroutines

The code contains seven equipment replacement and additions subroutines. The TEC subroutines for each service are followed by "ADD" subroutines that calculate the new and replacement equipment for the previous year based on the resultant current year's market share. The following steps are implemented in these subroutines:

1. The post-1990 vintage equipment additions are determined by the share of new (post-1990) houses from the MAM that demand that service.

2. Compute the surviving post-1990 vintage equipment in pre-1991 vintage houses.

3. Compute total equipment required for pre-1991 vintage houses.

4. Compute the equipment replacements in pre-1991 vintage houses by subtracting the surviving pre-1991 vintage equipment and the surviving post-1990 vintage equipment in the pre-1991 vintage houses from the total equipment demanded for pre-1991 vintage houses.

5. Compute the surviving post-1990 vintage equipment that were purchased as either additions or replacements for post-1990 houses.

6. Calculate the current year's replacements of post-1990 vintage equipment in post-1990 houses by subtracting the surviving replacements and equipment additions in post-1990 housed from the stock of surviving post-1990 houses.

These subroutines are as follows:

HADD

WADD

SADD

DADD

COOLAD

FADD

ZADD

7) End-use Consumption - CNS Subroutines (11)

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

HTCNS

CLCNS

HWCNS

CKCNS

DRYCNS

RFCNS

FZCNS

LTCNS

APCNS

SHTCNS

APPCNS

8) Emissions Subroutine (1)

The emissions from the residential sector are calculated in the **IRSEM** subroutine using the quantities of fuel and exogenous emissions factors.

9) EPACT Subroutine (1)

The model includes a subroutine identified as **EPACTWD** to estimate the EPACT window labeling impact.

10) Overall Consumption - CN Subroutines (2)

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

FUELCN	calculates fuel consumption
NEMSCN	Output NEMS consumption

11) Historical Consumption/Calibration Subroutines (2)

The code includes the following three subroutines to determine historical energy consumption and to calibrate to the historical SEDS values:

EXCONS	calculate 1990 consumption
SDCONS	calibrate UEC's to SEDS 1990 consumption
RSBENCH	calibrate consumption to 1991-1994 SEDS consumption

12) Report Subroutines (7)

The following seven subroutines produce the output reports:

PRTNEM

PRSEM

NMSRPT1

NMSRPT2

RESDRP

RESDRP2

HSERPT

Table 3. Primary NEMS Residential Sector Demand Module Subroutines, p. 1

SUBROUTINE NAME	DESCRIPTION OF THE SUBROUTINE
RDPR	READS PRICES
INTEQT	INITIALIZE HEATING EQUIPMENT MARKET SHARE
EXHSE	INITIALIZE EXISTING HOUSES; PROJECT
RDHTEQT	PROJECT 1990 VINTAGE HEATING EQUIPMENT
RDCLEQT	PROJECT EXISTING COOLING EQUIPMENT
RDHWEQ	PROJECT EXISTING HOT WATER HEATING EQUIPMENT
RDFZEQT	PROJECT EXISTING FREEZER EQUIPMENT
RDDRYEQ	PROJECT EXISTING CLOTHES DRYER EQUIPMENT
RDCKEQ	PROJECT EXISTING COOKING EQUIPMENT
RDRFEQ	PROJECT EXISTING REFRIGERATORS
RDUECS	INITIALIZE EQUIPMENT UECS (SERVICE AGGREGATES)
EXCONS	CALCULATE 1990 CONSUMPTION
ISHLEFF	INITIALIZE SHELL INTEGRITY
SDCONS	CALIBRATE TO SEDS 1990 CONSUMPTION
NEWHSE	CALCULATE NEW HOUSING.
H2OTEC	CHOOSE WATER HEATING EQUIPMENT
WADD	CALCULATE NEW WATER HEATING EQUIPMENT ADDITIONS AND REPLACEMENTS
HWCNS	CALCULATE CONSUMPTION FOR HOT WATER HEATING
CKTEC	CHOOSE COOKING EQUIPMENT
SADD	CALCULATE NEW AND REPLACEMENT STOVES
CKCNS	CALCULATE CONSUMPTION FOR COOKING
DRYTEC	CHOOSE DRYER EQUIPMENT
DADD	CALCULATE NEW AND REPLACEMENT DRYERS
DRYCNS	CALCULATE CONSUMPTION FOR DRYERS

Table 3. Primary NEMS Residential Sector Demand Module Subroutines, p. 2

Subroutine Name	Description of Subroutine
RDEFF	Read in efficiency of retiring equipment from 1990 stock
RDRET	Read in proportion of retiring equipment from 1990 stock
HTRTEC	Choose heating equipment and compute average efficiencies
HADD	Calculate new and replacement heating equipment
HTCNS	Calculate heating consumption
RACTEC	Choose room air-conditioning equipment and compute average efficiencies
CACTEC	Choose central air-conditioning equipment and compute average efficiencies
COOLAD	Calculate new and replacement cooling equipment
CLCNS	Calculate cooling consumption
REFTEC	Choose refrigeration equipment
FADD	Calculate new and replacement refrigerators
RFCNS	Calculate energy consumption for refrigerators
FRZTEC	Choose freezer equipment
ZADD	Calculate new and replacement freezer equipment
FZCNS	Calculate consumption by freezers
LTCNS	Calculate lighting consumption
APCNS	Calculate consumption for other appliances
SHTCNS	Calculate consumption for secondary heating
APPCNS	Calculate appliance consumption
FUELCN	Calculate fuel consumption
RSBENCH	Calibrate consumption to benchmark values
PRTNEM	Output NEMS consumption values
PRSE	Output emissions

Key Computations and Equations

This section presents the detailed calculations used in each of the module components. The calculations will be couched in terms of the space heating end use because it provides the best examples for generalization. Calculations for other end uses follow the space heating pattern, but different variable names are applied. For more detail refer to Appendix B, where calculations are provided at the subroutine level. Table 4 shows the correspondence between the subscript in the documentation and the subscripts in the FORTRAN source code. All variables appearing in the equations are cross-referenced and fully defined in Appendix A, Table A-1.

Table 4. Definition of Subscripts

Subscript in Documentation	Subscript in the FORTRAN Code
r	D or R, refers to Census Division
t	Y, when Y is a year increment
f	F, fuel types
b	B, housing type
y	Y, YR, or Y1, the annual index
p	P, pollutant
eg	E, general equipment type
es	E2, specific equipment type

Please note the following conventions:

- The above table of subscripts includes all of the major usages. In some minor instances, additional subscripts are defined as needed.
- The equations follow the logic of the FORTRAN code very closely to facilitate an understanding of the code and its structure. In several instances, a variable will appear on both sides of an equation. This is a FORTRAN programming device which allows a previous calculation to be updated (for example, multiplied by a factor) and re-stored

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

- The subscript, y, in the documentation refers to the year represented as 1990 through 2010. In the FORTRAN code, the subscripts for Y, YR and Y1 represent array dimensions starting with an index of 1 to represent 1990 (in some cases, the array index of 1 represents 1991 as explained below). Not all arrays begin with an array position for 1990. Specifically, the arrays representing and relating to equipment added after the 1990 base year begin with the first array position representing 1991 to economize on memory storage.
- Some variables are documented as having a "y" dimension when in fact they do not. The most common instances are for the variables, LFCY, OPCOST, SA, SHARESN, and SHARESR. These variables are calculated on an annual basis, but are retained only for the current year. The "y" dimension is used in the documentation to highlight 1) that the calculations do vary by year, and 2) to indicate the current year in formulae to avoid confusion.
- Summations which take place over all relevant variables will usually be written without upper and lower range limits on the summation.
- Unless otherwise stated, the range of y for an equation is 1991 through 2010.

Housing Stock Component

The Housing Stock Component tracks the number of existing dwellings by adding newly built homes to the inventory and subtracting demolitions. Housing construction starts are obtained from regional outputs of the MAM. Existing base year housing stock is designated as the "pre-1991" vintage, and new additions to the housing stock are referred to as the "post-1990" vintage. Additions and replacements for both housing vintages are tracked through the forecast period.

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

Single-Family Homes: 0.995 = HDR_1

Multifamily Homes: 0.990 = HDR_2

Mobile Homes: 0.961 = HDR_3

The surviving 1990 housing stock is defined by

$$
\begin{aligned}
EH_{y,b,r} &= RECS\ data, && \text{if } y = 1990 \\
EH_{y,b,r} &= EH_{y-1,b,r} * HDR_b, && \text{if } y > 1990
\end{aligned}
\qquad \textbf{(1)}
$$

where,

$EH_{y,b,r}$ is 1990 housing stock surviving by year, housing type and Census Division.

Technology Choice Component

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

The seven major services modeled are:

Space Heating
Space Cooling
Water Heating
Cooking
Clothes Drying
Refrigeration
Freezers

Lighting and other appliance decisions are modeled differently from the major services listed above.

Equipment operating costs are computed by the expression,

$$OPCOST_{y,es,b,r} = PRICES_{f,r,y} \times HTUEC_{r,eg,b} \times \left(1 + \frac{\frac{1}{EFF_{es}} - \frac{1}{BASEFF_{eg}}}{\frac{1}{BASEFF_{eg}}} \right) \quad \textbf{(2)}$$

where,

$OPCOST_{y,es,b,r}$	is the operating cost for the specific equipment type by year, housing type, and Census Division,
$PRICES_{f,r,y}$	is the fuel prices for the equipment by fuel, by region and forecast year,
$HTUEC_{r,eg,b}$	is the unit energy consumption by Census Division, general equipment type and housing type,
EFF_{es}	is the specific equipment efficiency,
$BASEFF_{eg}$	is the 1990 stock-average efficiency.

The consumer is allowed to choose among the various levels of cost and efficiency for a given piece of equipment. Specific equipment (denoted by es) refers to the same type of equipment with different efficiency ratings (e.g., high vs low efficiency heat pumps). General equipment (denoted by eg) refers to the type of equipment (e.g., heat pumps).

The module includes the option of using life-cycle costing to calculate market share weights using a logit function. The life cycle cost calculation is,

$$LFCY_{y,es,b,r} = CPCOST_{es} + OPCOST_{y,es,b,r} \times \left[\frac{1 - (1 + DISRT)^{-HO}}{DISRT} \right] \quad \textbf{(3)}$$

where,

$LFCY_{y,es,b,r}$	is the life cycle cost of specific equipment by forecast year,

housing type, and census division,

$CPCOST_{es}$ is the installed capital cost of the equipment by specific equipment type,

$HORIZON$ is the number of years into the future that is used to compute the present value of future operating cost expenditures presently set to seven years, and

$DISRT$ is the discount rate applied to compute the present value of future operating costs presently at 20 percent.

A weight for each general equipment type is calculated to estimate the market share for each of the 11 heating systems for new construction based on the cost factors computed above, base year Census construction data, and the bias. The functional form is expressed as,

$$HEATSYS_{y,eg,b,r} = e^{[\ BIAS_{eg} + \beta_g \times LFCY_{eg}\ ]} \qquad \textbf{(4)}$$

where,

$HEATSYS_{y,eg,b,r}$ is the equipment weight for general heating equipment for new housing by year, housing type, and Census Division,

$BIAS_{eg}$ is a consumer preference parameter that fits the current market share to historical shipment data,

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

β_g is a parameter value of the logit function.

Summing over the general equipment types computes the total weight for the general equipment types:

$$SYSTOT_{y,b,r} = \sum_{eg=1}^{eg=11} HEATSYS_{y,eg,b,r} \qquad \textbf{(5)}$$

where,

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

The general equipment fuel share is computed by

$$HSYSWGT_{y,eg,b,r} = \begin{pmatrix} \frac{HEATSYS_{y,eg,b,r}}{SYSTOT_{y,b,r}} & , \ SYSTOT_{y,b,r} > 0 \\ 0 & , \ otherwise \end{pmatrix} \qquad \textbf{(6)}$$

where,

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

A weight for each specific equipment type is calculated based on the cost factors computed above and the bias. The functional form is expressed as,

$$EQWTN_{y,es,b,r} = e^{[\ BIAS_{es} + \beta_1 \times CPCOST_{es} + \beta_2 \times OPCOST_{y,es,b,r} + \beta_3 \times LFCY_{y,es,}} \textbf{(7)}$$

where,

$EQWTN_{y,es,b,r}$	is the equipment weight for new specific equipment by year, housing type, and Census Division,
$BIAS_{es}$	is a consumer preference parameter that fits the current market share to shipment data,
$CPCOST_{es}$	is the installed capital cost for the specific equipment type,
$OPCOST_{y,es,b,r}$	is the operating cost for the specific equipment type by year, housing type, and Census Division,
$LFCY_{y,es,b,r}$	is the life cycle cost for the specific equipment type by year,

housing type, and Census Division, and

$\beta_1, \beta_2, \beta_3$ are parameter values of the logit function.

Summing over the specific equipment types computes the total weight for the general equipment types:

$$TOTEWTN_{y,eg,b,r} = \sum_{es=low\ eff}^{hi\ eff} EQWTN_{y,es,b,r} \qquad \textbf{(8)}$$

where,

$TOTEWTN_{y,eg,b,r}$ is the sum of specific equipment weights for the new general equipment type.

The specific equipment fuel share is computed by

$$EQFSHRN_{y,es,b,r} = \begin{pmatrix} \frac{EQWTN_{y,es,b,r}}{TOTEWTN_{y,eg,b,r}} & , TOTEWTN_{y,eg,b,r} > 0 \\ 0 & , otherwise \end{pmatrix} \qquad \textbf{(9)}$$

where,

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

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

$$_{,es,b,r} = EQFSHRN_{y,es,b,r} \times \Bigg(HSYSSHR_{1991,eg,b,r} \times \frac{HSYSW}{HSYSW(} \qquad \textbf{(10)}$$

where,

$NHTRSHR_{y,es,b,r}$	is the new market share for the specific equipment type by year, housing type, and Census Division, and
$HSYSSHR_{y,eg,b,r}$	is the base year market share of the general equipment type by year, housing type, and Census Division.

The new weighted equipment efficiencies are then computed as,

$$HEFFN_{y,eg,b,r} = \begin{cases} \dfrac{\sum_{es}\left[\dfrac{NHTRSHR_{y,es,b,r}}{EFF_{y,eg}}\right]}{\sum_{es} NHTRSHR_{y,es,b,r}} & , \sum_{es} NHTRSHR_{y,es,b,r} \\ \dfrac{1}{BASEFF_{eg}} & , \textit{otherwise} \end{cases} \quad \textbf{(11)}$$

where,

$WTHEFFN_{y,eg,b,r}$	is the new weighted equipment efficiency for each general equipment type 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.

Heading Equipment, UEC and Housing Shell Accounting Scheme

The above representation depicts the equipment accounting methodology. The subscripting of the variables is not included for simplicity, but will be explained below. The equipment accounting system partitions equipment into two major categories depending on the vintage of the housing unit: equipment installed in housing units which existed in 1990 (at the beginning of the 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 which survives, equipment purchased to replace other equipment, and equipment purchased for new construction. The categorization of equipment by housing vintage and surviving/replacement type results in six categories of equipment that are tracked.
The equipment categories for existing housing units are:

HTESE denotes the surviving 1990 equipment stock,

HTSR90 represents equipment from the 1990 stock which has been replaced after 1990 and which still survives, and

HTRP90 is current-year replacement equipment for 1990 housing.

For housing units added after 1990:

HTRSUR denotes equipment which has been modeled as added and still survives,

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

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

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

HTUEC is the average UEC for surviving equipment in housing units which existed in 1990,

HAUEC is the average UEC for surviving equipment in housing units added after 1990,

HRUEC is the UEC for all equipment added in the current year to replace 1990 equipment, and

HNUEC is the UEC for all equipment added in the current year for homes constructed after 1990.

Shell indices are modeled for three categories of housing units:

EHSHELL is the shell index applicable to housing units existing in 1990,

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

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

For example, in accounting for the heating energy consumption of surviving equipment installed in housing units which existed in 1990, the equipment stock, HTESE, would be multiplied by the unit energy consumption, HTUEC, and by the shell index EHSHELL. This explanation was designed for accounting for heating equipment, but the accounting principle is used throughout the residential module. For the existing housing example above, the appropriate space cooling variables would be CLESE, CLUEC and ECSHELL. The shell indices apply only to heating and cooling, thus, for example for refrigeration the accounting requires only RFESE and RFUEC.

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

$$RTE_{y-t,L_{\min},L_{\max}} = \begin{cases} y-t \leq L_{\min}: 1.0 \\ L_{\min} < y-t < L_{\max}: 1.0 - \left(\dfrac{y-t - L_{\min}}{L_{\max} - L_{\min}} \right) \\ y-t \geq L_{\max}: 0.0 \end{cases} \quad \textbf{(12)}$$

where,

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

Equipment in post-1990 (new) houses is calculated by multiplying the new houses by the market share of general equipment. This is expressed as,

$$HTRADD_{y,eg,b,r} = HSEADD_{y,b,r} \times SHARESN_{y,eg,b,r} \quad \textbf{(13)}$$

where,

$HTRADD_{y,eg,b,r}$	is the number of post-1990 vintage equipment added to new houses by forecast year, housing type and Census Division,
$HSEADD_{y,b,r}$	is the number of new housing units constructed in the forecast year by housing type and Census Division,
$SHARESN_{y,eg,b,r}$	is the current year market share of general equipment by housing

type and Census Division.

The surviving post-1990 vintage equipment in pre-1991 houses is computed as,

$$R90_{y,eg,b,r} = \sum_{t=1991}^{y-1} (HTRP90_{t,eg,b,r} \times SVRTE_{y-t,Lmin,Lmax} \times HDR \qquad \textbf{(14)}$$

where,

$HTSR90_{y,eg,b,r}$	is the surviving post-1990 vintage equipment in pre-1991 houses which accounts for housing demolition and equipment by housing type and Census Division,
$HTRP90_{t,eg,b,r}$	is the number of replacement (post-1990 vintage) equipment units demanded each year in pre-1991 houses by housing type and Census Division,
$SVRTE_{y-t,Lmin,Lmax}$	is the equipment survival function,
HDR_b	is the housing survival rate by housing type, and
$y\text{-}t$	represents the age of the equipment.

Total equipment required for pre-1991 houses is computed as:

$$HTND90_{y,eg,b,r} = \begin{pmatrix} HTESE_{1990,eg,b,r} \times HDR_b \ , \ if \ y = 1990 \\ HTND90_{y-1,eg,b,r} \times HDR_b \ , \ if \ y > 1990 \end{pmatrix} \qquad \textbf{(15)}$$

where,

$HTND90_{y,eg,b,r}$	is total equipment required for pre-1991 houses by year, general equipment type, housing type and Census Division,
$HTESE_{1990,eg,b,r}$	is the existing stock of equipment in 1990 by housing type and Census Division,
$HTND90_{y-1,eg,b,r}$	is the total amount of equipment demand in pre-1991 houses by

housing type and Census Division in the previous year,

HDR$_b$ is the housing survival rate by housing type.

Replacement units (post-1990) equipment required for pre-1991 houses in the current year are calculated as,

$$HTRP90_{y,eg,b,r} = HTND90_{y,eg,b,r} - HTESE_{y,eg,b,r} - HTSR90_{y,eg,b,r} \quad \textbf{(16)}$$

where,

$HTRP90_{y,eg,b,r}$	is the number of replacement units required for pre-1991 houses by forecast year, housing type and Census Division,
$HTND90_{y,eg,b,r}$	is the total equipment required for pre-1991 houses by forecast year, housing type and Census Division (i.e. the sum of HTRP90, HTSR90 and HTESE),
$HTESE_{y,eg,b,r}$	is the surviving pre-1991 vintage stock of equipment in pre-1991 vintage houses by forecast year, housing type and Census Division, and
$HTSR90_{y,eg,b,r}$	is the forecast of surviving post-1990 vintage equipment in pre-1991 houses.

Surviving post-1990 equipment, originally purchased as additions or replacements in post-1990 houses, is calculated as,

$$_{b,r} = \sum_{t=1991}^{y-1} [(HTRADD_{t,eg,b,r} + HTRREP_{t,eg,b,r}) \times SVRTE_{y-t,Lmin,Lma} \quad \textbf{(17)}$$

where,

$HTRSUR_{y,eg,b,r}$	is the surviving post-1990 equipment purchased as additions or replacements in post-1990 houses by housing type and Census Division,
$HTRADD_{t,eg,b,r}$	is the quantity of post-1990 vintage equipment added to post-1990 houses by forecast year, housing type and Census Division,
$SVRTE_{y\text{-}t,Lmin,Lmax}$	is the equipment survival function,
HDR_b	is the housing survival rate by housing type,
$HTRREP_{t,eg,b,r}$	is the number of equipment replacements of post-1990 equipment in post-1990 houses, and
y-t	represents the age of the equipment.

This value of the surviving post-1990 equipment is deducted from total demanded equipment in post-1990 houses to yield the number of replacements of post-1990 equipment in post-1990 houses:

$$HTRREP_{y,eg,b,r} = \sum_{t=1991}^{y-1} \left(HTRADD_{t,eg,b,r} \times HDR_b^{y-t} \right) - HTRSUR_{y,eg,b,r} \quad \textbf{(18)}$$

where,

$HTRREP_{y,eg,b,r}$	is the number of equipment replacements of post-1990 equipment in post-1990 houses,
HDR_b	is the housing survival rate by housing type,
$HTRSUR_{y,eg,b,r}$	is the surviving post-1990 equipment purchased as additions or replacement in post-1990 houses by housing type and Census Division,
$HTRADD_{t,eg,b,r}$	is the quantity of post-1990 vintage equipment added to post-1990 houses by forecast year, housing type and Census Division,

y-t represents the age of the equipment.

Shell Integrity Component

The shell integrity component uses three indices to capture the increases in the energy efficiency of building shells over time. One index corresponds to the pre-1991 housing stock, and two indices correspond to the post-1990 stock, one for housing constructed in the current year and the other for the average post-1990 stock. The shell indices are adjusted each year to account for fuel price increases (decreases have no effect on shell integrity, i.e., shell efficiency increases as price increases) and technology improvements. The first step in this algorithm calculates the percentage price change for all heating fuels as,

$$PRIDELTA_{f,r} = \frac{PRICES_{f,r,y} - PRICES_{f,r,1990}}{PRICES_{f,r,1990}} \times \frac{1}{PSTEP} \quad \textbf{(19)}$$

where,

$PRIDELTA_{f,r}$	is the percentage change in price from the base year by fuel and Census Division converted to 5 percentage point increments,
$PSTEP$	is a constant which is set to 0.05 to convert the percentage change in fuel price to the number of 5 percentage point increments of price change,
$PRICES_{f,r,y}$	is the fuel price by fuel, Census Division and year, and
$PRICES_{f,r,1990}$	is the 1990 (base year) fuel price by fuel and Census Division.

The existing housing heating shell index is calculated as,

$$= \begin{cases} EHSHELL_{y,f,r} = EHSHELL_{y-1,f,r} & , \; if \; EHSHELL_{y,f,r} \; > \; E\text{/} \\ EHSHELL_{y,f,r} = LIMIT & , \; if \; EHSHELL_{y,f,r} \; \geq \; LI\text{/} \\ EHSHELL_{y,f,r} = 1 - (PRIDELTA \; \times \; SSTEP) & , \; otherwise \end{cases} \quad \textbf{(20)}$$

where,

$EHSHELL_{y,f,r}$	is the shell integrity index for existing housing by year, fuel and Census Division,
LIMIT	limits the maximum shell index efficiency to 0.8 (i.e., maximum shell efficiency is limited to being 20 percent more efficient than the base year value), and
SSTEP	is set to 0.01 and is a component of the shell elasticity with respect to heating fuel price.

PSTEP converts the percentage change in price to the number of 5 percentage point increments of price change in Equation B-33. In equation B-34, PRIDELTA is multiplied by SSTEP and converted to the shell efficiency index. Every 5 percentage point increase in fuel price relative to the base year results in a shell efficiency index decrease of 1 percentage point of the base year shell efficiency up to the limit of 0.8.

The new housing heating shell index is calculated as,

$$= \begin{cases} NHSHELL_{y,f,r} = NHSHELL_{y-1,f,r} \; , & if \; NHSHELL_{y,f,r} \; > \; N\text{/} \\ NHSHELL_{y,f,r} = LIMIT \; , & if \; NHSHELL_{y,f,r} \; < \; LIMIT \\ NHSHELL_{y,f,r} = NHSHELL_{1990,f,r} - ((y-1) \; \times \; TECHG \; + \; PRIDELTA_{f,r} \; \times \; SSTE\text{/} \end{cases} \quad \textbf{(21)}$$

where,

$NHSHELL_{y,f,r}$	is the new housing units shell integrity index by year, fuel and Census Division,
TECHG	is a parameter representing the annual increase in new shell integrity due to technology improvements (assumed to be 1.0

percentage points of the base year index per year),

PRIDELTA$_{f,r}$ is the percent change in price of the fuel by Census Division in 5 percentage point increments,

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

The average post-1990 housing heating shell index is calculated as,

$$\frac{\sum_{b}\sum_{eg}[NHSHELL_{y,f,r} \times HTRADD_{y,eg,b,r} + AHSHELL_{y-1,f,r} \times (HTRREP_{y,eg,b,r}}{\sum_{b}\sum_{eg}[HTRADD_{y,eg,b,r} + HTRREP_{y,eg,b,r} + HTRSUR_{y,eg,b,r}]} \quad \textbf{(22)}$$

where,

AHSHELL$_{y,f,r}$ is the average post-1990 heating shell index by year, fuel and Census Division,

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

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

HTRREP$_{y,eg,b,r}$ is the number of equipment replacements of post-1990 equipment in post-1990 houses, and

HTRSUR$_{y,eg,b,r}$ is the surviving post-1990 equipment purchased as additions or replacement in post-1990 houses by forecast year, housing type and Census Division.

Consumption and UEC Component

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

$$= \left(\begin{array}{ll} HTUEC_{r,eg,b} \times \left[1 + \frac{\left(WTHEFFN_{y,eg,b,r} - \frac{1}{BSEFF_{eg}} \right)}{\frac{1}{BSEFF_{eg}}} \right] \times HDDADJ_{r}, if \;\; W' \\ HTUEC_{r,eg,b} \times HDDADJ_{\; r} & , \; othe \end{array} \right. \quad \textbf{(23)}$$

where,

$HNUEC_{y,eg,b,r}$	is the unit energy consumption for new equipment by forecast year, housing type and Census Division,
$WTHEFFN_{y,eg,b,r}$	is the general 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,
$BSEFF_{eg}$	is the 1990 stock-average efficiency of the general equipment type,
$HTUEC_{r,eg,b}$	is unit energy consumption for the general equipment type by Census Division and housing type, and
$HDDADJ_{r}$	is the heating degree day adjustment factor by Census Division to correct for the unusually warm weather during the RECS survey year.

Replacement equipment UEC values are calculated as:

$$
\begin{cases} HTUEC_{r,eg,b} \times \left[1 + \dfrac{(WTHEFFR_{y,eg,b,r} - \frac{1}{HTEFF_{eg}})}{\frac{1}{HTEFF_{eg}}} \right] \times HDDADJ_f \ , \ if \ W \\ HTUEC_{r,eg,b} \times HDDADJ_{\ r} \qquad , \ other \end{cases} \quad \textbf{(24)}
$$

where,

$HRUEC_{y,eg,b,r}$	is the unit energy consumption for replacement equipment by housing type and Census Division,
$HTEFF_{eg}$	is the efficiency of the weighted average of retiring units from the 1990 existing stock, and
$WTHEFFR_{y,eg,b,r}$	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 average UEC is calculated as:

$$= \begin{cases} HNUEC_{y,eg,b,r}\ , & if\ y{=}199 \\ HNUEC_{y,eg,b,r}\ , & if\ the\ equipment \\ \dfrac{\begin{array}{l}(HTRP90_{y,eg,b,r}+HTRREP_{y,eg,b,r})\times HNUEC_{y,eg,b,r} \\ \quad + HTRADD_{y,eg,b,r}\times HNUEC_{y,eg,b,r} \\ + (HTRSR90_{y,eg,b,r}+HTRSUR_{y,eg,b,r})\times HAUEC_{y-1,eg,b,r}\end{array}}{\begin{array}{l}HTRP90_{y,eg,b,r}+HTRREP_{y,eg,b,r}+HTRADD_{y,eg,b,r} \\ \quad +HTRSR90_{y,eg,b,r}+HTRSUR_{y,eg,b,r}\end{array}} & \end{cases} \quad \textbf{(25)}$$

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

$$\sum_{b}\sum_{eg}\left[\begin{pmatrix} HTESE_{y,eg,b,r}\times HTUEC_{eg,b,r}\times EHSHELL_{y,f,r}\ + \\ HTRADD_{y,eg,b,r}\times HNUEC_{y,eg,b,r}\times NHSHELL_{y,f,r} \\ +\ HTRP90_{y,eg,b,r}\times HNUEC_{y,eg,b,r}\times EHSHELL_{y,f,r} \end{pmatrix} \times \left(\frac{PRICES_{y,f,r}}{PRICES_{y-1,f,r}}\right)^{\alpha}\right]\times(1-EPA \quad \textbf{(26)}$$

and subsequent consumption as,

$$\sum_{eg}\left[\begin{pmatrix} HTESE_{y,eg,b,r}\times HTUEC_{eg,b,r}\times EHSHELL_{y,f,r} \\ +\ HTRADD_{y,eg,b,r}\times HNUEC_{y,eg,b,r}\times NHSHELL_{y,f,r} \\ +\ HTRP90_{y,eg,b,r}\times HRUEC_{y,eg,b,r}\times EHSHELL_{y,f,r} \\ +\ HTSR90_{y,eg,b,r}\times HAUEC_{y,eg,b,r}\times EHSHELL_{y,f,r} \\ +\ HTRREP_{y,eg,b,r}\times HNUEC_{y,eg,b,r}\times AHSHELL_{y,f,r} \\ +\ HTRSUR_{y,eg,b,r}\times HAUEC_{y,eg,b,r}\times AHSHELL_{y,f,r} \end{pmatrix} \times \left(\frac{PRICES_{y,f,r}}{PRICES_{y-1,f,r}}\right)^{\alpha}\right]\times(1-EPAC \quad \textbf{(27)}$$

where,

α	is the short-term price elasticity, and
$EPACTH_y$	is the projected savings from the EPACT window labeling program in year y.

Total Residential Energy Consumption by Fuel

The total residential energy consumption for the nation is computed by adding all the services' consumption by fuel for each census division as,

$$RSFLCN_{y,f,United\ States} = \sum_{r} \left(RSFLCN_{y,f,r} \right) \qquad \textbf{(28)}$$

where,

$RSFLCN_{y,f,r}$	is residential sector energy consumption by fuel and Census Division.

Emissions Component

Emissions are computed by applying pollutant-specific emissions factors to final end-use consumption. The pollutants modeled and the fuels to which the pollutants are attributable are discussed earlier in this report in the Emissions Component discussion of the module description. Airborne emissions are reported by fuel and then by pollutant. Emissions are calculated as,

$$EMRS_{f,p,y} = RSFLCN_{y,f,r} \times \frac{EMFAC_{p,f}}{1{,}000{,}000} \qquad \textbf{(29)}$$

where,

$EMRS_{f,p,y}$ is the level of emissions by fuel, pollutant and forecast year,

$RSFLCN_{y,f,r}$ is the residential sector energy consumption by forecast year, fuel and Census Division, and

$EMFAC_{p,f}$ is the emissions factor that converts MMBtu of fuel consumption to pounds of pollutant

The expression for emissions by pollutant is,

$$EMRSC_{r,p,y} = \sum_{f} \left[EMFAC_{p,f} \times \frac{RSFLCN_{y,f,r}}{1{,}000{,}000} \right] \qquad \textbf{(30)}$$

where,

$EMRSC_{r,p,y}$ is emissions by Census Division, pollutant and forecast year,

$RSFLCN_{y,f,r}$ is the residential sector energy consumption by forecast year, fuel, and Census Division, and

$EMFAC_{p,f}$ is the emissions factor that converts MMBtu of fuel consumption to pounds of pollutant.

Appendix A: Data Sources, Input Parameters, and Model Variables

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

Tables A-1 and A-2 reference the module variables, definitions and dimensions, and locations in the equations presented in the Key Computations and Equations section of the main text of Volume I of this report. The variables correspond to the variable names used in the FORTRAN source code of the Residential Sector Demand Module.

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

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[1] Lawrence Berkeley Laboratory, "Baseline Data for the Residential Sector and Development of a Residential Forecasting Database," Berkeley, CA, May, 1994.

[2] Arthur D. Little, "Technical Memorandum for Technology Advances and Forecasts-Residential/Commercial End-Use Equipment," 1990.

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

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

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

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

MODEL INPUT: Unit Energy Consumption (UEC)

MODEL COMPONENT: Consumption

DEFINITION: Unit energy consumption by service, general or specific equipment, equipment fuel, housing type, and Census Division.

DISCUSSION: The following chart shows the UEC disaggregations used in the Residential Sector Demand Module.

Table A-3. Unit Energy Consumption Disaggregation

Variable	Service	Equipment	Fuel	Housing Type	Census Division
HTUEC	Space Heating	X		X	X
CLUEC	Space Cooling	X		X	X
HWUEC	Water Heating		X	X	X
CKUEC	Cooking		X	X	X
DRYUEC	Clothes Drying		X	X	X
RFUEC	Refrigerators			X	X
FZUEC	Freezers			X	X
LTUEC	Lighting			X	X
EAUEC	Electric Appliances			X	X
SHTUEC	Secondary Space Heating		X	X	X
APPUEC	Other Appliances		X	X	X

SOURCE: U.S. Department of Energy, Energy Information Administration, *Residential Energy Consumption Survey 1990*, DOE/EIA-0321(90), Washington, D.C.

MODEL INPUT: BIAS, BETA1, BETA2, BETA3

MODEL COMPONENT: Technology Choice

DEFINITION: Parameter values that are used in the logistic function to weight costs to the market share changes.

DISCUSSION: BETA1 and BETA2 are determined by relative importance of first cost and operating cost in choosing the efficiency level of the equipment. BETA3 is used only when life-cycle cost choice is used (not currently used in the baseline scenario). BIAS for each technology is set to fit the market shares to historical shipment data.

SOURCES: Assumptions regarding the relative importance of first cost and operating cost are included in the module. BIAS is calibrated to fit the historical market share data.

MODEL INPUT: EFF

MODEL COMPONENT: Technology Choice

DEFINITION: Equipment Energy Efficiencies

DISCUSSION:

SOURCES: Lawrence Berkeley Laboratory, "Baseline Data for the Residential Sector and Development of a Residential Forecasting Database," Berkeley, CA, May, 1994.

MODEL INPUT: FS

MODEL COMPONENT: Technology Choice

DEFINITION: Freezer Saturation in the base year by Census Division and housing type

DISCUSSION: Tabulation of 1990 Residential Energy Consumption Survey (RECS) data provides market saturation levels of freezers in existing houses by Census Division and housing type.

SOURCES: U.S. Department of Energy, Energy Information Administration, *Residential Energy Consumption Survey 1990*, DOE/EIA-0321(90), Washington, D.C.

MODEL INPUT: HDR

MODEL COMPONENT: Housing Survival Rate

DEFINITION: The expected lifetimes of housing units by housing type.

DISCUSSION: Percent of houses surviving from year to year.

SOURCES: U.S. Department of Energy, *Technical Support Document: Energy Conservation Standards for Consumer Products: Dishwashers, Clothes Washers, and Clothes Dryers.* DOE/CE-0267, Washington, D.C.,July 1989, pp. 3-4.

MODEL INPUT: LMIN, LMAX

MODEL COMPONENT: Appliance Stock

DEFINITION: Expected minimum and maximum lifetimes for specific types of equipment.

DISCUSSION:

	LMIN	LMAX
Heat Pumps	8	16
Furnaces	18	29
Central Air Conditioners	8	16
Room Air Conditioners	12	18
Water Heaters	5	30
Stoves	16	21

Clothes Dryers	6	30
Refrigerators	7	29
Freezers	11	31

SOURCES: Lawrence Berkeley Laboratory, "Baseline Data for the Residential Sector and Development of a Residential Forecasting Database," Berkeley, CA, May, 1994.

MODEL INPUT: CACSAT, RACSAT

MODEL COMPONENT: Technology Choice

DEFINITION: Saturation level of central and room air conditioning by Census Division and housing type.

DISCUSSION: Cross-tabulations of the RECS data provide these saturation levels by housing type and Census Division.

SOURCES: U.S. Department of Energy, Energy Information Administration, *Residential Energy Consumption Survey 1990*, DOE/EIA-0321(90), Washington, D.C., February 1993.

MODEL INPUT: UPSHR

MODEL COMPONENT: Technology Choice

DEFINITION: Market share of new houses with upright freezers.

DISCUSSION: Current value set to 41% of the new housing additions.

SOURCES: Association of Home Appliance Manufacturers, "Freezers: Energy Efficiency and Consumption Trends," Chicago, IL, August, 1994.

MODEL INPUT: SLSHR

MODEL COMPONENT: Technology Choice

DEFINITION: Market share of solar water heaters in the base year.

DISCUSSION: Market shares by housing type and Census Division are derived from cross tabulations of the RECS data. Single- Family homes are the only housing type using solar water heaters.

SOURCES: U.S. Department of Energy, Energy Information Administration, *Residential Energy Consumption Survey 1990*, DOE/EIA-0321(90), Washington, D.C., February 1993.

MODEL INPUT: EFFTTD

MODEL COMPONENT: Technology Choice

DEFINITION: Efficiency of side-by-side refrigerators with through-the-door features.

DISCUSSION:

SOURCES: Association of Home Appliance Manufacturers, "Refrigerators: Energy Efficiency and Consumption Trends," Chicago, IL, August, 1993.

MODEL INPUT: TTDSHR

MODEL COMPONENT: Technology Choice

DEFINITION: Share of side-by-side refrigerators with through the door features.

DISCUSSION: Current value at 0.221.

SOURCES: Association of Home Appliance Manufacturers, "Refrigerators: Energy Efficiency and Consumption Trends," Chicago, IL, August, 1993.

MODEL INPUT: BSEFF

MODEL COMPONENT: Technology Choice

DEFINITION: Base year equipment efficiency by fuel or equipment type, depending upon usage.

DISCUSSION:

SOURCES: In house analysis of historical shipment data.

MODEL INPUT: LIMIT

MODEL COMPONENT: Shell Integrity

DEFINITION: Maximum level of shell efficiency improvement.

DISCUSSION: This value places a cap on the shell efficiency improvements due to technology and price effects. The limit is currently set to 0.8 for the index.

SOURCES: This is an assumed parameter value based on analyst judgement.

MODEL INPUT: SSTEP

MODEL COMPONENT: Shell Integrity

DEFINITION: A parameter that represents a conservation supply curve of shell efficiency in existing housing.

DISCUSSION: The conservation supply curve represents the minor shell efficiency improvement such as general maintenance on existing homes that increases the energy efficiency of the house. Current value set to 0.01

SOURCES: This is an assumed parameter value based on analyst judgement.

MODEL INPUT: HSE90

MODEL COMPONENT: Housing Stock

DEFINITION: Existing Stock of housing units in the year 1990.

DISCUSSION: This data is disaggregated by building types and by Census Division. The three building types are:

(1) Single-Family Homes

(2) Multifamily Homes

(3) Mobile Homes

SOURCES: U.S. Department of Energy, *Residential Energy Consumption Survey: Household Energy Consumption and Expenditures*, DOE/CE-0314(90), Washington, D.C., May, 1992.

MODEL INPUT: HORIZON

MODEL COMPONENT: Technology Choice

DEFINITION: Number of years over which consumers are assumed to calculate equipment life-cycle cost. HORIZON is used to determine the present value of future operating costs.

DISCUSSION: The value is currently set to seven years, based upon analyst judgement and the average length of time that a homeowner is likely to remain in the same home.

SOURCES: Analyst judgement, combined with residency patterns from the RECS studies cited in Appendix C of this report.

MODEL INPUT: DISRT

MODEL COMPONENT: Technology Choice

DEFINITION: Consumer discount rate

DISCUSSION: The discount rate is used to compute the present value of future expenditures and operating costs of energy consuming equipment.

SOURCES: AEO93, EPRI studies cited in Appendix C of this report.

MODEL INPUT: HDD

CDD

MODEL COMPONENT: Consumption

DEFINITION: Heating and cooling degree days for history and normal weather by Census Division.

DISCUSSION: These climate adjustment factors are used since the last RECS survey spans a period of unusually mild winter weather.

SOURCES: U.S. Department of Energy, Energy Information Administration, *Residential Energy Consumption Survey 1990*, DOE/EIA-0321(90), Wash., DC, February 1993.

MODEL INPUT: SHTSHR

MODEL COMPONENT: Consumption

DEFINITION: Market share of residential households with secondary space heating in the base year.

DISCUSSION: Market shares are derived from cross tabulations of the RECS data by fuel and Census Division for houses that use a secondary space heating source.

SOURCES: U.S. Department of Energy, Energy Information Administration, *Residential Energy Consumption Survey 1990*, DOE/EIA-0321(90), Washington, D.C., February 1993.

MODEL INPUT: PSTEP

MODEL COMPONENT: Shell Integrity

DEFINITION: Price elasticity of shell efficiency for both new and existing housing.

DISCUSSION: The price change in fuel from the base year is multiplied by the reciprocal of PSTEP to get PRICEDELTA. The current value of PSTEP is 0.05.

SOURCES: This is an assumed parameter value based on analyst judgement.

MODEL INPUT: TECHG

MODEL COMPONENT: Shell Integrity

DEFINITION: Rate of increase in the shell efficiency of new (post-1990 vintage) housing due to technology improvements.

DISCUSSION: This growth rate in the shell efficiency represents technology improvements in building materials and housing design and greater market penetration of these materials and methods.

SOURCES: This is an assumed parameter based on analyst judgement.

MODEL INPUT: GSL

MODEL COMPONENT: Technology Choice

DEFINITION: Limit to the number of the space heaters by Census Division and fuel that can potentially to switch to natural gas.

DISCUSSION: These estimates were developed based on analysis of RECS and American Gas Association fuel switching data.

SOURCES: RECS studies cited in Appendix C of this report and American Gas Association, "Residential Natural Gas Market Survey: 1992," Arlington, VA, June, 1993.

MODEL INPUT: HTSHR

MODEL COMPONENT: Technology Choice

DEFINITION: Market share of general space heating equipment in the base year.

DISCUSSION: Market shares by housing type and Census Division are derived from cross tabulations of the RECS data for the 11 general space heating equipment types. The 11 equipment types are:

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

SOURCES: U.S. Department of Energy, Energy Information Administration, *Residential Energy Consumption Survey 1990*, DOE/EIA-0321(90), Washington, D.C., February 1993.

MODEL INPUT: CLSHR

MODEL COMPONENT: Technology Choice

DEFINITION: Market share of general space cooling equipment in the base year.

DISCUSSION: Market shares are derived from cross tabulations of the RECS data by housing type and Census Division for the three general space cooling equipment types. The three equipment types are room air conditioners, central air conditioners, and heat pumps. In addition, the market share of housing that has no air conditioning is derived from RECS.

SOURCES: U.S. Department of Energy, Energy Information Administration, *Residential Energy Consumption Survey 1990*, DOE/EIA-0321(90), Washington, D.C., February 1993.

MODEL INPUT: HWSHR

MODEL COMPONENT: Technology Choice

DEFINITION: Market share of general water heating equipment in the base year.

DISCUSSION: Market shares by housing type and Census Division are derived from cross tabulations of the RECS data for the four general water heating equipment types. The four equipment types are determined by the fuel consumed. They are natural gas, electric, oil, and LPG.

SOURCES: U.S. Department of Energy, Energy Information Administration, *Residential Energy Consumption Survey 1990*, DOE/EIA-0321(90), Washington, D.C., February 1993.

MODEL INPUT: CKSHR

MODEL COMPONENT: Technology Choice

DEFINITION: Market share of cooking equipment in the base year.

DISCUSSION: Market shares are derived from cross tabulations of the RECS data by housing type and Census Division for the three general equipment types. The three equipment types are defined by the fuel consumed. The three types are electric, natural gas, and LPG.

SOURCES: U.S. Department of Energy, Energy Information Administration, *Residential Energy Consumption Survey 1990*, DOE/EIA-0321(90), Washington, D.C., February 1993.

MODEL INPUT: DRYSHR

MODEL COMPONENT: Technology Choice

DEFINITION: Market share of clothes drying equipment in the base year.

DISCUSSION: Market shares by house type and Census Division are derived from cross tabulations of the RECS data for the two general equipment types. The two equipment types are defined by the fuel consumed (natural gas or electricity). The market share of households that do not have clothes dryers is also developed using RECS.

SOURCES: U.S. Department of Energy, Energy Information Administration, *Residential Energy Consumption Survey 1990*, DOE/EIA-0321(90), Washington, D.C., February 1993.

MODEL INPUT: RFSHR

MODEL COMPONENT: Technology Choice

DEFINITION: Market shares of homes that have second refrigerators, for the base year of 1990.

DISCUSSION: Market shares by house type and Census Division are derived from cross tabulations of the RECS data for houses with a second refrigerator.

SOURCES: U.S. Department of Energy, Energy Information Administration, *Residential Energy Consumption Survey 1990*, DOE/EIA-0321(90), Washington, D.C., February 1993.

MODEL INPUT: FZSHR

MODEL COMPONENT: Technology Choice

DEFINITION: Market share of residential households that have a freezer, for the base year of 1990.

DISCUSSION: Market shares by house type and Census Division are derived from cross tabulations of the RECS data for houses with a freezer.

SOURCES: U.S. Department of Energy, Energy Information Administration, *Residential Energy Consumption Survey 1990*, DOE/EIA-0321(90), Washington, D.C., February 1993.

MODEL INPUT: EMFAC

MODEL COMPONENT: Consumption

DEFINITION: Emission factors

DISCUSSION: These emissions factors were developed for the residential sector using EPA estimates of emission rates of residential equipment. The emissions factors are provided by fuel and pollutant. The pollutants modeled are total carbon, carbon monoxide, carbon dioxide, sulfur oxides, nitrogen oxides, non-methane volatile organic compounds, methane, and particulate matter.

SOURCES: EPA Compilation of Stationary Source Air Emissions Estimates

MODEL INPUT: SAVEHTR

MODEL COMPONENT: Consumption

DEFINITION: Savings of space heating fuel due to The 1992 National Energy Policy Act (EPACT) window labeling program.

DISCUSSION: An EIA internal analysis of the program yielded estimated savings of 0.08 percent per year.

SOURCES: American Council for an Energy-Efficient Economy, "Energy Savings Estimates from the Energy Efficiency Provisions in the

Senate and House Energy Bills," Washington, D.C., August 1993.

MODEL INPUT: SAVECLR

MODEL COMPONENT: Consumption

DEFINITION: Savings of space cooling fuel due to EPACT window labeling program.

DISCUSSION: An EIA internal analysis of the program yielded an estimated savings of 0.03 percent per year.

SOURCES: American Council for an Energy-Efficient Economy, "Energy Savings Estimates from the Energy Efficiency Provisions in the Senate and House Energy Bills," Washington, D.C., August 1993.

MODEL INPUT: WINPCT

MODEL COMPONENT: Consumption

DEFINITION: Percent of existing homes replacing windows.

DISCUSSION: The RECS data provided information on the market shares of existing homes likely to replace windows over the forecast horizon. The variable construct provides three rates of participation in window replacement. The first rate is 1% over the first five years. The second rate is 10% from the fifth to the tenth year, and the third rate is 20% from the eleventh year to the horizon.

SOURCES: U.S. Department of Energy, Energy Information Administration, *Residential Energy Consumption Survey 1990*, DOE/EIA-0321(90), Washington, D.C., February 1993.

MODEL INPUT: MC_HUSTS1

MC_HUSTS2

MC_SHUMBL

MODEL COMPONENT: Housing Stock

DEFINITION: Construction starts of single-family and multi-family homes, and shipments of mobile homes.

DISCUSSION: These inputs are obtained at the Census Division level of detail each forecast year from the NEMS MAM.

SOURCES: Input from NEMS MAM.

MODEL INPUT: USAGE

MODEL COMPONENT: Technology Choice

DEFINITION: Usage component of unit energy consumption for space cooling.

DISCUSSION: The USAGE variable is constructed from an analysis of the RECS data by space cooling equipment type and Census Division.

SOURCES: U.S. Department of Energy, Energy Information Administration, *Residential Energy Consumption Survey 1990*, DOE/EIA-0321(90), Washington, D.C., February 1993.

MODEL INPUT: PEN_RATE

MODEL COMPONENT: Technology Choice

DEFINITION: Market penetration rate of central air conditioners in existing housing.

DISCUSSION: The RECS data provided the market shares of existing housing that do not have central air conditioning but do have duct work for space heating systems.

SOURCES: U.S. Department of Energy, Energy Information Administration, *Residential Energy Consumption Survey 1990*, DOE/EIA-0321(90), Washington, D.C., February 1993.

MODEL INPUT: EPACT

MODEL COMPONENT: Consumption

DEFINITION: Percent savings in water heating UEC due to EPACT mandated showerhead standards.

DISCUSSION: It was assumed that showers account for 30% of hot water use and that low-flow shower heads can cut use by 50%.

SOURCES: In house analysis of RECS data.

MODEL INPUT: EFFUP

MODEL COMPONENT: Technology Choice

DEFINITION: Efficiency of upright freezers.

DISCUSSION: Currently set at 492.

SOURCES: Association of Home Appliance Manufacturers, "Freezers: Energy Efficiency and Consumption Trends," Chicago, IL, August, 1992.

MODEL INPUT: MKTSHR

MODEL COMPONENT: Technology Choice

DEFINITION: Market shares for lighting technologies.

DISCUSSION:

SOURCES: Analyst judgement

MODEL INPUT: RACUNTS

MODEL COMPONENT: Consumption

DEFINITION: Average number of room air conditioners per household.

DISCUSSION:

SOURCES: U.S. Department of Energy, Energy Information Administration, *Residential Energy Consumption Survey 1990*, DOE/EIA-0321(90), Washington, D.C., February 1993.

Appendix B: Detailed Mathematical Description

This section presents the detailed calculations used in each of the module components. Table B-1 shows the correspondence between the subscript in the documentation and the subscripts in the FORTRAN source code.

Table B-1. Subscript Correspondence

Subscript in Documentation	Subscript in the FORTRAN Code
r	D or R, refers to Census Division
t	Y, when Y is a year increment
f	F, fuel types
b	B, housing type
y	Y, YR, or Y1, the annual index
p	P, pollutant
eg	E, general equipment type
es	E2, specific equipment type

Please note the following conventions:

- The above table of subscripts includes all of the major usages. In some minor instances, additional subscripts are defined as needed.
- The equations follow the logic of the FORTRAN code very closely to facilitate an understanding of the code and its structure. In several instances, a variable will appear on both sides of an equation. This is a FORTRAN programming device which allows a previous calculation to be updated (for example, multiplied by a factor) and re-stored under the same variable name (i.e., in the same memory location).
- The subscript, y, in the documentation refers to the year represented as 1990 through 2010. In the FORTRAN code, the subscripts for Y, YR and Y1 represent array dimensions starting with an index of 1 to represent 1990 (in some cases, the array index

of 1 represents 1991 as explained below). Not all arrays begin with an array position for 1990. Specifically, the arrays representing and relating to equipment added after the 1990 base year begin with the first array position representing 1991 to economize on memory storage.

- Some variables are documented as having a "y" dimension when in fact they do not. The most common instances are for the variables, LFCY, OPCOST, SA, SHARESN, and SHARESR. These variables are calculated on an annual basis, but are retained only for the current year. The "y" dimension is used in the documentation to highlight 1) that the calculations do vary by year, and 2) to indicate the current year in formulae to avoid confusion.
- Summations which take place over all relevant variables will usually be written without upper and lower range limits on the summation.
- Unless otherwise stated, the range of y for an equation is 1991 through 2010.

The equations in this appendix are organized by the following services:

Space Heating
Space Cooling
Water Heating
Cooking
Clothes Drying
Refrigeration
Freezers
Lighting
Other Appliances
Secondary Heating

Equipment Survival, Housing Survival and Housing Additions

SVRTE (Equipment Survival Function)

$$E_{y-t,L_{min},L_{max}} = \begin{cases} y-t \le L_{min}: & 1. \\ L_{min} < y-t < L_{max}: & 1.0 - \left(\dfrac{y-t - L_{m}}{L_{max} - L_{m}} \right. \\ y-t \ge L_{max}: & 0. \end{cases} \qquad \text{B-(1)}$$

where,

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

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

EXHSE (Existing Housing Survival Function)

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

Single-Family Homes:	$0.995 = HDR_1$
Multifamily Homes:	$0.990 = HDR_2$
Mobile Homes:	$0.961 = HDR_3$

The surviving 1990 housing stock is defined by:

$$EH_{y,b,r} = RECS\ data, \qquad if\ y = 1990$$
$$EH_{y,b,r} = EH_{y-1,b,r} * HDR_b, \qquad if\ y > 1990 \qquad \textbf{B-(2)}$$

where,

$EH_{y,b,r}$	is the 1990 housing stock surviving in year y,
HDR_b	is the housing survival rate.

NEWHSE (Calculate New Housing)

The NEMS Macroeconomic Activity Module provides forecasts of housing starts by Census Division for each forecast year.

$$HSEADD_{y,single\ family,r} = 1{,}000{,}000 \times MC\_HUSTS1_{r,y} \qquad \textbf{B-(3)}$$

$${}_{ily,r} = HSEADD_{y,single\ family,r} + NH_{y-1,single\ family,r} \times HL \qquad \textbf{B-(4)}$$

$$HSEADD_{y,multiple\ family,r} = 1{,}000{,}000 \times MC\_HUSTS2_{r,} \qquad \textbf{B-(5)}$$

$${}_{y,r} = HSEADD_{y,multiple\ family,r} + NH_{y-1,multiple\ family,r} \times \qquad \textbf{B-(6)}$$

$$HSEADD_{y,mobilehome,r} = 1{,}000{,}000 \times MC\_SHUMBL_{r,y} \qquad \textbf{B-(7)}$$

$${}_{home,r} = HSEADD_{y,mobile\ home,r} + NH_{y-1,mobile\ home,r} \times HDR \qquad \textbf{B-(8)}$$

where,

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

$MC\_HUSTS1_{r,y}$	single family housing starts by Census Division and year,
$MC\_HUSTS2_{r,y}$	multi-family housing starts by Census Division and year,
$MC\_SHUMBL_{r,y}$	mobile home shipments by Census Division and year,
$NH_{y,b,r}$	is the total post-1990 housing units by housing type, Census Division and year, and
HDR_b	is the housing survival rate by housing type.

Space Heating

Heating Equipment, UEC and Housing Shell Accounting Scheme

The above representation depicts the equipment accounting methodology. The subscripting of the variables is not included for simplicity, but will be explained later in the appendix. The equipment accounting system partitions equipment into two major categories depending on the vintage of the housing unit: equipment installed in housing units which existed in 1990 (at the beginning of the model run) and equipment added to new housing units (those added during the model run). Equipment is further partitioned into three additional surviving/replacement categories: equipment which survives, equipment purchased to replace other equipment, and equipment purchased for new construction. Currently the replacement equipment for all equipment types (heating, cooling, refrigeration, etc.) is assigned the same unit energy consumption values as equipment added for new construction (i.e., HRUEC and HNUEC are the same). The categorization of equipment markets by housing vintage and surviving/replacement category results in six categories of equipment that are tracked. The equipment categories for existing housing units are:

HTESE denotes the surviving 1990 equipment stock,

HTSR90 represents equipment from the 1990 stock which has been replaced after 1990 and which still survives, and

HTRP90 is current-year replacement equipment for 1990 housing.

For housing units added after 1990:

HTRSUR denotes equipment which has been modeled as added and still survives,

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

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

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

HTUEC is the average UEC for surviving equipment in housing units which existed in 1990,

HAUEC is the average UEC for surviving equipment in housing units added after 1990,

HRUEC is the UEC for all equipment added in the current year to replace 1990 equipment, and

HNUEC is the UEC for all equipment added in the current year for homes constructed after 1990.

Shell indices are modeled for three categories of housing units:

EHSHELL is the shell index applicable to housing units existing in 1990,

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

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

For example, in accounting for the heating energy consumption of surviving equipment installed in housing units which existed in 1990, the equipment stock, HTESE, would be multiplied by the unit energy consumption, HTUEC, and by the shell index EHSHELL. This explanation was designed for accounting for heating equipment, but the accounting principle is used throughout the residential module. For the existing housing example above, the appropriate space cooling variables would be CLESE, CLUEC and ECSHELL. The shell indices apply only to heating and cooling, thus, for example for refrigeration the accounting requires only RFESE and RFUEC.

RDHTEQT (Project 1990 Vintage Heating Equipment)

Calculate surviving heating equipment in the pre-1991 housing stock for 1990,

$$_{990,eg,b,r} = \frac{HTSHR_{eg,b,r}}{100} \times EH_{1990,b,r} \quad for\ all\ r,\ l \qquad \textbf{B-(9)}$$

where,

$HTESE_{1990,eg,b,r}$	is the existing (pre-1991 vintage) stock of equipment in the base year by housing type and Census Division,
$HTSHR_{eg,b,r}$	is the 1990 market shares of heating equipment from RECS by general equipment type, housing type and Census Division,
$EH_{1990,b,r}$	is the number of surviving pre-1991 housing units by year, housing type and Census Division.

For y > 1990,

$$_{,eg,b,r} = HTESE_{1990,eg,b,r} \times SVRTE_{y-1990,Lmin,Lmax} \times HL \qquad \textbf{B-(10)}$$

$HTESE_{y,eg,b,r}$	is the amount of surviving pre-1991 vintage equipment in pre-1991 housing by housing type and Census Division,
$SVRTE_{y-1990,Lmin,Lmax}$	is the equipment survival function, and
HDR_b	is the housing demolition rate by housing type.

HTRTEC (Space Heating Technology Choice)

Compute current year operating costs,

$$T_{y,es,b,r} = PRICES_{f,r,y} \times HTUEC_{r,eg,b} \times \left(1 + \frac{\frac{1}{EFF_{es}} - \frac{}{BA}}{\frac{1}{BASEF}} \right. \qquad \textbf{B-(11)}$$

where,

$OPCOST_{y,es,b,r}$	is the current year operating cost for the specific equipment type by housing type, Census Division and year,
$PRICES_{f,r,y}$	are the fuel prices for the equipment by fuel, region and forecast year,
$HTUEC_{r,eg,b}$	is the unit energy consumption by Census Division, general equipment category and housing type,
EFF_{es}	is the specific equipment efficiency,
$BASEFF_{eg}$	is the 1990 stock-average equipment efficiency,
es	refers to specific equipment (model or vintage) within a technology class, and
eg	refers to general equipment or technology class.

Compute current year life cycle costs,

$$_{s,b,r} = CPCOST_{es} + OPCOST_{y,es,b,r} \times \left[\frac{1 - (1 + DISRT)}{DISRT} \right. \qquad \textbf{B-(12)}$$

where,

$LFCY_{y,es,b,r}$	is the current year life cycle cost of specific equipment by housing type and Census Division,
$CPCOST_{es}$	is the installed capital cost of the equipment by specific equipment

type,

$OPCOST_{y,es,b,r}$ is the operating cost of the specific equipment type by housing type and Census Division in the forecast year,

$HORIZON$ is the number of years into the future that is used to compute the present value of future operating cost expenditures presently set to seven years, and

$DISRT$ is the discount rate applied to compute the present value of future operating costs presently at 20 percent.

A weight for each general equipment type is calculated to estimate the market share for each of the 11 heating sytems for new construction based on the cost factors computed above, base year Census construction data, and the bias. The functional form is expressed as,

$$HEATSYS_{y,eg,b,r} = e^{[\ BIAS_{eg} + \beta_g \times LFCY_{eg}\ ]} \qquad \textbf{B-(13)}$$

where,

$HEATSYS_{y,eg,b,r}$ is the equipment weight for general heating equipment for new housing by year, housing type, and Census Division,

$BIAS_{eg}$ is a consumer preference parameter that fits the current market share to historical shipment data,

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

β_g is a parameter value of the logit function.

Summing over the general equipment types computes the total weight for the general equipment types:

$$SYSTOT_{y,b,r} = \sum_{eg=1}^{eg=11} HEATSYS_{y,eg,b,r} \qquad \textbf{B-(14)}$$

where,

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

The general equipment fuel share is computed by

$$HSYSWGT_{y,eg,b,r} = \begin{pmatrix} \frac{HEATSYS_{y,eg,b,r}}{SYSTOT_{y,b,r}} & , SYSTOT_{y,b,r} > 0 \\ 0 & , otherwise \end{pmatrix} \qquad \textbf{B-(15)}$$

where,

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

Weights for each specific equipment type are calculated based on the cost factors computed above and the bias. The functional forms are expressed as,

$$N_{y,es,b,r} = e^{\left[BIASH_{es} + \beta_1 * CPCOST_{es} + \beta_2 * OPCOST_{y,es,b,r} + \beta_3 * LFCY_{y}\right.} \qquad \textbf{B-(16)}$$

$$R_{y,es,b,r} = e^{\left[BIASH_{es} + \beta_1 * CPCOST_{es} + \beta_2 * OPCOST_{y,es,b,r} + \beta_3 * LFCY_{y}\right.} \qquad \textbf{B-(17)}$$

where,

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

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

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

$CPCOST_{es}$ is the installed capital cost for the specific equipment type in the forecast year,

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

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

$\beta_1, \beta_2, \beta_3$ are parameter values of the logit function.

Sum over specific equipment types to get total weight for the general equipment types,

$$TOTEWTN_{y,eg,b,r} = \sum_{es=low\ eff}^{hi\ eff} EQWTN_{y,es,b,r} \qquad \textbf{B-(18)}$$

$$TOTEWTR_{y,eg,b,r} = \sum_{es=low\ eff}^{hi\ eff} EQWTR_{y,es,b,r} \qquad \textbf{B-(19)}$$

where,

$TOTEWTN_{y,eg,b,r}$ is the sum of specific equipment weights for the new general equipment type, and

$TOTEWTR_{y,eg,b,r}$ is the sum of specific equipment weights for the replacement equipment type,

$EQWTN_{y,es,b,r}$ is the specific equipment weight for new equipment, and

$EQWTR_{y,es,b,r}$ is the specific equipment weight for replacement equipment.

$$QFSHRN_{y,es,b,r} = \begin{cases} \frac{EQWTN_{y,es,b,r}}{TOTEWTN_{y,eg,b,r}} & , TOTEWTN_{y,eg,b,r} > 0 \\ 0 & , otherwise \end{cases}$$ **B-(20)**

$$QFSHRR_{y,es,b,r} = \begin{cases} \frac{EQWTR_{y,es,b,r}}{TOTEWTR_{y,eg,b,r}} & , TOTEWTR_{y,eg,b,r} > 0 \\ 0 & , otherwise \end{cases}$$ **B-(21)**

where,

$EQFSHRN_{y,es,b,r}$	is the fuel share of new specific equipment type by year, housing type and Census Division,
$EQFSHRR_{y,es,b,r}$	is the fuel share of replacement specific equipment type by year, housing type and Census Division,
$TOTEWTN_{y,eg,b,r}$	is the sum of general equipment weights for the new general equipment type,
$TOTEWTR_{y,eg,b,r}$	is the sum of replacement general equipment weights for the new general equipment type,
$EQWTN_{y,es,b,r}$	is the specific equipment weight for new equipment, and
$EQWTR_{y,es,b,r}$	is the specific equipment weight for replacement equipment.

$$RHTRSHR_{y,es,b,r} = EQFSHRR_{y,es,b,r}$$ **B-(23)**

$$_{r} = EQFSHRN_{y,es,b,r} \times \left(HSYSSHR_{1991,eg,b,r} \times \frac{HSYS}{HSYSW} \right.$$ **B-(22)**

where,

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

$RHTRSHR_{y,es,b,r}$	is the market share of replacement specific heating equipment by housing type, Census Division and forecast year,
$EQFSHRN_{y,es,b,r}$	is the fuel share of new specific equipment type by year, housing type and Census Division,
$EQFSHRR_{y,es,b,r}$	is the fuel share of replacement specific equipment type by year, housing type and Census Division,
$HSYSSHR_{y,eg,b,r}$	is the base year market share for general equipment by housing type and Census Division.

$$FN_{y,eg,b,r} = \begin{cases} \dfrac{\sum_{es}\left[\dfrac{NHTRSHR_{y,es,b,r}}{EFF_{y,eg}}\right]}{\sum_{es} NHTRSHR_{y,es,b,r}} \; , & \sum_{es} NHTRSHR_{y,es,b} \\ \dfrac{1}{BASEFF_{eg}} \; , & otherwise \end{cases} \qquad \textbf{B-(24)}$$

where,

$WTHEFFN_{y,eg,b,r}$	is the weighted efficiency of new general heating equipment by year, housing type and Census Division,
$NHTRSHR_{y,es,b,r}$	is the market share of new specific heating equipment by year, housing type and Census Division,
$EFF_{y,eg}$	is the general equipment efficiency, and
$BASEFF_{eg}$	is the 1990 stock-average equipment efficiency.

HADD (Additions and Replacement of Space Heating Equipment)

$$SHARESN_{y,eg,b,r} = \sum_{es=low\ eff}^{high\ eff} NHTRSHR_{y,es,b,r} \qquad \textbf{B-(25)}$$

$$SHARESR_{y,eg,b,r} = \sum_{es=low\ eff}^{high\ eff} RHTRSHR_{y,es,b,r} \qquad \textbf{B-(26)}$$

where,

$SHARESN_{y,eg,b,r}$ is the current year, aggregate market share for new equipment by general equipment type, housing type and Census Division,

$SHARESR_{y,eg,b,r}$ is the current year, aggregate market share for replacement equipment by general equipment type, housing type and Census Division. This is currently set to the same value as SHARESN.

$$HTRADD_{y,eg,b,r} = HSEADD_{y,b,r} \times SHARESN_{y,eg,b,r} \qquad \textbf{B-(27)}$$

where,

$HTRADD_{y,eg,b,r}$ is the number of post-1990 vintage equipment additions for new housing units in the current year by general equipment type, housing type and Census Division,

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

$SHARESN_{y,eg,b,r}$ is the market share of general equipment by housing type and Census Division.

$$HTSR90_{y,eg,b,r} = \sum_{t=1991}^{y-1} \left(HTRP90_{t,eg,b,r} \times SVRTE_{y-t,L_{\min},L_{\max}} \times HDR_b^{y-t} \right) \qquad \textbf{B-(28)}$$

where,

$HTSR90_{y,eg,b,r}$	is the surviving post-1990 vintage equipment in pre-1991 housing units which accounts for housing demolition and equipment by housing type and Census Division,
$HTRP90_{t,eg,b,r}$	is the number of replacement (post-1990 vintage) equipment units demanded in pre-1991 housing units by housing type and Census Division each year,
$SVRTE_{y-t, Lmin, Lmax}$	is the equipment survival function,
HDR_b	is the housing survival rate by housing type, and
y-t	represents the age of the equipment.

$$HTND90_{y,eg,b,r} = \begin{pmatrix} HTESE_{1990,eg,b,r} \times HDR_b \text{ , if } y=1990 \\ HTND90_{y-1,eg,b,r} \times HDR_b \text{ , if } y>1990 \end{pmatrix} \qquad \textbf{B-(29)}$$

where,

$HTND90_{y,eg,b,r}$	is the total amount of equipment demanded in pre-1991 housing units by year, general equipment category, housing type and Census Division,
$HTESE_{1990,eg,b,r}$	is the surviving stock of equipment in pre-1991 housing in 1990 by general equipment category, housing type and Census Division,
$HTND90_{y-1,eg,b,r}$	is the prior year total amount of equipment required for pre-1991 housing units by housing type and Census Division,
HDR_b	is the housing survival rate by housing type.

$$HTRP90_{y,eg,b,r} = HTND90_{y,eg,b,r} - HTESE_{y,eg,b,r} - HTSR90_{y,eg,b,r} \qquad \textbf{B-(30)}$$

where,

$HTRP90_{y,eg,b,r}$	is the number of replacement units required for pre-1991 housing units by housing type, Census Division and forecast year,
$HTND90_{y,eg,b,r}$	is the current year total amount of general equipment required for pre-1991 housing units by housing type and Census Division,
$HTESE_{y,eg,b,r}$	is the current year surviving appliance stock for pre-1991 vintage housing units by housing type and Census Division, and
$HTSR90_{y,eg,b,r}$	is the current year amount of surviving post-1990 vintage equipment in pre-1991 housing units by housing type and Census Division.

$$SA_{y,eg,b,r} = \sum_{t=1991}^{y-1} HTRADD_{t,eg,b,r} \times HDR_b^{y-t} \qquad \textbf{B-(31)}$$

where,

$SA_{y,eg,b,r}$	is the current year amount of surviving post-1990 vintage equipment added to new housing units not accounting for equipment attrition by housing type and Census Division,
$HTRADD_{t,eg,b,r}$	is the amount of new (post-1990 vintage) space heaters added in new housing units in the year by housing type and Census Division, and
HDR_b	is the housing survival rate by housing type.

$$_{eg,b,r} = \sum_{t=1991}^{y-1} \left[\left(HTRADD_{t,eg,b,r} + HTRREP_{t,eg,b,r} \right) \times SVRTE_{y-t,L_{min},L_{max}} \right. \qquad \textbf{B-(32)}$$

where,

$HTRSUR_{y,eg,b,r}$	is surviving post-1990 equipment purchased as additions or

	replacements in post-1990 housing units by housing type and Census Division,
$HTRADD_{t,eg,b,r}$	is the number of post-1990 vintage equipment added to post-1990 housing units by housing type, Census Division and forecast year,
$SVRTE_{y-t,Lmin,Lmax}$	is the equipment survival function,
HDR_b	is the housing decay rate by housing type,
$HTRREP_{t,eg,b,r}$	is the number of equipment replacements of post-1990 equipment in post-1990 housing units, and
y-t	represents the age of the equipment.

$$HTRREP_{y,eg,b,r} = SA_{y,eg,b,r} - HTRSUR_{y,eg,b,r} \quad \textbf{B-(33)}$$

where,

$HTRREP_{y,eg,b,r}$	is the number of equipment replacements of post-1990 equipment in post-1990 housing units,
$SA_{y,eg,b,r}$	is the current year amount of surviving post-1990 vintage equipment added to new housing units not accounting for equipment attrition by housing type and Census Division,
$HTRSUR_{t,eg,b,r}$	is the surviving post-1990 equipment purchased as additions or replacement in post-1990 housing units by housing type and Census Division,

HTCNS (Heating Consumption Subroutine)

The first step is to construct shell integrity indices for housing units. There are three indices used to capture the increases in the energy efficiency of building shells over time. One index corresponds to the pre-1991 housing stock, and two indices which correspond to the post-1990 stock, one for housing constructed in the current year and the other for the average stock. The shell indices are adjusted each year to account for fuel price increases (decreases have no effect on shell integrity, that is shell efficiency ratchets up as price increases) and technology improvements. The first step in this algorithm calculates the percentage price change for all heating fuels as,

$$RIDELTA_{f,r} = \frac{PRICES_{f,r,y} - PRICES_{f,r,1990}}{PRICES_{f,r,1990}} \times \frac{1}{PSTE} \qquad \textbf{B-(34)}$$

where,

$PRIDELTA_{f,r}$	is the percentage change in price from the base year by fuel and Census Division converted to 5 percentage point increments,
$PSTEP$	is a constant which is set to 0.05 to convert the percentage change in fuel price to the number of 5 percentage point increments of price change,
$PRICES_{f,r,y}$	is the fuel price by fuel, Census Division and year, and
$PRICES_{f,r,1990}$	is the 1990 (base year) fuel price by fuel and Census Division.

The existing housing heating shell index is calculated as,

$$_{r} = \left(\begin{array}{ll} EHSHELL_{y,f,r} = EHSHELL_{y-1,f,r} & , \text{ if } EHSHELL_{y,f,r} > EHS \\ EHSHELL_{y,f,r} = LIMIT & , \text{ if } EHSHELL_{y,f,r} \geq LIM \\ EHSHELL_{y,f,r} = 1 - (PRIDELTA \times SSTEP) & , \text{ otherwise} \end{array} \right. \qquad \textbf{B-(35)}$$

where,

$EHSHELL_{y,f,r}$	is the heating shell integrity index for existing housing by year, fuel and Census Division (the lower the value of the index, the greater the shell efficiency),
$LIMIT$	limits the maximum shell index efficiency to 0.8 (i.e., maximum shell efficiency is limited to being 20 percent more efficient than the base year value), and
$SSTEP$	is set to 0.01 and is a component of the shell elasticity with respect to heating fuel price.

PSTEP converts the percentage change in price to the number of 5 percentage point increments of price change in Equation B-33. In equation B-34, PRIDELTA is multiplied by SSTEP and converted to the shell efficiency index. Every 5 percentage point increase in fuel price relative to the base year results in a shell efficiency index decrease of 1 percentage point of the base year shell efficiency up to the limit of 0.8.

The new housing heating shell index is calculated as,

$$\begin{aligned} SHELL_{y,f,r} &= NHSHELL_{y-1,f,r}\,, && \text{if } NHSHELL_{y,f,r} > NHSH \\ SHELL_{y,f,r} &= LIMIT\,, && \text{if } NHSHELL_{y,f,r} < LIMIT \\ SHELL_{y,f,r} &= NHSHELL_{1990,f,r} - ((y-1990) \times TECHG + PRIDELTA_{f,r} \times SS \end{aligned} \qquad \textbf{B-(36)}$$

where,

$NHSHELL_{y,f,r}$	is the new housing units shell integrity index by year, fuel and Census Division,
$TECHG$	is a parameter representing the annual increase in new shell integrity due to technology improvements (assumed to be 1.0 percentage points of the base year index per year),
$PRIDELTA_{f,r}$	is the percent change in price of the fuel by Census Division in 5 percnetage point increments,

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

The cooling shell indices are linked to the heating shell index calculations,

$$\frac{\sum_{eg} EHSHELL_{y,f(eg),r} \times \left(HTESE_{y,eg,b,r} + HTRP90_{y,eg,b,\ldots}\right.}{\sum_{b}\sum_{eg}\left(HTESE_{y,eg,b,r} + HTRP90_{y,eg,b,r} + HTSR9\ldots\right.} \qquad \textbf{B-(37)}$$

where,

$ECSHELL_{y,r}$	is the existing housing units cooling shell efficiency index by year and Census Division,
$EHSHELL_{y,f(eg),r}$	is the heating shell integrity index for existing housing by year, fuel for equipment type eg and Census Division,
$HTSR90_{y,eg,b,r}$	is the surviving post-1990 vintage general equipment in pre-1991 housing units in the current year by housing type and Census Division,
$HTRP90_{y,eg,b,r}$	is the number of replacement (post-1990 vintage) equipment demanded in pre-1991 housing units by housing type and Census Division, and
$HTESE_{y,eg,b,r}$	is the surviving pre-1991 vintage stock of equipment in pre-1991 vintage housing units by housing type and Census Division.

$$NCSHELL_{y,r} = \frac{\sum_{b}\sum_{eg} NHSHELL_{y,f,r} \times HTRADD_{y,eg,b,r}}{\sum_{b}\sum_{eg} HTRADD_{y,eg,b,r}} \qquad \textbf{B-(38)}$$

where,

$NCSHELL_{y,r}$	is the new housing unit cooling shell efficiency index by year and Census Division,
$NHSHELL_{y,f,r}$	is the new housing units heating shell efficiency index by year, fuel and Census Division, and
$HTRADD_{y,eg,b,r}$	is the number of post-1990 vintage equipment added to post-1990 housing units by housing type, Census Division and forecast year.

The average post-1990 housing shell indices are calculated as,

$$\frac{\sum_{eg}\left[NHSHELL_{y,f,r}\times HTRADD_{y,eg,b,r} + AHSHELL_{y-1,f,r}\times(HTRREP_{y,eg}\right.}{\sum_{b}\sum_{eg}\left[HTRADD_{y,eg,b,r} + HTRREP_{y,eg,b,r} + HTRSUR_{y,eg,}\right.} \qquad \textbf{B-(39)}$$

where,

$AHSHELL_{y,f,r}$	is the average heating shell index by year, fuel and Census Division,
$NHSHELL_{y,f,r}$	is the new housing units shell integrity index by year, fuel and Census Division,
$HTRADD_{y,eg,b,r}$	is the number of equipment units installed in new construction by housing type, Census Division and forecast year,
$HTRREP_{y,eg,b,r}$	is the number of equipment replacements of post-1990 equipment in post-1990 housing units, and
$HTRSUR_{y,eg,b,r}$	is the surviving post-1990 equipment purchased as additions or replacement in post-1990 housing units by housing type and Census Division.

$$\frac{\sum\sum_{eg}\left[AHSHELL_{y,f,r}\times(HTRADD_{y,eg,b,r} + HTRREP_{y,q,b,r} +\right.}{\sum_{b}\sum_{eg}\left[HTRADD_{y,eg,b,r} + HTRREP_{y,eg,b,r} + HTRSU\right.}$$

B-(40)

where,

$ACSHELL_{y,f,r}$	is the average cooling shell index by year, fuel and Census Division,
$AHSHELL_{y,f,r}$	is the average heating shell index by year, fuel and Census Division,
$HTRADD_{y,eg,b,r}$	is the number of post-1990 vintage equipment added to post-1990 housing units by housing type, Census Division and forecast year,
$HTRREP_{y,eg,b,r}$	is the number of equipment replacements of post-1990 equipment in post-1990 housing units, and
$HTRSUR_{y,eg,b,r}$	is surviving post-1990 equipment purchased as additions or replacements in post-1990 housing units by housing type and Census Division.

$$= \begin{cases} HTUEC_{r,eg,b} \times \left[1 + \dfrac{\left(WTHEFFN_{y,eg,b,r} - \frac{1}{BSEFF_{eg}}\right)}{\frac{1}{BSEFF_{eg}}} \right] & ,\ if \\ HTUEC_{r,eg,b} & ,\ ot \end{cases} \qquad \textbf{B-(41)}$$

where,

$HNUEC_{y,eg,b,r}$	is the unit energy consumption by year for new equipment by housing type and Census Division,
$WTHEFFN_{y,eg,b,r}$	is the equipment efficiency by year, general equipment type, housing type and Census Division,
$BSEFF_{eg}$	is the average efficiency of the general equipment type,
$HTUEC_{r,eg,b}$	is unit energy consumption for surviving equipment in pre-1991 housing by Census Division, general equipment type and housing type.

$$\left\{ \begin{array}{ll} HTUEC_{r,eg,b} \times \left[1 + \frac{(WTHEFFR_{y,eg,b,r} - \frac{1}{HTEFF_{y,eg}})}{\frac{1}{HTEFF_{y,eg}}} \right] & , \; if \\ HTUEC_{r,eg,b} & , \; ot \end{array} \right. \quad \text{B-(42)}$$

where,

$HRUEC_{y,eg,b,r}$ is the replacement equipement unit energy consumption by year, general equipment type, housing type and Census Division, and

$HTEFF_{y,eg}$ is the efficiency of retiring 1990 vintage equipment by year.

$$\begin{array}{ll} HNUEC_{y,eg,b,r} \, , & if \; y=1991 \\ HNUEC_{y,eg,b,r} \, , & if \; the \; equ \\ \multicolumn{2}{c}{\frac{[HTRP90_{y,eg,b,r} \times HRUEC_{y,eg,b,r} + (HTRADD_{y,eg,b,r} + HTRREP_{y,eg,b,r}) \times HNUEC_{y,eg,b,r} + (HTRSR90_{y,eg,b,r} + HTRSUR_{y,eg,b,r}) \times HAUEC_{y-1,eg,b,r}}{[HTRP90_{y,eg,b,r} + HTRREP_{y,eg,b,r} + HTRADD_{y,eg,b,r} + HTRSR90_{y,eg,b,r} + HTRSUR_{y,eg,b,r}]}} \end{array} \quad \text{B-(43)}$$

where,

$HAUEC_{y,eg,b,r}$ is the average unit energy consumption general equipment type, housing type and Census Division.

$$\left(\begin{array}{l} HTESE_{y,eg,b,r} \times HTUEC_{r,eg,b} \times EHSHELL_{y,f,r} \\ + HTRADD_{y,eg,b,r} \times HNUEC_{y,eg,b,r} \times NHSHELL_{y,f,r} \\ + HTRP90_{y,eg,b,r} \times HRUEC_{y,eg,b,r} \times EHSHELL_{y,f,r} \end{array}\right) \times \left(\frac{PRICES_{y,f,r}}{PRICES_{y-1,f,r}}\right)^{\alpha} \Bigg] \times (1 \qquad \textbf{B-(44)}$$

$$\left(\begin{array}{l} HTESE_{y,eg,b,r} \times HTUEC_{r,eg,b} \times EHSHELL_{y,f,r} \\ HTRADD_{y,eg,b,r} \times HNUEC_{y,eg,b,r} \times NHSHELL_{y,f,r} \\ HTRP90_{y,eg,b,r} \times HRUEC_{y,eg,b,r} \times EHSHELL_{y,f,r} \\ HTSR90_{y,eg,b,r} \times HAUEC_{y-1,eg,b,r} \times EHSHELL_{y,f,r} \\ HTRREP_{y,eg,b,r} \times HNUEC_{y,eg,b,r} \times AHSHELL_{y-1,f,r} \\ HTRSUR_{y,eg,b,r} \times HAUEC_{y-1,eg,b,r} \times AHSHELL_{y-1,f,r} \end{array}\right) \times \left(\frac{PRICES_{y,f,r}}{PRICES_{y-1,f,r}}\right)^{\alpha} \Bigg] \qquad \textbf{B-(45)}$$

where,

$HTRCON_{y,f,r}$	is the consumption for the service category,
$HTSR90_{y,eg,b,r}$	is the surviving post-1990 vintage general equipment in pre-1991 housing units in the current year by housing type and Census Division,
$HTRP90_{y,eg,b,r}$	is the number of replacement (post-1990 vintage) equipment demanded in pre-1991 housing units by housing type and Census Division, and
$HTRREP_{y,eg,b,r}$	is the number of equipment replacements of post-1990 equipment in post-1990 housing units,
$HTRSUR_{y,eg,b,r}$	is surviving post-1990 equipment purchased as additions or replacements in post-1990 housing units by housing type and Census Division.
$HTRADD_{y,eg,b,r}$	is the number of post-1990 vintage equipment added to post-1990 housing units by housing type, Census Division and forecast year,
$HTESE_{y,eg,b,r}$	is the surviving pre-1991 vintage stock of equipment in pre-1991

vintage housing units by housing type and Census Division.

$EHSHELL_{y,f,r}$	is the heating shell integrity index for existing housing by year, fuel and Census Division,
$NHSHELL_{y,f,r}$	is the new housing units shell integrity index by year, fuel and Census Division,
$AHSHELL_{y,f,r}$	is the average heating shell index by year, fuel and Census Division,
$HTUEC_{r,eg,b}$	is unit energy consumption for surviving equipment in pre-1991 housing by Census Division, general equipment type and housing type,
$HRUEC_{y,eg,b,r}$	is the replacement equipement unit energy consumption by year, general equipment type, housing type and Census Division.
$HAUEC_{y,eg,b,r}$	is the average unit energy consumption general equipment type, housing type and Census Division,
$PRICES_{f,r,y}$	is the fuel price by fuel, Census Division and year,
α	is the short-term price elasticity, and
$EPACTH_y$	is the projected savings from window labeling program in year y, and
$HDDADJ_r$	is the heating degree day adjustment factor by region to correct for the unusually warm weather during the RECS survey year.

SPACE COOLING

RDCLEQT (Project Existing Cooling Equipment)

For y = 1990:

$$\ldots 990_{,eg,b,r} = HTESE_{1990,eg,b,r} \;\forall\; elec,\ gas,\ geo\ heat \qquad \textbf{B-(46)}$$

$$\ldots 990_{,eg,b,r} = \frac{CLSHR_{eg,b,r}}{100} \times EH_{1990,b,r} \quad \forall\; non\text{-}heat \qquad \textbf{B-(47)}$$

where,

$CLESE_{1990,eg,b,r}$ is the base year space cooling equipment stock by housing type and Census Division,

$HTESE_{1990,eg,b,r}$ is the base year number of heat pumps for space heating by housing type and Census Division,

$CLSHR_{eg,b,r}$ is the base year market share of space cooling equipment by building type and Census Division, and

$EH_{1990,b,r}$ is the base year existing (pre-1991 vintage) housing stock by housing type and Census Division.

For y > 1990:

$$\ldots_{,eg,b,r} = HTESE_{y,eg,b,r} \quad \forall\; elec,\ gas,\ geo\ heat \qquad \textbf{B-(48)}$$

$$\ldots LESE_{1990,eg,b,r} \times SVRTE_{y-1990,L_{min},L_{max}} \times HDR_b^{y-1990} \;\forall \qquad \textbf{B-(49)}$$

where,

$CLESE_{y,eg,b,r}$ is the amount of surviving pre-1991 vintage space cooling equipment in pre-1991 vintage housed by housing type and Census Division,

$HTESE_{y,eg,b,r}$ is the surviving number of original heat pumps used for space heating in pre-1991 housing units by housing type and Census Division,

$SVRTE_{y-1990,Lmin,Lmax}$ is the equipment survival rate,

HDR_b is the housing survival rate by housing type, and

$y\text{-}1990$ is the age of the pre-1991 vintage equipment.

RACTEC (Room air conditioning equipment choice)

$$ {}_{es,b,r} = PRICES_{electricty,r,y} \times \left[USAGE_{r,b} \times \left(1 + \frac{\frac{1}{EFF_{es}}}{\overline{B\ldots}} \right. \right. \qquad \text{B-(50)} $$

where,

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

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

$USAGE_{r,b}$ is the electricity unit energy consumption of room air conditioning equipment by Census Division and housing type,

EFF_{es} is the specific equipment efficiency, and

$BASEFF$ is the 1990 stock-average room air conditioner equipment efficiency.

The following variables are computed as in the equations indicated:

$LFCY_{y,es,b,r}$ is the specific room air conditioner's life cycle cost by year, housing type and Census Division. It is computed as in B-12 above.

$EQWTN_{y,es,b,r}$ is the equipment weight for new specific equipment by housing type, Census Division and year. It is computed as in B-13 above.

$EQWTR_{y,es,b,r}$ is the equipment weight for replacement specific equipment by housing type, Census Division and year. It is computed as in B-14 above.

$TOTEWTN_{y,eg,b,r}$ is the sum of specific equipment weights for the new general equipment type. It is computed as in B-15 above.

$TOTEWTR_{y,eg,b,r}$ is the sum of specific equipment weights for the new general equipment type. It is computed as in B-16 above.

$$RRACSHR_{y,es,b,r} = \frac{EQWTR_{y,es,b,r}}{TOTEWTR_{y,eg,b,r}} \qquad \textbf{B-(51)}$$

$$NRACSHR_{y,es,b,r} = \frac{EQWTN_{y,es,b,r}}{TOTEWTN_{y,eg,b,r}} \qquad \textbf{B-(52)}$$

where,

$NRACSHR_{y,es,b,r}$ is the new market share for the new room air conditioner specific equipment type by year, housing type and Census Division,

$RRACSHR_{y,es,b,r}$ is the new market share for the new room air conditioner specific equipment type by year, housing type and Census Division,

$TOTEWTN_{y,eg,b,r}$ is the sum of specific equipment weights for the new general equipment type,

$TOTEWTR_{y,eg,b,r}$ is the sum of specific equipment weights for the new general equipment type,

$EQWTN_{y,es,b,r}$ is the specific equipment weight for new equipment, and

$EQWTR_{y,es,b,r}$ is the specific equipment weight for replacement equipment.

$$R_{y,RAC,b,r} = \begin{cases} \dfrac{\sum_{es}\left[\dfrac{RRACSHR_{y,es,b,r}}{EFF_{y,es}}\right]}{\sum_{es} RRACSHR_{y,es,b,r}} & , \sum_{es} RRACSHR_{y,es,} \\ \dfrac{1}{BASEFF} & , otherwise \end{cases} \qquad \textbf{B-(53)}$$

$$N_{y,RAC,b,r} = \begin{cases} \dfrac{\sum_{es}\left[\dfrac{NRACSHR_{y,es,b,r}}{EFF_{y,es}}\right]}{\sum_{es} NRACSHR_{y,es,b,r}} & , \sum_{es} NRACSHR_{y,es,} \\ \dfrac{1}{BASEFF} & , otherwise \end{cases} \qquad \textbf{B-(54)}$$

where,

$WTACEFN_{y,RAC,b,r}$	is the weighted efficiency of new room air conditioners by year, housing type and Census Division,
$WTACEFR_{y,RAC,b,r}$	is the weighted efficiency of replacement room air conditioners by year, housing type and Census Division,
$NRACSHR_{y,es,b,r}$	is the new market share for the new room air conditioner specific equipment type by year, housing type and Census Division,
$RRACSHR_{y,es,b,r}$	is the new market share for the new room air conditioner specific equipment type by year, housing type and Census Division,
EFF_{es}	is the specific equipment efficiency, and
$BASEFF$	is the 1990 stock-average room air conditioner equipment efficiency.

CACTEC (Central room air conditioning equipment choice)

The following variables are computed as in the equations indicated:

$OPCOST_{y,es,b,r}$ is the operating cost for the specific central air conditioner equipment type by housing type, Census Division and year. It is computed as in B-49 above.

$LFCY_{y,es,b,r}$ is the specific central air conditioner's life cycle cost by year, housing type and Census Division. It is computed as in B-12 above.

$EQWTN_{y,es,b,r}$ is the equipment weight for new specific equipment by housing type, Census Division and year. It is computed as in B-13 above.

$EQWTR_{y,es,b,r}$ is the equipment weight for replacement specific equipment by housing type, Census Division and year. It is computed as in B-14 above.

$TOTEWTN_{y,eg,b,r}$ is the sum of specific equipment weights for the new general equipment type. It is computed as in B-15 above.

$TOTEWTR_{y,eg,b,r}$ is the sum of specific equipment weights for the new general equipment type. It is computed as in B-16 above.

$$CSHR_{y,es,b,r} = \begin{cases} \dfrac{EQWTN_{y,es,b,r}}{TOTEWTN_{y,eg,b,r}} & , TOTEWTN_{y,eg,b,r} \\ 0 & , otherwise \end{cases} \qquad \textbf{B-(55)}$$

$$CSHR_{y,es,b,r} = \begin{cases} \dfrac{EQWTR_{y,es,b,r}}{TOTEWTR_{y,eg,b,r}} & , TOTEWTR_{y,eg,b,r} \\ 0 & , otherwise \end{cases} \qquad \textbf{B-(56)}$$

where,

$NCACSHR_{y,es,b,r}$ is the new market share for the new central air conditioner specific equipment type by year, housing type and Census Division,

$RCACSHR_{y,es,b,r}$	is the new market share for the new central air conditioners specific equipment type by year, housing type and Census Division,
$TOTEWTN_{y,eg,b,r}$	is the sum of specific equipment weights for the new general equipment type,
$TOTEWTR_{y,eg,b,r}$	is the sum of specific equipment weights for the new general equipment type,
$EQWTN_{y,es,b,r}$	is the specific equipment weight for new equipment, and
$EQWTR_{y,es,b,r}$	is the specific equipment weight for replacement equipment.

$$N_{y,CAC,b,r} = \begin{cases} \dfrac{\sum_{es}\left[\dfrac{NCACSHR_{y,es,b,r}}{EFF_{es}}\right]}{\sum_{es} NCACSHR_{y,es,b,r}} , & \sum_{es} NCACSHR_{y,es,} \\ \dfrac{1}{BASEFF} , & otherwise \end{cases} \qquad \textbf{B-(57)}$$

$$R_{y,CAC,b,r} = \begin{cases} \dfrac{\sum_{es}\left[\dfrac{RCACSHR_{y,es,b,r}}{EFF_{es}}\right]}{\sum_{es} RCACSHR_{y,es,b,r}} , & \sum_{es} RCACSHR_{y,es,} \\ \dfrac{1}{BASEFF} , & otherwise \end{cases} \qquad \textbf{B-(58)}$$

where,

$WTACEFN_{y,RAC,b,r}$	is the weighted efficiency of new central air conditioners by year, housing type and Census Division,
$WTACEFR_{y,RAC,b,r}$	is the weighted efficiency of replacement central air conditioners

by year, housing type and Census Division,

$NCACSHR_{y,es,b,r}$ is the new market share for the new central air conditioner specific equipment type by year, housing type and Census Division,

$RCACSHR_{y,es,b,r}$ is the new market share for the new central air conditioner specific equipment type by year, housing type and Census Division,

EFF_{es} is the specific equipment efficiency, and

$BASEFF$ is the 1990 stock-average room air conditioner equipment efficiency.

COOLAD (Additions and replacements of cooling equipment)

$$CLADD_{y,CAC,b,r} = HSEADD_{y,b,r} \times CACSAT_{b,r} \quad \textbf{B-(59)}$$

where,

$CLADD_{y,CAC,b,r}$ is the number of central air conditioners added to new (post-1990) housing units by year, housing type and Census Division,

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

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

$$CLADD_{y,RAC,b,r} = HSEADD_{y,b,r} \times RACSAT_{b,r} \quad \textbf{B-(60)}$$

where,

$CLADD_{y,RAC,b,r}$ is the number of room air conditioners added to new (post-1990) housing units by year, housing type and Census Division,

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

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

$$CLADD_{y,HP,b,r} = HTRADD_{y,HP,b,r} \qquad \forall \; heat\ pumps \tag{B-(61)}$$

where,

$CLADD_{y,HP,b,r}$	is the number of heat pumps used for space cooling added to new (post-1990) housing units by year, housing type and Census Division, and
$HTRADD_{y,HP,b,r}$	is the number of heat pumps used for space heating added to new housing units by year, housing type and Census Division.

$$= \begin{cases} 0.1 \times CLADD_{y,elec\ HP,b,r}\ ,\ if\ CLADD_{y,CAC,b,r} \leq \sum_{eg=3}^{5} \\ CLADD_{y,CAC,b,r} - \sum_{eg=3}^{5} CLADD_{y,eg,b,r}\ ,\ otherwise \end{cases} \tag{B-(62)}$$

where,

$CLADD_{y,eg,b,r}$	is the number of general space cooling equipment added to new (post-1990) housing units by year, housing type and Census Division,
eg	is the general space cooling equipment type where 1=RAC, 2=CAC, 3=Electric heat pump, 4= Geothermal heat pump, and 5=Natural gas heat pump.

$$9_{y,eg,b,r} = \sum_{t=1991}^{y-1} \Big[CLRP90_{t,eg,b,r} \times HDR_b^y \times SVRTE_{y-t,L} \tag{B-(63)}$$

$$for\ eg = RAC, CAC$$

$$CLSR90_{y,eg,b,r} = HTSR90_{y,eg,b,r} \quad \forall \text{ heat pumps} \qquad \textbf{B-(64)}$$

where,

$CLSR90_{y,eg,b,r}$ is the surviving post-1990 cooling equipment in pre-1991 housing units by year, housing type and Census Division,

$CLRP90_{y,eg,b,r}$ is the number of replacement (post-1990 vintage) equipment required for pre-1991 housing units by year, housing type and Census Division,

HDR_b is the housing survival rate by housing type, and

$SVRTE_{y-t,Lmin,Lmax}$ is the equipment survival rate.

$$CLND90_{y,eg,b,r} = \begin{pmatrix} CLESE_{1990,eg,b,r} \times HDR_b \times PNRT \text{ , if } y=1990 \\ CLND90_{y-1,eg,b,r} \times HDR_b \times PNRT \text{ , if } y>1990 \end{pmatrix} \qquad \textbf{B-(65)}$$

$$\text{for } eg=RAC,CAC$$

where,

$CLND90_{y,eg,b,r}$ is the total amount of room and central air conditioning equipment demanded in pre-1991 housing each year by housing type and Census Division,

$CLESE_{1990,eg,b,r}$ is the pre-1991 air conditioning equipment in pre-1991 housing units in the base year by housing type and Census Division,

HDR_b is the housing survival rate by housing type, and

$$PNRT = \begin{pmatrix} 1.0 + PEN\_RATE_r \text{ ,} & \forall \text{ singlefamilyhomeswithCAC} \\ 1.0 \text{ ,} & \text{otherwise} \end{pmatrix} \qquad \textbf{B-(66)}$$

where,

$PNRT$ is market penetration of central air conditioning equipment into single family homes which contain existing ductwork for the space heating system.

$$0_{y,eg,b,r} = CLND90_{y,eg,b,r} - CLESE_{y,eg,b,r} - CLSR90_{y}$$
$$for\ eg = RAC, CAC \qquad \textbf{B-(67)}$$

$$CLRP90_{y,eg,b,r} = HTRP90_{y,eg,b,r} \quad \forall\ heat\ pumps \qquad \textbf{B-(68)}$$

where,

$CLSR90_{y,eg,b,r}$	is the surviving post-1990 central and room air conditioning equipment in pre-1991 housing units by year, housing type and Census Division,
$CLRP90_{y,eg,b,r}$	is the number of replacement (post-1990 vintage) equipment demanded in pre-1991 housing units by year, housing type and Census Division,
$CLESE_{y,es,b,r}$	is the amount of surviving pre-1991 vintage space cooling equipment in pre-1991 vintage housed by housing type and Census Division,
$CLND90_{y,eg,b,r}$	is the total amount of room and central air conditioning equipment demanded in pre-1991 housing each year by housing type and Census Division, and
$HTRP90_{y,eg,b,r}$	is the number of heat pump replacements for space heating in pre-1991 housing units by year, housing type and Census Division.

$$SA_{y,eg,b,r} = \sum_{t=1991}^{y-1} \left[CLADD_{t,eg,b,r} \times HDR_b^{y-t} \right] \qquad \textbf{B-(69)}$$
$$for\ eg = RAC,\ CAC$$

where,

$SA_{y,eg,b,r}$	is the number of surviving air conditioning units originally purchased for new housing additions by year, housing type and Census Division,
$CLADD_{t,eg,b,r}$	is the number of air conditioning units added to new (post-1990) housing units by year, housing type and Census Division, and
HDR_b	is the housing demolition rate by housing type.

$$_{g,b,r} = \sum_{t=1991}^{y-1} \left[\left(CLADD_{t,eg,b,r} + CLREP_{t,eg,b,r} \right) \times HDR_b^{y-t} \times SVRTE \right.$$
$$for\ eg = RAC, CAC \qquad \textbf{B-(70)}$$

$$SUR_{y,eg,b,r} = HTRSUR_{y,eg,b,r} \qquad for\ eg = heat\ pum \qquad \textbf{B-(71)}$$

where,

$CLSUR_{y,eg,b,r}$	is the number of surviving room and central air conditioners in post-1990 housing units by year, housing type and Census Division,
$CLADD_{t,eg,b,r}$	is the number of general space cooling equipment added to new (post-1990) housing units by year, housing type and Census Division,
$CLREP_{t,eg,b,r}$	is the number of equipment replacements demanded in post-1990 housing units by year, housing type and Census Division,
HDR_b	is the housing demolition rate by housing type, and
$SVRTE_{y-t,Lmin,Lmax}$	is the equipment survival rate.

$$_{,eg,b,r} = \left(\begin{array}{ll} SA_{y,eg,b,r} - CLSUR_{y,eg,b,r} & , if\ eg \in [RAC, \\ HTRREP_{y,eg,b,r} & , if\ eg \in [heat \end{array} \right. \qquad \textbf{B-(72)}$$

where,

$CLREP_{y,eg,b,r}$	is the number of equipment replacements demanded in post-1990 housing units by year, housing type and Census Division,
$CLSUR_{y,eg,b,r}$	is the number of surviving room and central air conditioners in post-1990 housing units by year, housing type and Census Division,
$SA_{y,eg,b,r}$	is the amount surviving central air conditioners originally purchased for new housing additions by year, housing type and Census Division, and
$HTRREP_{y,eg,b,r}$	is the number of heat pumps replaced for space heating in post-1990 housing units by year, housing type and Census Division.

CLCNS (Cooling Consumption)

$$_{.\,elec\ HP,b,r} = \left(\begin{array}{ll} \dfrac{\sum_{es} \left[\dfrac{NHTRSHR_{y,es,b,r}}{HPEFF_{y,es}} \right]}{\sum_{es} NHTRSHR_{y,es,b,r}} & , \sum_{es} NHTRSHR_{y,ele} \\ \dfrac{1}{BSEFF_{electric\ hp}} & , otherwise \end{array} \right. \qquad \textbf{B-(73)}$$

where,

$WTACEFN_{y,elec\ HP,b,r}$	is the weighted efficiency of new electric heat pumps by year, housing type and Census Division,
$HPEFF_{es}$	is the efficiency rating of the specific heat pump equipment type,
$BSEFF_{electric\ hp}$	is the 1990 stock-average efficiency of electric heat pumps, and
$NHTRSHR_{y,eg,b,r}$	is the market share of new general heating equipment by year, housing type and Census Division.

$$
CEFN_{y,geo\ HP,b,r} = \begin{cases} \dfrac{1}{GEOEFF_{es}} & , HSYSSHR_{y,geo\ HP,b,r} \\ \dfrac{1}{BSEFF_{geo\ HP}} & , otherwise \end{cases} \qquad \textbf{B-(74)}
$$

where,

$WTACEFN_{y,geo\ HP,b,r}$	is the weighted efficiency of new geothermal heat pumps by year, housing type and Census Division,
$GEOEFF_{es}$	is the efficiency rating of geothermal heat pump equipment type,
$BSEFF_{geo\ HP}$	is the 1990 stock-average efficiency of geothermal heat pumps, and
$HSYSSHR_{y,eg,b,r}$	is the base year market share of geothermal heat pumps by housing type and Census Division.

$$
CEFN_{y,gas\ HP,b,r} = \begin{cases} \dfrac{1}{GHPEFF_{es}} & , HSYSSHR_{y,gas\ HP,b,r} \\ \dfrac{1}{BSEFF_{gas\ HP}} & , otherwise \end{cases} \qquad \textbf{B-(75)}
$$

where,

$WTACEFN_{y,gsa\ HP,b,r}$	is the weighted efficiency of new natural gas heat pumps by year, housing type and Census Division,
$GHPEFF_{es}$	is the efficiency rating of natural gas heat pump equipment type,
$BSEFF_{gas\ HP}$	is the 1990 stock-average efficiency of gas heat pumps, and
$HSYSSHR_{y,eg,b,r}$	is the base year market share of gas heat pumps by housing type and Census Division.

$$_{elec\ HP,b,r} = \left(\begin{array}{ll} \dfrac{\sum_{es}\left[\dfrac{RHTRSHR_{y,eg,b,r}}{HPEFF_{y,es}}\right]}{\sum_{es} RHTRSHR_{y,eg,b,r}} & , \sum_{es} RHTRSHR_{y,elec} \\ \dfrac{1}{BSEFF_{electric\ hp}} & , otherwise \end{array} \right. \qquad \textbf{B-(76)}$$

where,

$WTACEFR_{y,elec\ HP,b,r}$	is the weighted efficiency of replacement electric heat pumps by year, housing type and Census Division,
$HPEFF_{es}$	is the efficiency rating of the specific heat pump equipment type,
$BSEFF_{electric\ hp}$	is the 1990 stock-average efficiency of electric heat pumps, and
$RHTRSHR_{y,eg,b,r}$	is the market share of replacement general heating equipment by year, housing type and Census Division.

$$EFR_{y,geo\ HP,b,r} = \left(\begin{array}{ll} \dfrac{1}{GEOEFF_{es}} & , RHTRSHR_{y,geo_{HP},b,} \\ \dfrac{1}{BSEFF_{geo\ hp}} & , otherwise \end{array} \right. \qquad \textbf{B-(77)}$$

where,

$WTACEFR_{y,geo\ HP,b,r}$	is the weighted efficiency of replacement geothermal heat pumps by year, housing type and Census Division,
$GEOEFF_{es}$	is the efficiency rating of geothermal heat pump equipment type,
$BSEFF_{geo\ HP}$	is the 1990 stock-average efficiency of geothermal heat pumps, and
$RHTRSHR_{y,eg,b,r}$	is the market share of replacement geothermal heat pumps equipment type by year, housing type and Census Division.

$$
EFR_{y,gas\ HP,b,r} = \begin{cases} \frac{1}{GHPEFF_{es}} & , RHTRSHR_{y,gas\ HP,b} \\ \frac{1}{BSEFF_{gas\ hp}} & , otherwise \end{cases}
$$ **B-(78)**

where,

$WTACEFN_{y,geo\ HP,b,r}$	is the weighted efficiency of replacement natural gas heat pumps by year, housing type and Census Division,
$GHPEFF_{es}$	is the efficiency rating of natural gas heat pump equipment type,
$BSEFF_{gas\ HP}$	is the average efficiency of gas heat pumps, and
$RHTRSHR_{y,eg,b,r}$	is the market share of replacement natural gas heat pumps equipment type by year, housing type and Census Division.

$$
: \begin{cases} CLUEC_{r,eg,b} \times \left[1 + \frac{\left(WTACEFN_{y,eg,b,r} - \frac{1}{BSEFF_{eg}} \right)}{\frac{1}{BSEFF_{eg}}} \right] & , \quad if\ WTACE \\ CLUEC_{r,eg,b} & , \quad otherwi \end{cases}
$$ **B-(79)**

where,

$CNUEC_{y,eg,b,r}$	is the efficiency weighted unit energy consumption of new air conditioning equipment by year, housing type and Census Division,
$CLUEC_{r,eg,b}$	is the unit energy consumption of the general space cooling equipment type by housing type and Census Division,
$WTACEFN_{y,eg,b,r}$	is the weighted efficiency of new space cooling equipment by

year, housing type and Census Division,

$BSEFF_{eg}$ is the 1990 stock-average efficiency of space cooling the general equipment type.

$$\begin{cases} CLUEC_{r,eg,b} \times \left[1 + \dfrac{\left(WTACEFR_{y,eg,b,r} - \frac{1}{CLEFF_{y,eg}}\right)}{\frac{1}{CLSEFF_{y,eg}}}\right], & if\ WTACE \\ CLUEC_{r,eg,b}, & otherwi \end{cases} \qquad \textbf{B-(80)}$$

where,

$CRUEC_{y,eg,b,r}$ is the efficiency weighted unit energy consumption of replacement air conditioning equipment by year, housing type and Census Division,

$CLUEC_{r,eg,b}$ is the unit energy consumption of the general space cooling equipment type by housing type and Census Division,

$WTACEFR_{y,eg,b,r}$ is the weighted efficiency of replacement space cooling equipment by year, housing type and Census Division,

$CLEFF_{y,eg}$ is the retiring efficiency of the 1990 equipment stock by general equipment type and year.

$$\begin{cases} CNUEC_{y,eg,b,r}, & if\ y=1991 \\ \dfrac{\begin{gathered}\left[CLRP90_{y,eg,b,r} \times CRUEC_{y,eg,b,r}\right] \\ + \left[(CLADD_{y,eg,b,r} + CLREP_{y,eg,b,r}) \times CNUEC_{y,eg,b,r}\right] \\ + \left[(CLSR90_{y,eg,b,r} + CLSUR_{y,eg,b,r}) \times CAUEC_{y-1,eg,b,r}\right]\end{gathered}}{90_{y,eg,b,r} + CLREP_{y,eg,b,r} + CLADD_{y,eg,b,r} + CLSR90_{y,eg,b,r} + CLSUR_{y,eg,b,r})}, & \\ CNUEC_{y,eg,b,r}, & otherwise \end{cases} \qquad \textbf{B-(81)}$$

where,

$CAUEC_{y,eg,b,r}$ is the average unit energy consumption of the space cooling general equipment by year, housing type and Census Division,

$CLSR90_{y,eg,b,r}$ is the surviving post-1990 central and room air conditioning equipment in pre-1991 housing units by year, housing type and Census Division,

$CLRP90_{y,eg,b,r}$ is the number of replacement (post-1990 vintage) equipment demanded in pre-1991 housing units by year, housing type and Census Division,

$CRUEC_{y,eg,b,r}$ is the efficiency weighted unit energy consumption of replacement air conditioning equipment by year, housing type and Census Division,

$CLREP_{y,eg,b,r}$ is the number of equipment replacements demanded in post-1990 housing units by year, housing type and Census Division,

$CLSUR_{y,eg,b,r}$ is the number of surviving room and central air conditioners in post-1990 housing units by year, housing type and Census Division,

$CLADD_{y,eg,b,r}$ is the number of general space cooling equipment added to new (post-1990) housing units by year, housing type and Census Division, and

$CNUEC_{y,eg,b,r}$ is the efficiency weighted unit energy consumption of new air conditioning equipment by year, housing type and Census Division.

$$WTACEFN_{1991,eg,b,r} \text{ , if } y=1991$$

$$\frac{\begin{pmatrix}(CLSR90_{y,eg,b,r}+CLSUR_{y,eg,b,r})\times WTACEFA_{y-1,eg,b,r}\\ CLRP90_{y,eg,b,r}+CLADD_{y,eg,b,r}+CLREP_{y,eg,b,r})\times WTACETN_{y,eg,b,r}\end{pmatrix}}{\begin{pmatrix}CLSR90_{y,eg,b,r}+CLSUR_{y,eg,b,r}+CLRP90_{y,eg,b,r}\\ +CLADD_{y,eg,b,r}+CLREP_{y,eg,b,r}\end{pmatrix}} , \qquad \text{B-(82)}$$

$$WTACEFN_{y,eg,b,r} \text{ , otherwise}$$

where,

$WTACEFA_{y,eg,b,r}$	is the weighted average efficiency of space cooling general equipment types by year, housing type and Census Division,
$WTACETN_{y,eg,b,r}$	is weighted average efficiency of new space cooling equipment by year, housing type and Census Division,
$CLSR90_{y,eg,b,r}$	is the surviving post-1990 central and room air conditioning equipment in pre-1991 housing units by year, housing type and Census Division,
$CLRP90_{y,eg,b,r}$	is the number of replacement (post-1990 vintage) equipment demanded in pre-1991 housing units by year, housing type and Census Division,
$CLREP_{y,eg,b,r}$	is the number of equipment replacements demanded in post-1990 housing units by year, housing type and Census Division,
$CLSUR_{y,eg,b,r}$	is the number of surviving room and central air conditioners in post-1990 housing units by year, housing type and Census Division, and
$CLADD_{y,eg,b,r}$	is the number of general space cooling equipment added to new (post-1990) housing units by year, housing type and Census Division.

$$\ldots_{gy,r} = \sum_{b} \left[\begin{pmatrix} CLESE_{y,b,r,geo\ hp} + CLRP90_{y,b,r,geo\ hp} \\ + CLSR90_{y,b,r,geo\ hp} + CLADD_{y,b,r,geo\ hp} \\ + CLSUR_{y,b,r,geo\ hp} + CLREP_{y,b,r,geo\ hp} \end{pmatrix} \times \frac{\left(\frac{CLUEC_{r,elec}}{CLUEC_{r,geo}} \right.}{.33} \right. \qquad \textbf{B-(83)}$$

where,

$CLESE_{y,es,b,r}$	is the amount of surviving pre-1991 vintage space cooling equipment in pre-1991 vintage housed by housing type and Census Division,
$CLSR90_{y,eg,b,r}$	is the surviving post-1990 central and room air conditioning

	equipment in pre-1991 housing units by year, housing type and Census Division,
$CLRP90_{y,eg,b,r}$	is the number of replacement (post-1990 vintage) equipment demanded in pre-1991 housing units by year, housing type and Census Division,
$CLSUR_{y,eg,b,r}$	is the number of surviving room and central air conditioners in post-1990 housing units by year, housing type and Census Division,
$CLADD_{y,eg,b,r}$	is the number of general space cooling equipment added to new (post-1990) housing units by year, housing type and Census Division,
$EPACTC_y$	is the savings from the EPACT window labeling program on space cooling costs by year.

For y = 1991,

$$_{,f,r} = \sum_{b} \sum_{eg} \left[\begin{array}{l} \left(\begin{array}{l} CLESE_{y,eg,b,r} \times CLUEC_{r,eg,b} \times ECSHEL \\ + CLADD_{y,eg,b,r} \times CNUEC_{y,eg,b,r} \times NCSHE \\ + CLRP90_{y,eg,b,r} \times CRUEC_{y,eg,b,r} \times ECSHI \end{array} \right. \\ \times \left(\frac{PRICES_{f,r,y}}{PRICES_{f,r,1990}} \right)^{\alpha} \times (1 - EPACTC_{y}) \times \end{array} \right. \qquad \textbf{B-(84)}$$

For y > 1991,

$$
{}_{,f,r} = \sum_{b}\sum_{eg}\left[\left(\begin{array}{l} CLESE_{y,eg,b,r}\times CLUEC_{r,eg,b}\times ECSHEL \\ +CLADD_{y,eg,b,r}\times CNUEC_{y,eg,b,r}\times NCSHE \\ +CLRP90_{y,eg,b,r}\times CRUEC_{y,eg,b,r}\times ECSHI \\ +CLSR90_{y,eg,b,r}\times CAUEC_{y-1,eg,b,r}\times ECSH \\ +CLREP_{y,eg,b,r}\times CNUEC_{y,eg,b,r}\times ACSHEL \\ +CLSUR_{y,eg,b,r}\times CAUEC_{y-1,eg,b,r}\times ACSHE \end{array}\right. \right. \\ \left. \times\left(\frac{PRICES_{f,r,y}}{PRICES_{f,r,y-1}}\right)^{\alpha}\times(1-EPACTC_{y})\times C \right. \qquad \textbf{B-(85)}
$$

where,

$CLSR90_{y,eg,b,r}$ is the surviving post-1990 central and room air conditioning equipment in pre-1991 housing units by year, housing type and Census Division,

$CLRP90_{y,eg,b,r}$ is the number of replacement (post-1990 vintage) equipment demanded in pre-1991 housing units by year, housing type and Census Division,

$CLREP_{y,eg,b,r}$ is the number of equipment replacements demanded in post-1990 housing units by year, housing type and Census Division,

$CLSUR_{y,eg,b,r}$ is the number of surviving room and central air conditioners in post-1990 housing units by year, housing type and Census Division,

$CLADD_{y,eg,b,r}$ is the number of general space cooling equipment added to new (post-1990) housing units by year, housing type and Census Division,

$CLESE_{y,es,b,r}$ is the amount of surviving pre-1991 vintage space cooling equipment in pre-1991 vintage housed by housing type and Census Division,

$ECSHELL_{y,r}$ is the existing housing units cooling shell efficiency index by year and Census Division,

$NCSHELL_{y,r}$ is the new housing units cooling shell efficiency index by year and Census Division,

$ACSHELL_{y,r}$ is the average cooling shell index by year, fuel and Census Division,

$CAUEC_{y,eg,b,r}$ is the average unit energy consumption of the space cooling general equipment by year, housing type and Census Division,

$CNUEC_{y,eg,b,r}$ is the efficiency weighted unit energy consumption of new air conditioning equipment by year, housing type and Census Division,

$CRUEC_{y,eg,b,r}$ is the efficiency weighted unit energy consumption of replacement air conditioning equipment by year, housing type and Census Division,

$PRICES_{f,r,y}$ are fuel prices by Census Division and forecast year,

α is the short-term price elasticity of space cooling energy demand,

$EPACTC_y$ is the savings from the EPACT window labeling program on space cooling use by year, and

$CDDADJ_r$ is the cooling degree day adjustment factor by region.

Water Heating

RDHWEQ (Project Hot Water Heating Equipment Stock)

For y = 1990,

$$SE_{1990,eg,b,r} = \frac{HWSH_{eg,b,r}}{100} \times EH_{1990,b,r} \quad \forall\ r,b\ anc$$ **B-(86)**

where,

$HWESE_{1990,eg,b,r}$	is the existing stock of equipment in 1990 by housing type and Census Division,
$HWSH_{eg,b,r}$	is the 1990 water heater market share in pre-1991 housing units by general equipment type, housing type and Census Division, and
$EH_{y,b,r}$	is the 1990 stock of housing by housing type and Census Division.

$$SLESE_{1990,r} = EH_{1990,b,r} \times SLSHR_r \quad b=1$$ **B-(87)**

where,

$SLESE_{1990,r}$	is the existing 1990 solar water heaters by Census Division for single-family homes,
$SLSHR_r$	is the 1990 market share of solar water heaters in pre-1991 housing units by Census Division, and
$EH_{1990,b,r}$	is the 1990 stock of housing by housing type and Census Division.

For y > 1990,

$$_{eg,b,r} = HWESE_{1990,eg,b,r} \times SVRTE_{y-1990,L_{min},L_{max}} \times HDI$$ **B-(88)**

where,

$HWESE_{y,eg,b,r}$	is the surviving pre-1991 vintage general water heaters in pre-1991

housing by year, housing type and Census Division,

$SVRTE_{y-1990,Lmin,Lmax}$ is the equipment survival rate, and

HDR_b is the housing demolition rate.

$$E_{y,eg,b,r} = SLESE_{1990,r} \times SVRTE_{y-1990,L_{\min},L_{\max}} \times HDR_b^y \quad \text{for } b\text{=single family} \qquad \text{B-(89)}$$

where,

$SLESE_{y,r}$ is the amount of surviving pre-1991 vintage solar water heaters in pre-1991 housing units by Census Division,

$SVRTE_{y-1990,Lmin,Lmax}$ is the equipment survival rate, and

HDR_b is the housing survival rate by building type.

H2OTEC (Water Heater Equipment Choice)

$$TOTN_{b,r} = \sum_{eg} HSYSSHR_{y,eg,b,r} \qquad \text{B-(90)}$$

where,

$TOTN_{b,r}$ is the sum of the base year market shares of general space heating equipment types by housing type and Census Division, and

$HSYSSHR_{y,eg,b,r}$ is the base year market share of the general space heating equipment type by housing type and Census Division.

$$NH2OSH_{y,eg_{wh},b,r} = \frac{\sum_{eg} HSYSSHR_{y,eg,b,r}}{TOTN_{b,r}} \qquad \text{B-(91)}$$

where,

$NH2OSH_{y,eg,b,r}$ is the market share of new water heater by general equipment type, housing type and Census Division. There are four general equipment types for water heaters: natural gas, electric, distillate, and LPG.

$TOTN_{b,r}$ is the sum of the base year market shares of general space heating equipment types by housing type and Census Division, and

$HSYSSHR_{y,eg,b,r}$ is the base year market share of the general space heating equipment type by housing type and Census Division. There are 11 types of general equipment types for space heaters.

The following variables are computed as in the equations indicated:

$OPCOST_{y,es,b,r}$ is the operating cost for the specific water heater equipment type by housing type, Census Division, and year. It is computed as in B-11 above.

$LFCY_{y,es,b,r}$ is the water heater's life cycle cost by year, housing type and Census Division. It is computed as in B-12 above.

$EQWTN_{y,es,b,r}$ is the equipment weight for new specific equipment by housing type, Census Division, and year. It is computed as in B-13 above.

$EQWTR_{y,es,b,r}$ is the equipment weight for replacement specific equipment by housing type, Census Division, and year. It is computed as in B-14 above.

$TOTEWTN_{y,eg,b,r}$ is the sum of specific equipment weights for the new general equipment type. It is computed as in B-15 above.

$TOTEWTR_{y,egb,r}$ is the sum of specific equipment weights for the new general equipment type. It is computed as in B-16 above.

$EQFSHRN_{y,es,b,r}$ is the fuel share of new specific equipment type by year, housing type and Census Division. It is computed as in B-17 above.

$EQFSHRR_{y,es,b,r}$ is the fuel share of replacement specific equipment type by year, housing type and Census Division. It is computed as in B-18 above.

$$NH2OSHR_{y,es,b,r} = NH2OSH_{y,eg,b,r} \times EQFSHRN_{y,es,r} \qquad \textbf{B-(92)}$$

where,

$NH2OSH_{y,es,b,r}$ is the market share of new water heaters by specific equipment type, housing type and Census Division.

$$FFN_{y,eg,b,r} = \begin{cases} \dfrac{\sum_{es}\left[\dfrac{EQFSHRN_{y,es,b,r}}{EFF_{y,es}}\right]}{\sum_{es} EQFSHRN_{y,es,b,r}} & , EQFSHRN_{y,es,b,} \\ \dfrac{1}{BASEFF_{eg}} & , otherwise \end{cases} \qquad \textbf{B-(93)}$$

$$FFR_{y,eg,b,r} = \begin{cases} \dfrac{\sum_{es}\left[\dfrac{EQFSHRR_{y,es,b,r}}{EFF_{y,es}}\right]}{\sum_{es} EQFSHRR_{y,es,b,r}} & , EQFSHRR_{y,es,b,} \\ \dfrac{1}{BASEFF_{eg}} & , otherwise \end{cases} \qquad \textbf{B-(94)}$$

where,

$WTWEFFN_{y,eg,b,r}$ is the weighted efficiency for new general water heating equipment types by year, housing type and Census Division,

$WTWEFFR_{y,eg,b,r}$ is the weighted efficiency for replacement general water heating equipment types by year, housing type and Census Division,

$EQFSHRN_{y,es,b,r}$ is the market share of new hot water heating equipment defined by its efficiency within a fuel category by building type and Census

Division,

$EQFSHRR_{y,es,b,r}$	is the market share of replacement hot water heating equipment defined by its efficiency within a fuel category by building type and Census Division, and
$BASEFF_{eg}$	is the efficiency of the general water heating equipment types.

WADD (Water Heater Additions and Replacements)

$$SOLADD_{y,r} = HSEADD_{y,single\ family,r} \times SLSHR_r \qquad \textbf{B-(95)}$$

where,

$SOLADD_{y,r}$	is the amount of new solar water heaters purchased for new housing units by year and Census Division,
$HSEADD_{y,b,r}$	is the number of new housing additions in the year by housing type and Census Division, and
$SLSHR_r$	is the penetration level of solar water heaters in new housing units by Census Division.

$$H2OADD_{y,eg,b,r} = HSEADD_{y,b,r} \times NH2OSH_{y,eg,b,r} \qquad \textbf{B-(96)}$$

where,

$H2OADD_{y,eg,b,r}$	is the amount of new general water heating equipment in new housing units by year, 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
$NH2OSH_{y,eg,b,r}$	is the market share for the hot water heating equipment defined by fuel category for the building type and region.

$$)_{y,eg,b,r} = \sum_{t=1991}^{y-1} \Big[HWRP90_{t,eg,b,r} \times SVRTE_{y-t,L_{\min},L_{\max}} \times \qquad \textbf{B-(97)}$$

$$SR90_{y,r} = \sum_{t=1991}^{y-1} \left[SLRP90_{t,r} \times SVRTE_{y-t,L_{min},L_{max}} \times HDR \right. \qquad \text{B-(98)}$$

where,

$SLSR90_{y,r}$	is the surviving post-1990 vintage solar water heating equipment in pre-1991 housing units by year and Census Division,
$HWSR90_{y,eg,b,r}$	is the surviving post-1990 vintage general equipment in pre-1991 housing units by year, housing type and Census Division,
$SLRP90_{t,r}$	is the replacement (post-1990 vintage) solar water heating equipment demanded in pre-1991 single family housing units by year and Census Division,
$HWRP90_{t,eg,b,r}$	is the replacement (post-1990 vintage) equipment demanded in pre-1991 housing units by housing type and Census Division,
$SRVTE_{y-t,Lmin,Lmax}$	is the equipment survival rate, and
HDR_b	is the housing survival rate by building type.

$${}_{b,r} = HWESE_{1990,eg,b,r} \times HDR_b^{y-1990} - HWESE_{y,eg,b,r} - Hw \qquad \text{B-(99)}$$

$$P90_{y,r} = SLESE_{1990,r} \times HDR_b^{y-1990} - SLESE_{y,r} - SLSR9 \qquad \text{B-(100)}$$

where,

$HWRP90_{y,eg,b,r}$	is the number of replacement units demanded in pre-1991 housing units by year, housing type and Census Division,
$HWESE_{y,eg,b,r}$	is surviving pre-1991 vintage equipment in pre-1991 housing units by year, housing type and Census Division,
$SLSR90_{y,r}$	is the surviving post-1990 vintage solar water heating equipment in pre-1991 housing units by year and Census Division for single-family homes,

$HWSR90_{y,eg,b,r}$ is the surviving post-1990 vintage general equipment in pre-1991 housing units by year, housing type and Census Division,

$SLRP90_{y,r}$ is the replacement (post-1990 vintage) solar water heating equipment demanded in pre-1991 housing units by Census Division for single-family homes, and

HDR_b is the housing survival rate.

The following variables are computed as in the equations indicated:

$SA_{y,eg,b,r}$ is the amount of equipment demanded in post-1990 vintage housing by housing type and Census Division. It is computed as in B-30 above using H2OADD instead of HTRADD.

$H2OADD_{t,eg,b,r}$ is the amount of post-1991 water heaters by general equipment types added to new housing units by housing type and Census Divisions.

$H2OSUR_{y,eg,b,r}$ is the surviving post-1990 water heaters by general equipment type in post-1990 housing units by year, housing type and Census Division. It is computed as in B-31 above using H2OADD and H2OREP where appropriate.

$$H2OREP_{y,eg,b,r} = SA_{y,eg,b,r} - H2OSUR_{y,eg,b,r} \qquad \textbf{B-(101)}$$

where,

$H2OREP_{y,eg,b,r}$ is the number of equipment replacements of post-1990 equipment in post-1990 housing units by year, housing type and Census Division.

The following variables are computed as in the equations indicated:

$SA_{y,eg,b,r}$ is the amount of solar water heaters demanded in post-1990 vintage housing by housing type and Census Division. It is computed as in B-30 above using SOLADD instead of HTRADD.

$SOLADD_{y,r}$ is the amount of new solar water heaters purchased for new housing units by year and Census Division.

$SOLSUR_{y,r}$ is the surviving post-1990 solar water heaters in post-1990 housing units by year, housing type and Census Division. It is computed as in B-31 above using SOLADD and SOLREP where appropriate.

$$SOLREP_{y,r} = SA_{y,solar,singlefamily,r} - SOLSUR_{y,r} \qquad \textbf{B-(102)}$$

where,

$SOLREP_{y,r}$ is the amount of replacement units (post-1990 vintage) demanded in post-1990 housing units by year and Census Division.

HWCNS (Hot Water Heater Energy Consumption)

If year < 1995,

$$HWUEC_{r,eg,b} \times \left(1 + \frac{WTWEFFN_{y,eg,b,r} - \frac{1}{BASEFF_{eg}}}{\frac{1}{BASEFF_{eg}}} \right) \text{, if } WT \qquad \textbf{B-(103)}$$

$$HWUEC_{r,eg,b} \text{ , otherwise}$$

If the year ≥ 1995,

$$EC_{r,eg,b} \times EPACT \times \left(1 + \frac{WTWEFFN_{y,eg,b,r} - \frac{1}{BASEFF_{eg}}}{\frac{1}{BASEFF_{eg}}} \right) \text{, if } W \qquad \textbf{B-(104)}$$

$$HWUEC_{r,eg,b} \times EPACT \text{ ,} \quad \text{otherwise}$$

where,

$WNUEC_{y,eg,b,r}$	is the unit energy consumption for new equipment by year, housing type and Census Division,
$HWUEC_{r,eg,b}$	is the unit energy consumption for the general equipment type by housing type and Census Division,
$WTWEFFN_{y,eg,b,r}$	is the weighted efficiency for new general water heating equipment types by year, housing type and Census Division,
$EPACT$	is the fraction by which the UEC must be adjusted to reflect mandated low-flow shower head standards as part of the Energy Policy Act of 1990, and
$BASEFF_{eg}$	is the efficiency of the general water heating equipment types.

$$WUEC_{r,eg,b} \times \left(1 + \frac{WTWEFFR_{y,eg,b,r} - \frac{1}{HWEFF_y},eg}{\frac{1}{HWEFF_y},eg} \right) \text{ , if } W$$

$$HWUEC_{r,eg,b} \text{ , otherwise}$$ **B-(105)**

where,

$WTWEFFR_{y,eg,b,r}$	is the weighted efficiency for replacement general water heating equipment types by year, housing type and Census Division,
$WRUEC_{y,eg,b,r}$	is the unit energy consumption for replacement equipment by year, housing type and Census Division, and
$HWUEC_{r,eg,b}$	is the unit energy consumption for the general equipment type by housing type and Census Division, and
$HWEFF_{y,eg}$	is the efficiency retiring equipment from the 1990 stock by year.

If y = 1991,

$$WTWEFFA_{y,eg,b,r} = WTWEFFN_{y=1991,eg,b,r}$$ **B-(106)**

If y > 1991 and denominator >0,

$$g,b,r = \left(\frac{(HWSR90_{y,eg,b,r} + H2OSUR_{y,eg,b,r}) \times WTWEFFA_{y-1,eg,} + (HWRP90_{y,eg,b,r} + H2OADD_{y,eg,b,r} + H2OREP_{y,eg,b,r}) \times WTWE}{HWSR90_{y,eg,b,r} + H2OSUR_{y,eg,b,r} + HWRP90_{y,eg,b,r} + H2OADD_{y,eg,b,r} + H2OREP_{y,eg,b,r}} \right.$$ **B-(107)**

If y > 1991 and denominator ≤ 0,

$$WTWEFFA_{y,eg,b,r} = WTWEFFN_{y,eg,b,r}$$ **B-(108)**

where,

$WTWEFFA_{y,eg,b,r}$ is the weighted average water heater efficiency by general equipment type, housing type, Census Division, and year.

$$WNUEC_{y,r,eg,b}\,, \qquad if\ y = 1991$$

$$_{r,eg,b}\,,\ if\ HWRP90_{y,eg,b,r} + H2OREP_{y,eg,b,r} + H2OADD_{y,eg,b,r} + HWSR90_{y,eg}$$

$$\frac{\left(\begin{array}{l} \left(HWRP90_{y,eg,b,r} + H2OREP_{y,eg,b,r}\right) \times WRUEC_{y,eg,b,r} \\ \quad + \left(H2OADD_{y,eg,b,r} \times WNUEC_{y,eg,b,r}\right) \\ + \left(HWSR90_{y,eg,b,r} + H2OSUR_{y,eg,b,r}\right) \times WAUEC_{y-1,eg,b,r} \end{array}\right)}{\begin{array}{l} (HWRP90_{y,eg,b,r} + H2OREP_{y,eg,b,r} + H2OADD_{y,eg,b,r} \\ \quad + HWSR90_{y,eg,b,r} + H2OSUR_{y,eg,b,r}) \end{array}}\,, \qquad \textbf{B-(109)}$$

where,

$WAUEC_{y,eg,b,r}$ is the average unit energy consumption for water heaters by year, general equipment type, housing type and Census Division.

If y = 1991,

$$_{,r} = \sum_{b} \left[\left(\begin{array}{l} HWESE_{y,eg,b,r} \times HWUEC_{r,eg,b} \\ + H2OADD_{y,eg,b,r} \times WNUEC_{y,eg,b,r} \\ + HWRP90_{y,eg,b,r} \times WRUEC_{y,eg,b,r} \end{array} \right) \times \left(\frac{PRICE}{PRICES} \right. \right. \qquad \textbf{B-(110)}$$

If y > 1991,

$$
{}_r = \sum_b \left[\left(\begin{array}{c} HWESE_{y,eg,b,r} \times HWUEC_{r,eg,b} \\ + H2OADD_{y,eg,b,r} \times WNUEC_{y,eg,b,r} \\ + HWRP90_{y,eg,b,r} \times WRUEC_{y,eg,b,r} \\ + HWSR90_{y,eg,b,r} \times WAUEC_{y-1,eg,b,r} \\ + H2OREP_{y,eg,b,r} \times WRUEC_{y,eg,b,r} \\ + H2OSUR_{y,eg,b,r} \times WAUEC_{y-1,eg,b,r} \end{array} \right) \times \left(\frac{PRIC}{PRICE} \right. \right. \qquad \textbf{B-(111)}
$$

where,

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

$$
SLCON_{y,r} = \left(\begin{array}{c} SLESE_{y,r} + SOLADD_{y,r} \\ + SRLP90_{y,r} + SLSR90_{y-1,r} \\ + SOLREP_{y,r} + SOLSUR_{y,r} \end{array} \right) \times SLUEC_r \qquad \textbf{B-(112)}
$$

where,

$SLCON_{y,r}$ is consumption for solar water heating.

Cooking Equipment

RDCKEQ (Project Cooking Equipment Stock)

$$SE_{1991,eg,b,r} = \frac{CKSH_{eg,b,r}}{100} \times EH_{1990,b,r} \quad \forall\ r,b\ and \qquad \textbf{B-(113)}$$

where,

$CKESE_{1990,eg,b,r}$	is the surviving old (pre-1991 vintage) cooking equipment in old (pre-1991) housing units by housing type and Census Division,
$CKSH_{eg,b,r}$	is the base year market share of the general cooking equipment type by housing type and Census Division, and
$EH_{1990,b,r}$	is the base year housing stock by housing type and Census Division.

If y > 1990,

$$_{b,r} = CKESE_{y-1990,eg,b,r} \times SVRTE_{y-1990,L_{min},L_{max}} \times HDR_b^{y-1990} \qquad \textbf{B-(114)}$$

where,

$CKESE_{y,eg,b,r}$	is the surviving old (pre-1991 vintage) cooking equipment in old (pre-1991) housing units in the current year by housing type and Census Division,
$SVRTE_{y-1990,Lmin,Lmax}$	is the equipment survival rate, and
HDR_b	is the housing survival rate.

CKTEC (Choose Cooking Equipment)

$$NH2OSH_{y,eg,b,r} \times .63,\ if\ eg = gas\ stov$$
$$NH2OSH_{y,eg,b,r},\quad if\ eg = lpg\ stoves \qquad \textbf{B-(115)}$$
$$_{,oil,b,r} + NH2OSH_{y,electricity,b,r} + (NH2OSH_{y,ng,b,r} \times .37$$

where,

$NCKSH_{y,eg,b,r}$ is the new market share of general cooking equipment in the current year by housing type and Census Division, and

$NH2OSH_{y,eg,b,r}$ is the new market share of water heaters in the current year by general equipment type, housing type and Census Division.

$$OPCOST_{y,es,b,r} = PRICES_{f,r,y} \times CKUEC_{r,eg,b} \qquad \textbf{B-(116)}$$

where,

$OPCOST_{y,es,b,r}$ is the current year operating cost of the specific cooking equipment type by housing type and Census Division,

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

$CKUEC_{r,eg,b}$ is the unit energy consumption for the general cooking equipment type by housing type and Census Division.

$LFCY_{y,es,b,r}$ is the current year cooking equipment life cycle cost by year, housing type and Census Division as computed in B-12 above.

$$NCKSH_{y,eg,b,r} \times .9,\ for\ es = 1,3,5 \wedge eg = 1,2,3,\ Re$$
$$NCKSH_{y,eg,b,r} \times .1,\ for\ es = 2,4,6 \wedge eg = 1,2,3,\ Re \qquad \textbf{B-(117)}$$

where,

$NCKSHR_{y,es,b,r}$ is the new market share of stoves by specific equipment type, housing type and Census Division, and

$NCKSH_{y,eg,b,r}$ is the new market share of general cooking equipment in the current year by housing type and Census Division.

$$F_{y,eg,b,r} = NCKSHR_{y,eg,b,r} \times \frac{1}{eff_{es}} + NCKSHR_{y,eg,b,r} \times \quad \text{B-(118)}$$

where,

$WTKEFF_{y,eg,b,r}$ is the weighted cooking equipment efficiency in the current year by housing type and Census Division.

SADD (Stove Additions)

$$COKADD_{y,eg,b,r} = HSEADD_{y,b,r} \times NCKSH_{y,eg,b,r} \quad \text{B-(119)}$$

where,

$COKADD_{y,eg,b,r}$ is the new cooking equipment (post-1990) in new housing additions 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

$NCKSH_{y,eg,b,r}$ is the new market share of general cooking equipment in the current year by housing type and Census Division.

$$)_{y,eg,b,r} = \sum_{t=1991}^{y-1} \left[CKRP90_{t,eg,b,r} \times SVRTE_{y-t,L_{\min},L_{\max}} \times \right. \quad \text{B-(120)}$$

where,

$CKSR90_{y,eg,b,r}$ is the surviving replacement equipment (post-1990 vintage) in old (pre-1991 vintage) housing units in the current year by housing type and Census Division,

$CKRP90_{y,eg,b,r}$	is the number of replacements (post-1990 vintage equipment) in old (pre-1991 vintage) housing units by year, housing type and Census Division,
$SVRTE_{y-t,Lmin,Lmax}$	is the equipment survival rate, and
HDR_b	is the housing survival rate by housing type.

$$,r = CKESE_{y=1990,eg,b,r} \times HDR_b^{y-1990} - CKESE_{y,eg,b,r} - C \qquad \textbf{B-(121)}$$

where,

$CKRP90_{y,eg,b,r}$	is the number of replacements (post-1990 vintage equipment) in old (pre-1991 vintage) housing units by year, housing type and Census Division,
$CKESE_{y,eg,b,r}$	is the surviving old (pre-1991 vintage) cooking equipment in old (pre-1991) housing units by housing type and Census Division,
$CKSR90_{y,eg,b,r}$	is the surviving replacement equipment (post-1990 vintage) in old (pre-1991 vintage) housing units in the current year by housing type and Census Division, and
HDR_b	is the housing survival rate by housing type.

The following variables are computed as in the equations indicated:

$SA_{eg,b,r}$	is the amount of cooking equipment demanded in post-1990 vintage housing by housing type and Census Division. It is computed as in B-30 above using COKADD instead of HTRADD.
$COKADD_{y,eg,b,r}$	is the new cooking equipment (post-1990) in new housing additions in the current year by housing type and Census Division.

$COKSUR_{y,eg,b,r}$ is the surviving new (post-1990 vintage) cooking equipment in new (post-1990 vintage) housing units in the current year by housing type and Census Division. It is computed as in B-31 above using COKADD and COKREP where appropriate.

$COKREP_{y,eg,b,r}$ is the amount of replacement equipment in new (post-1990 vintage) housing units in the current year by housing type and Census Division.

$$COKREP_{y,eg,b,r} = SA_{eg,b,r} - COKSUR_{y,eg,b,r} \qquad \textbf{B-(122)}$$

where,

$COKREP_{y,eg,b,r}$ is the amount of replacement equipment in new (post-1990 vintage) housing units in the current year by housing type and Census Division.

CKCNS (Cooking Consumption)

$$\begin{cases} CKUEC_{r,eg,b} \times \left(1 + \dfrac{WTKEFF_{y,eg,b,r} - \frac{1}{BASEFF_{eg}}}{\frac{1}{BASEFF_{eg}}} \right) \text{, if } WT \\ CKUEC_{r,eg,b} \text{, otherwise} \end{cases} \qquad \textbf{B-(123)}$$

where,

$KNUEC_{y,eg,b,d}$ is the unit energy consumption for new cooking equipment in the current year by housing type and Census Division,

$CKUEC_{r,eg,b}$ is the unit energy consumption for general cooking equipment by

	housing type and Census Division,
$WTKEFF_{y,eg,b,r}$	is the weighted cooking equipment efficiency in the current year by housing type and Census Division, and
$BASEFF_{eg}$	is the 1990 stock-average efficiency of the general cooking equipment type.

If y = 1991,

$$KAUEC_{y,eg,b,r} = KNUEC_{y,eg,b,r} \qquad \textbf{B-(124)}$$

If y > 1991,

$$\begin{matrix} KNUEC_{y,eg,b,r}\ , & if \\ \dfrac{RP90_{y,eg,b,r}+COKREP_{y,eg,b,r}+COKADD_{y,eg,b,r})\times KNUEC_{y} \\ +(CKSR90_{y,eg,b,r}+COKSUR_{y,eg,b,r})\times KAUEC_{y-1,eg,b,r}}{\begin{pmatrix} CKRP90_{y,eg,b,r}+COKREP_{y,eg,b,r} \\ +COKADD_{y,eg,b,r}+CKSR90_{y,eg,b,r} \\ +COKSUR_{y,eg,b,r} \end{pmatrix}} & \end{matrix} \qquad \textbf{B-(125)}$$

$$CON_{y,f,r} = \sum_{b} \begin{bmatrix} CKESE_{y,eg,b,r}\times CKUEC_{r,eg,b} \\ +COKADD_{y,eg,b,r}\times CKUEC_{r,eg,b} \\ +CKRP90_{y,eg,b,r}\times CKUEC_{r,eg,b} \end{bmatrix},\ if\ y=19 \qquad \textbf{B-(126)}$$

$$KCON_{y,f,r} = \sum_{b} \begin{bmatrix} CKESE_{y,eg,b,r} \times CKUEC_{r,eg,b} \\ + COKADD_{y,eg,b,r} \times CKUEC_{r,eg,b} \\ + CKRP90_{y,eg,b,r} \times CKUEC_{r,eg,b} \\ + CKSR90_{y,eg,b,r} \times CKUEC_{r,eg,b} \\ + COKREP_{y,eg,b,r} \times CKUEC_{r,eg,b} \\ + COKSUR_{y,eg,b,r} \times CKUEC_{r,eg,b} \end{bmatrix}, \ if \ y > 199 \qquad \textbf{B-(127)}$$

Clothes Drying

RDDRYEQ (Project Existing Clothes Dryer Stock)

$$DRYSAT_{b,r} = 1 - \frac{DRYSHR_{1,b,r}}{100} \qquad \textbf{B-(128)}$$

where,

$DRYSHR_{1,b,r}$ is the market share without clothes dryers by housing type and Census Division, and

$DRYSAT_{b,r}$ is the level of market penetration of clothes dryer equipment by housing type and Census Division.

$$DRYESE_{1990,eg,b,r} = \frac{DRYSHR_{eg,b,r}}{100} \times EH_{1990,b,r} \qquad \textbf{B-(129)}$$

where,

$DRYESE_{1990,eg,b,r}$ is the surviving old (pre-1991 vintage) equipment in pre-1991 housing units in the current year by housing type and Census Division,

$DRYSHR_{eg,b,r}$ is the market share of clothes dryers by general equipment type, housing type and Census Division, and

$EH_{1990,b,r}$ is the base year housing stock by housing type and Census Division.

$$SE_{y,eg,b,r} = DRYESE_{1990,eg,b,r} \times SRVTE_{y-1990,L_{min},L_{max}} \times HDR_i \qquad \textbf{B-(130)}$$

where,

$DRYESE_{y,eg,b,r}$ is the surviving old (pre-1991 vintage) equipment in pre-1991 housing units in the current year by housing type and Census Division,

$SRVTE_{y-1990,Lmin,Lmax}$ is the equipment survival rate, and

HDR_b is the housing survival rate.

DRYTEC (Clothes Dryer Technology Choice)

The following variables are computed as in the equations indicated:

$OPCOST_{y,es,b,r}$ is the operating cost of the specific clothes drying equipment type by housing type and Census Division. It is computed as in B-11 above.

$LFCY_{y,es,b,r}$ is the current year clothes dryer life cycle cost, housing type and Census Division. It is computed as in B-12 above.

$$EQWT_{y,es,b,r} = e^{[\beta_1 * CPCOST_{es} + \beta_2 * OPCOST_{y,es,b,r} + \beta_{3,eg} * LFCY_{y,es,b,r}} \qquad \textbf{B-(131)}$$

where,

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

$CPCOST_{es}$ is the installed capital cost for the specific equipment type in the forecast year.

$$TOTEWT_{y,eg,b,r} = \sum_{es} EQWT_{y,es,b,r} \qquad \textbf{B-(132)}$$

where,

$TOTEWT_{eg}$ is the sum of specific equipment weights for the new general equipment type, and

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

$$NDRYSHR_{y,es,b,r} = \frac{EQWT_{y,es,b,r}}{TOTEWT_{y,eg,b,r}} \times \frac{DRYSHR_{eg,b,r}}{100} \qquad \textbf{B-(133)}$$

where,

$NDRYSHR_{y,es,b,r}$	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 specific equipment weights for the new general equipment type,
$EQWT_{es}$	is the specific equipment weight for new equipment,and
$DRYSHR_{eg,\ b,r}$	is the market share of clothes dryers equipment types by housing type and Census Division.

$$F_{y,eg,b,r} = \begin{cases} \dfrac{\dfrac{EQWT_{elec\ high,b,r}}{EFF_{elec\ high}} + \dfrac{EQWT_{elec\ low,b,r}}{EFF_{elec\ low}}}{EQWT_{elec\ high,b,r} + EQWT_{elec\ low,b,r}}, \\ if\ eg = 1 \wedge EQWT_{elec\ high,b,r} + EQWT_{elec\ low,b} \\ \dfrac{\dfrac{EQWT_{gas\ high,b,r}}{EFF_{gas\ high}} + \dfrac{EQWT_{gas\ low,b,r}}{EFF_{gas\ low}}}{EQWT_{gas\ high,b,r} + EQWT_{gas\ low,b,r}}, \\ if\ eg = 2 \wedge EQWT_{gas\ high,b,r} + EQWT_{gas\ low,b,} \end{cases} \qquad \textbf{B-(134)}$$

where,

$WTDEFF_{y,es,b,r}$	is the weighted efficiency of clothes dryers equipment types in the current year by housing type and Census Division, and
$EQWT_{es}$	is the specific equipment weight for new equipment.

DADD (Dryer Additions)

$$ADD_{y,b,r} \times \left[NDRYSHR_{y,elec\ high,b,r} + NDRYSHR_{y,elec\ low,b,r} \right] \times DRYSAT_{b,r}\ ,\ i$$
$$HSEADD_{y,b,r} \times \left[NDRYSHR_{y,gas\ high,b,r} + NDRYSHR_{y,gas\ low,b,r} \right] \times DRYSAT_{b,r}\ ,$$

B-(135)

where,

$DRYADD_{y,eg,b,r}$	is the amount of new (post-1990 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,
$NDRYSHR_{y,es,b,r}$	is the new market share of clothes dryer equipment types by housing type and Census Division in the current year, and
$DRYSAT_{b,r}$	is the level of market penetration of clothes dryer equipment by housing type and Census Division.

The following variable was computed as in the equation indicated:

$DRSR90_{y,eg,b,r}$	is the surviving post-1990 vintage equipment in pre-1991 housing units in the current year by housing type and Census Division. It is computed as in B-25 above using DRRP90 instead of HTRP90.
$DRRP90_{y,eg,b,r}$	is the number of replacement unites demanded in pre-1991 housing units each year by housing type and Census Division.

$$_{b,r} = DRYESE_{1990,eg,b,r} \times HDR_b^{y-1990} - DRYESE_{y,eg,b,r} - DR$$

B-(136)

where,

$DRRP90_{y,eg,b,r}$	is the number of replacement unites demanded in pre-1991 housing units each year by housing type and Census Division,
$DRSR90_{y,eg,b,r}$	is the surviving post-1990 vintage equipment in pre-1991 housing units in the current year by housing type and Census Division,
$DRYESE_{1990,eg,b,r}$	is the base year old equipment in pre-1991 housing units by housing type and Census Division,
HDR_b	is the housing survival rate by housing type.

The following equations are computed as in the equations indicated:

$SA_{y,eg,b,r}$	is the amount of dryer equipment demanded in post-1990 vintage housing by housing type and Census Division. It is computed as in B-30 above using DRYADD instead of HTRADD.
$DRYADD_{y,eg,b,r}$	is the amount of new (post-1990 vintage) equipment added in new housing units in the current year by housing type and Census Division.
$DRYSUR_{y,eg,b,r}$	is the surviving new (post-1990 vintage) equipment in the current year by housing type and Census Division. It i computed as in B-31 above using DRYADD and DRYREP as appropriate.
$DRYREP_{y,eg,b,r}$	is the number of replacement units (post-1990 vintage) equipment demanded in new (post-1990 vintage) housing units by housing type and Census Division.

$$DRYREP_{y,eg,b,r} = SA_{y,eg,b,r} - DRYSUR_{y,eg,b,r} \qquad \textbf{B-(137)}$$

where,

$DRYREP_{t,eg,b,r}$	is the number of replacement units (post-1990 vintage) equipment demanded in new (post-1990 vintage) housing units by housing type

and Census Division.

DRYCNS (Clothes Dryer Consumption)

The following variable is computed as in the equation indicated:

$DNUEC_{y,eg,b,r}$	is the unit energy consumption for new equipment by housing type and Census Division. It is computed as in B-102 using DRYUEC and WTDEFF as appropriate.
$WTDEFF_{y,es,b,r}$	is the weighted efficiency of clothes dryers equipment types in the current year by housing type and Census Division,
$BASEFF_{eg}$	is the average efficiency of the general clothes drying equipment type, and
$DRYUEC_{r,eg,b}$	is the unit energy consumption for the general equipment type by housing type and Census Division.

$$EC_{y,eg,b,r}\ , \quad if \begin{pmatrix} DRRP90_{y,eg,b,r}+DRYREP_{y,eg,b,r}+ \\ DRYADD_{y,eg,b,r}+DRSR90_{y,eg,b,r}+ \\ DRYSUR_{y,eg,b,r} \end{pmatrix} \leq 0,\ for\ y=$$

$$\frac{\begin{pmatrix} \left(DRRP90_{y,eg,b,r}+DRYREP_{y,eg,b,r}+DRYADD_{y,eg,b,r}\right)\times DNUEC_{y,eg,b,r} \\ +\ \left(DRSR90_{y,eg,b,r}+DRYSUR_{y,eg,b,r}\right)\times DAUEC_{y,eg,b,r} \end{pmatrix}}{P90_{y,eg,b,r}+DRYREP_{y,eg,b,r}+DRYADD_{y,eg,b,r}+DRSR90_{y,eg,b,r}+DRYSUR_{y,}} \qquad \textbf{B-(138)}$$

$$CON_{y,eg,r} = \sum_{b} \begin{bmatrix} DRYESE_{y,eg,b,r}\times DRYUEC_{r,eg,b} \\ +DRYADD_{y,eg,b,r}\times DNUEC_{y,eg,b,r} \\ +DRRP90_{y,eg,b,r}\times DNUEC_{y,eg,b,r} \end{bmatrix},\ if\ y=1 \qquad \textbf{B-(139)}$$

$$DRYCON_{y,eg,r} = \sum_{b} \left[\begin{array}{l} DRYESE_{y,eg,b,r} \times DRYUEC_{r,eg,b} \\ + DRYADD_{y,eg,b,r} \times DNUEC_{y,eg,b,r} \\ + DRRP90_{y,eg,b,r} \times DNUEC_{y,eg,b,r} \\ + DRSR90_{y,eg,b,r} \times DAUEC_{y,eg,b,r} \\ + DRYREP_{y,eg,b,r} \times DNUEC_{y,eg,b,r} \\ + DRYSUR_{y,eg,b,r} \times DAUEC_{y,eg,b,r} \end{array} \right] \quad \textbf{B-(140)}$$

Refrigeration

RDRFEQ (Project existing refrigerators)

$$RFESE_{1990,b,r} = EH_{1990,b,r} \times \left(1 + \frac{RFSHR_{b,r}}{100}\right) \qquad \textbf{B-(141)}$$

where,

$RFESE_{1990,b,r}$	is the amount of old (pre-1991) refrigerators in old (pre-1991 vintage) housing units in the base year by housing type and Census Division,
$EH_{1990,b,r}$	is the amount of old (pre-1991) housing units in the base year by housing type and Census Division, and
$RFSHR_{b,r}$	is the market share of housing units with a second refrigerator by housing type and Census Division.

The following variable is computed as in the equation indicated:

$RFESE_{y,b,r}$	is the surviving old (pre-1991 vintage) equipment in old (pre-1991 vintage) housing units in the current year by housing type and Census Division. It is computed as in equation B-10 above.

REFTEC (Refrigerator Technology Choice)

$$OPCOST_{y,es,r} = PRICES_{electricity,r,y} \times UEC_{es} \qquad \textbf{B-(142)}$$

where,

$OPCOST_{y,es,r}$	is the operating cost of the specific equipment type by housing type

and Census Division in the current year,

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

UEC_{es} is the unit energy consumption by the specific refrigerator type.

The following variables are computed as in the equations indicated:

$LFCY_{es,r}$ is the life cycle cost for the specific type of equipment by Census Division. It is computed as in B-12 above.

$EQWTN_{es,b,r}$ is the equipment weight for new specific equipment by housing type and Census Division. It is computed as in B-13 above.

$EQWTR_{es,b,r}$ is the equipment weight for replacement specific equipment by housing type and Census Division. It is computed as in B-14 above.

$BIASR_{es}$ is the constant that fits the current market share to historical shipment data.

$TOTEWTN_{b,r}$ is the sum of the individual weights for each specific type of new equipment by housing type and Census Division. It is computed as in B-15 above.

$TOTEWTR_{b,r}$ is the sum of the individual weights for each specific type of replacement equipment by housing type and Census Division. It is computed as in B-16 above.

$$NREFSHR_{y,es,b,r} = \frac{EQWTN_{es,b,r}}{TOTEWTN_{b,r}} \times (1 - TTDSHR) \qquad \textbf{B-(143)}$$

$$RREFSHR_{y,es,b,r} = \frac{EQWTR_{es,b,r}}{TOTEWTR_{b,r}} \times (1 - TTDSHR) \qquad \textbf{B-(144)}$$

where,

$NREFSHR_{y,es,b,r}$	is the new market share for the specific equipment type in the current year by housing type and Census Division,
$RREFSHR_{y,es,b,r}$	is the market share for the replacements of specific equipment type in the current year by housing type and Census Division, and
$TTDSHR$	is the share of side-by-side refrigerators with through-the-door access feature.

$$FFN_{y,b,r} = \sum_{es} \left[EFF_{es} \times NREFSHR_{y,es,b,r}\right] + (EFFTTD \times TTD \qquad \textbf{B-(145)}$$

$$FFR_{y,b,r} = \sum_{es} \left[EFF_{es} \times RREFSHR_{y,es,b,r}\right] + (EFFTTD \times TTD \qquad \textbf{B-(146)}$$

where,

$WTREFFN_{y,b,r}$	is the weighted average efficiency of new refrigerators by housing type and Census Division,
$WTREFFR_{y,b,r}$	is the weighted average efficiency of replacement refrigerators by housing type and Census Division,
EFF_{es}	is the efficiency by specific refrigerator types,
$NREFSHR_{y,es,b,r}$	is the new market share for the specific equipment type in the current year by housing type and Census Division,
$RREFSHR_{y,es,b,r}$	is the market share for the replacements of specific equipment type in the current year by housing type and Census Division,
$TTDSHR$	is the share of side-by-side refrigerators with through-the-door access feature, and

EFFTTD is the efficiency of side-by-side refrigerators with through-the-door access feature.

FADD (Additions to the Refrigerator Stock)

$$DD_{y,b,r} = \begin{cases} HSEADD_{y,b,r} \times 1.1 \text{ , if } b = \text{single family h} \\ HSEADD_{y,b,r} \text{ , } \quad \text{otherwise} \end{cases} \qquad \textbf{B-(147)}$$

where,

$REFADD_{y,b,r}$ is the amount of new (post-1990 vintage) refrigerators added in new housing units in the current year by housing type and Census Division, and

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

The following variables are computed as in the equations indicated:

$RFSR90_{y,b,r}$ is the surviving new (post-1990 vintage) equipment in old (pre-1991 vintage) housing units by housing type and Census Division. It is computed as in B-25 above using RFRP90 instead of HTRP90.

$RFRP90_{t,b,r}$ is the number of replacement (post-1990 vintage) equipment in pre-1991 housing units in the current year by housing type and Census Division.

$$90_{y,b,r} = RFESE_{y=1990,b,r} \times HDR_b^{y-1990} - RFESE_{y,b,r} - RFSR9 \qquad \textbf{B-(148)}$$

where,

$RFESE_{y,b,r}$ is the surviving old (pre-1991 vintage) equipment in old (pre-1991 vintage) housing units in the current year by housing type and Census Division, and

HDR_b is the housing survival rate.

The following variables are computed as in the equations indicated:

$SA_{y,b,r}$	is the amount of refrigerators demanded in new (post-1990 vintage) housing units by housing type and Census Division. It is computed as in B-30 above using REFADD instead of HTRADD.
$REFSUR_{y,b,r}$	is the amount of surviving new (post-1990 vintage) equipment in new (post-1990 vintage) housing units in the current year by housing type and Census Division. It is computed as in B-31 above using REFADD and REFREP as appropriate.

$$REFREP_{y,b,r} = SA_{y,b,r} - REFSUR_{y,b,r} \qquad \textbf{B-(149)}$$

$REFREP_{y,b,r}$	is the number of replacements for the current year in new (post-1990 vintage) housing units by housing type and Census Division.

RFCNS (Refrigerator Energy Consumption)

$$RNUEC_{y,b,r} = RFUEC_{r,b} \times \left(1 + \frac{WTREFFN_{y,b,r} - BSEFF}{BSEFF}\right) \qquad \textbf{B-(150)}$$

where,

$RNUEC_{y,b,r}$	is the efficiency weighted unit energy consumption for new refrigerators in the current year by housing type and Census Division,
$RFUEC_{r,b}$	is the unit energy consumption for refrigerators by housing type and Census Division,
$WTREFFN_{y,b,r}$	is the market share weighted efficiency of new refrigerators in the current year by housing type and Census Division,
$BSEFF$	is the 1990 stock-average efficiency of refrigerators.

$$RRUEC_{y,b,r} = RFUEC_{r,b} \times \left(1 + \frac{WTREFFR_{y,b,r} - BSEFF}{BSEFF} \right) \quad \textbf{B-(151)}$$

where,

$RRUEC_{y,b,r}$	is the efficiency weighted unit energy consumption for replacement refrigerators in the current year by housing type and Census Division,
$WTREFFR_{y,b,r}$	is the market share weighted efficiency of replacement refrigerators in the current year by housing type and Census Division,
$BSEFF$	is the 1990 stock-average efficiency of refrigerators.

$$_{r} = \left(\begin{array}{ll} RNUEC_{y,b,r}\ , & if\ y = 1991 \\ \dfrac{\left(\begin{array}{c} (RFRP90_{y,b,r} + REFREP_{y,b,r}) \times RRUEC_{y,b,r} + \\ REFADD_{y,b,r} \times RNUEC_{y,b,r} + \\ (RFSR90_{y,b,r} + REFSUR_{y,b,r}) \times RAUEC_{y-1,b,r} \end{array} \right)}{\left(\begin{array}{c} RFRP90_{y,b,r} + RFSR90_{y,b,r} \\ + REFADD_{y,b,r} + REFREP_{y,b,r} + REFSUR_{y,b,r} \end{array} \right)} & , if \end{array} \right. \quad \textbf{B-(152)}$$

where,

$RAUEC_{y,b,r}$	is the average unit energy consumption of refrigerators in the current year by housing type and Census Division,

$$WTREFFN_{y,b,r}\ ,\ if\ y=1991\ or\ WTREFFN_{Y,B,}$$

$$\frac{(RFSR90_{y,b,r}+REFSUR_{y,b,r})\times WTREFFA_{y-1,b,r} +(RFRP90_{y,b,r}+REFADD_{y,b,r}+REFREP_{y,b,r})\times WTREFFN_{y,b,}}{RFSR90_{y,b,r}+REFSUR_{y,b,r} +RFRP90_{y,b,r}+REFADD_{y,b,r}+REFREP_{y,b,r}} \qquad \textbf{B-(153)}$$

If year = 1991,

$$N_{y,r} = \sum_b \left[\begin{pmatrix} RFESE_{y,b,r}\times RFUEC_{r,b} \\ + REFADD_{y,b,r}\times RNUEC_{y,b,r} \\ + RFRP90_{y,b,r}\times RRUEC_{y,b,r} \end{pmatrix} \times \left(\frac{PRICES_{electricity,r}}{PRICES_{electricity,r,}} \right. \right. \qquad \textbf{B-(154)}$$

where,

$REFCON_{y,r}$	is consumption for refrigeration,
$RFESE_{y,b,r}$	is the surviving old (pre-1991 vintage) equipment in old (pre-1991 vintage) housing units in the current year by housing type and Census Division,
$REFADD_{y,b,r}$	is the amount of new (post-1990 vintage) refrigerators added in new housing units in the current year by housing type and Census Division,
$RFRP90_{t,b,r}$	is the number of replacement (post-1990 vintage) equipment in pre-1991 housing units in the current year by housing type and Census Division,
$RRUEC_{y,b,r}$	is the efficiency weighted unit energy consumption for replacement refrigerators in the current year by housing type and Census Division, and
$RNUEC_{y,b,r}$	is the efficiency weighted unit energy consumption for new

	refrigerators in the current year by housing type and Census Division.
$RFUEC_{r,b}$	is the unit energy consumption for refrigerators by housing type and Census Division,
$PRICES_{f,r,y}$	is the fuel price in the current year by Census Division.

If year >1991,

$$V_{y,f,r} = \sum_{b} \left[\begin{pmatrix} REFESE_{y,b,r} \times RFUEC_{r,b} \\ + REFADD_{y,b,r} \times RNUEC_{y,b,r} \\ + RFRP90_{y,b,r} \times RRUEC_{y,b,r} \\ + RFSR90_{y,b,r} \times RAUEC_{y-1,b,r} \\ + REFREP_{y,b,r} \times RRUEC_{y,b,r} \\ + REFSUR_{y,b,r} \times RAUEC_{y-1,b,r} \end{pmatrix} \times \left(\frac{PRICES_{electricit}}{PRICES_{electricity}} \right. \right. \quad \textbf{B-(155)}$$

Freezers

RDFZEQT (Project Existing Freezers Stock)

The following variables are computed as in the equations indicated:

$FZESE_{1990,b,r}$	is the stock of upright freezers in the base year by housing type and Census Division. It is computed as in B-9 above using FZSHR instead of HTESE.
$FZSHR_{b,r}$	is the share of housing units with upright freezers.
$FZESE_{y,b,r}$	is the surviving pre-1991 equipment in pre-1991 housing units in current year by housing type and Census Division. It is computed as in B-10 above using FZESE instead of HTESE.

FRZTEC (Freezer Technology Choice)

The following variables are computed as in the equations indicated:

$OPCOST_{y,es,r}$	is the operating cost of the specific equipment type by housing type and Census Division in the current year. It is computed as in B-141 above.
$LFCY_{es,r}$	is the life cycle cost for the specific type of equipment by Census Division. It is computed as in B-12 above.
$EQWTN_{es,b,r}$	is the equipment weight for new specific equipment by housing type and Census Division. It is computed as in B-13 above.
$EQWTR_{es,b,r}$	is the equipment weight for replacement specific equipment by housing type and Census Division. It is computed as in B-14 above.
$BIASR_{es}$	is the constant that fits the current market share to historical shipment

data.

$TOTEWTN_{b,r}$ is the sum of the individual weights for each specific type of new equipment by housing type and Census Division. It is computed as in B-15 above.

$TOTEWTR_{b,r}$ is the sum of the individual weights for each specific type of replacement equipment by housing type and Census Division. It is computed as in B-16 above.

$$NFRZSHR_{y,es,b,r} = \frac{EQWTN_{es,b,r}}{TOTEWTN_{b,r}} \qquad \textbf{B-(156)}$$

$$RFRZSHR_{y,es,b,r} = \frac{EQWTR_{es,b,r}}{TOTEWTR_{b,r}} \qquad \textbf{B-(157)}$$

where,

$NFRZSHR_{y,es,b,r}$ is the new market share for the specific equipment type in the current year by housing type and Census Division,

$RFRZSHR_{y,es,b,r}$ is the market share for the replacements of specific equipment type in the current year by housing type and Census Division.

$$, r = \sum_{es}\left[EFF_{es} \times NFRZSHR_{y,es,b,r}\right] \times (1 - UPSHR) + (EFFI \qquad \textbf{B-(158)}$$

$$, r = \sum_{es}\left[EFF_{es} \times RFRZSHR_{y,es,b,r}\right] \times (1 - UPSHR) + (EFFI \qquad \textbf{B-(159)}$$

where,

$NFRZSHR_{y,es,b,r}$ is the new market share for the specific equipment type in the current year by housing type and Census Division,

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

UPSHR is the share of housing units with upright freezers,

EFFUP is the efficiency level associated with upright freezers, and

EFF is the efficiency of the specific freezer.

ZADD (Additions to the Freezer Stock)

$$FRZADD_{y,b,r} = HSEADD_{y,b,r} \times \frac{FS_{b,r}}{100} \qquad \textbf{B-(160)}$$

where,

$FRZADD_{y,b,r}$ is the amount of new (post-1990 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

$FS_{b,r}$ is the market penetration level of freezers by housing type and Census Division.

The following variables are computed as in the equations indicted:

$FZSR90_{y,b,r}$ is the surviving new (post-1990 vintage) equipment in old (pre-1991 vintage) housing units by housing type and Census Division. It is computed as in B-25 above using FZRP90 instead of HTRP90.

$FZRP90_{y,b,r}$ is the number of replacement (post-1990 vintage) equipment in pre-1991 housing units in the current year by housing type and Census Division,

$$)_{y,b,r} = FZESE_{1990,b,r} \times HDR_b^{y-1990} - FZESE_{y,b,r} \times .69 - FZSI \qquad \textbf{B-(161)}$$

The following variables are computed as in the equations indicated:

$SA_{y,b,r}$	is the amount of freezers demanded in new (post-1990 vintage) housing units by housing type and Census Division. It is computed as in B-30 above using FRZADD instead of HTRADD.
$FRZADD_{y,b,r}$	is the amount of new (post-1990 vintage) equipment added in new housing units in the year by housing type and Census Division.
$FRZSUR_{y,b,r}$	is the amount of surviving new (post-1990 vintage) equipment in new (post-1990 vintage) housing units in the current year by housing type and Census Division. It is computed as in B-31 above using FRZADD and FRZREP as appropriate.
$FRZREP_{y,b,r}$	is the number of replacements for the current year in new (post-1990 vintage) housing units by housing type and Census Division. It is computed as in B-148 above using FZRSUR instead of REFSUR.

FZCNS (Freezer Energy Consumption)

The following variables are computed as in the equations indicated:

$FNUEC_{y,b,r}$	is the efficiency weighted unit energy consumption for new freezers in the current year by housing type and Census Division. It is computed as in B-149 above using FZUEC and WTZEFFN as appropriate.
$FRUEC_{y,b,r}$	is the efficiency weighted unit energy consumption for replacement freezers in the current year by housing type and Census Division. It is computed as in B-150 using FZUEC and WTZEFFR as appropriate.
$FZUEC_{r,b}$	is the unit energy consumption for freezers by housing type and Census Division.
$WTZEFFN_{y,b,r}$	is the market share weighted efficiency of new freezers in the current

year by housing type and Census Division,

$WTZEFFR_{y,b,r}$	is the market share weighted efficiency of replacement freezers in the current year by housing type and Census Division,
$BSEFF$	is the base efficiency of freezers.

$$\left(\begin{array}{c} WTZEFFN_{y=1991,b,r} \;\; if \; y = 1991 \; or \; WTZEFFA \leq 0 \\ \dfrac{\begin{array}{c}(FZSR90_{y,b,r} + FRZSUR_{y,b,r}) \times WTZEFFA_{y-1,b,r} \\ + (FZRP90_{y,b,r} + FRZADD_{y,b,r} + FRZREP_{y,b,r}) \times WTZEFFN_{y,b,r}\end{array}}{FZSR90_{y,b,r} + FRZSUR_{y,b,r} + FZRP90_{y,b,r} + FRZADD_{y,b,r} + FRZREP_{y,b,r}} \end{array} \right. \qquad \textbf{B-(162)}$$

where,

$WTZEFFA_{y,b,r}$	is the market share weighted average efficiency of freezers in the current year by housing type and Census Division,

$$AUEC_{y,b,r} = \frac{\left(\begin{array}{c} (FZRP90_{y,b,r} + FRZREP_{y,b,r}) \times FRUEC_{y,b,r} + \\ FRZADD_{y,b,r} \times FNUEC_{y,b,r} + \\ (FZSR90_{y,b,r} + FRZSUR_{y,b,r}) \times FAUEC_{y-1,b,r} \end{array} \right.}{\left(\begin{array}{c} FZRP90_{y,b,r} + FZSR90_{y,b,r} \\ + FRZADD_{y,b,r} + FRZREP_{y,b,r} + FRZSUR_{y,b,r} \end{array} \right)} \qquad \textbf{B-(163)}$$

$$= \sum_{b} \left[\left(\begin{array}{c} FZESE_{y,b,r} \times FZUEC_{r,b} \\ + FRZADD_{y,b,r} \times FNUEC_{y,b,r} \\ + FZRP90_{y,b,r} \times FRUEC_{y,b,r} \end{array} \right) \times \left(\frac{PRICES_{electricity,r,y}}{PRICES_{electricity,r,y-1}} \right)^{\alpha} \right], \qquad \textbf{B-(164)}$$

$$= \sum_{b} \left[\begin{pmatrix} FRZESE_{y,b,r} \times FZUEC_{r,b} \\ + FRZADD_{y,b,r} \times FNUEC_{y,b,r} \\ + FZRP90_{y,b,r} \times FRUEC_{y,b,r} \\ + FZSR90_{y,b,r} \times FAUEC_{y-1,b,r} \\ + FRZREP_{y,b,r} \times FRUEC_{y,b,r} \\ + FRZSUR_{y,b,r} \times FAUEC_{y-1,b,r} \end{pmatrix} \times \left(\frac{PRICES_{electricity,r,y}}{PRICES_{electricity,r,y-1}} \right)^{\alpha} \right], \qquad \textbf{B-(165)}$$

Lighting

LTCNS (Lighting Consumption)

For es = 1, 2, 3

$$
{}_{es} = \begin{cases} \dfrac{MKTSHR_{y-1,es} + MKTSHR_{y=2000,es} - MKTSHR_{y=1989,es}}{12} \text{ , if} \\ \dfrac{MKTSHR_{y-1,es} + MKTSHR_{y=2025,es} - MKTSHR_{y=2000,es}}{14} \text{ , ot} \end{cases} \qquad \text{B-(166)}
$$

$$
WTLEFF_{y,b,r} = \sum_{es} \left(\frac{1}{EFF_{es}} \times MKTSHR_{y,es} \right), \quad for\ es = 1,2,3 \qquad \text{B-(167)}
$$

$$
\sum_{b} \left[\begin{array}{c} \left(NH_{y,b,r} + EH_{y,b,r}\right) \times \\ \left(LTUEC_{r,b} \times \left(1 + \dfrac{\left(WTLEFF_{y,b,r} - \dfrac{1}{BASEFF}\right)}{\dfrac{1}{BASEFF}} \right) \right) \times \left(\dfrac{PRICES}{PRICES} \right. \end{array} \right. \qquad \text{B-(168)}
$$

Other Electric Appliances

APCNS (Electric Appliance Consumption)

$$CON_{y,r} = \sum_{b} \Big[\left(NH_{y,b,r} + EH_{y,b,r} \right) \times EAUEC_{r,b} \times (1 + PENRATE)^{y-1} \qquad \textbf{B-(169)}$$

where,

$APCON_{y,r}$	is electric appliance consumption, and
$PENRATE$	is the penetration rate from RECS 87 and 90 annual growth rates.

Secondary Space Heating

SHTCNS (Secondary Heating Consumption)

$$\sum_b \left[SHTSHR_{r,coal} \times EH_{y,b,r} \times SHTUEC_{r,coal,b} \times AHSHEL\right.$$

$$\left[SHTSHR_{r,wood} \times NH_{y,b,r} + EH_{y,b,r} \times SHTUEC_{r,f,b} \times ACSHELL\right. \qquad \textbf{B-(170)}$$

$$\left[SHTSHR_{r,f} \times (NH_{y,b,r} + EH_{y,b,r}) \times SHTUEC_{r,f,b} \times ACSHELL_{y,}\right.$$

Other Appliances

APPCNS (Appliance Consumption)

$$APLCON_{y,f,r} = \sum_{b} \left[\left(NH_{y,b,r} + EH_{y,b,r} \right) \times APPUEC_{r,f,b} \right] \qquad \textbf{B-(171)}$$

Fuel Consumption Totals

FUELCN (Fuel Consumption Totals)

The total residential energy consumption for the nation is computed by summing end use service consumption by fuel for each Census Division:

Natural Gas

$$_{ng,r} = \frac{HTRCON_{y,ng,r} + H2OCON_{y,ng,r} + CKCON_{y,ng,r} + DRYCON_{y,ng,r} + COOLCN_{y,ng,r} + SHTCON_{y,ng,r} + APL}{1000000} \quad \textbf{B-(172)}$$

Electricity

$$\frac{HTRCON_{y,electricity,r} + COOLCN_{y,electricity,r} + H2O \; + REFCON_{y,electricity,r} + CKCON_{y,electricity,r} + DRY \; HTCON_{y,electricity,r} + FRZCON_{y,electricity,r} + LTCON_{y,electr}}{1000000} \quad \textbf{B-(173)}$$

Distillate

$$CN_{y,distillate,r} = \frac{APLCON_{y,distillate,r} + HTRCON_{y,distill} + H2OCON_{y,distillate,r} + SHTCON_{y,distil}}{1000000} \quad \textbf{B-(174)}$$

LPG

$$FLCN_{y,LPG,r} = \frac{SHTCON_{y,LPG,r} + APLCON_{y,LPG,r} + HTRCON_{y,LPG,r} + H2OCON_{y,LPG,r} + CKCON_{y,LF}}{1000000} \quad \textbf{B-(175)}$$

Kerosene

$$SFLCN_{y,kerosene,r} = \frac{HTRCON_{y,kerosene,r}+SHTCON_{y,kerosene}}{1000000} \tag{B-(176)}$$

Coal

$$RSFLCN_{y,coal,r} = \frac{SHTCON_{y,coal,r}}{1000000} \tag{B-(177)}$$

Wood

$$RSFLCN_{y,wood,r} = \frac{HTRCON_{y,wood,r}+SHTCON_{y,wood,r}}{1000000} \tag{B-(178)}$$

Geothermal

$$LCN_{y,geothermal,r} = \frac{HTRCON_{y,geothermal,r}+COOLCN_{y,geother}}{1000000} \tag{B-(179)}$$

National Total,

$$RSFLCN_{y,f,United\ States} = \sum_{r} \left(RSFLCN_{y,f,r}\right) \tag{B-(180)}$$

Emissions

IRSEM (Emissions)

Emissions are computed by applying pollutant-specific emissions factors to final end-use consumption. The pollutants modeled and the fuels to which the pollutants are attributable are discussed earlier in this report in the Emissions Component discussion of the module description. Airborne emissions are reported by fuel and then by pollutant. Emissions are calculated as,

$$EMRS_{f,p,y} = RSFLCN_{y,f,r} \times \frac{EMFAC_{p,f}}{1{,}000{,}000} \qquad \textbf{B-(181)}$$

where,

$EMRS_{f,p,y}$	is the level of emissions by fuel, pollutant, and forecast year,
$RSFLCN_{y,f,r}$	is the residential energy consumption by fuel for each census division,
$EMFAC_{p,f}$	is the emissions factor which gives a MMBtu to pounds of pollutant conversion ratio.

The expression for emissions by pollutant is,

$$EMRSC_{r,p,y} = \sum_{f} \left[EMFAC_{p,f} \times \frac{RSFLCN_{y,f,r}}{1{,}000{,}000} \right] \qquad \textbf{B-(182)}$$

where,

$EMRSC_{r,p,y}$	is the emissions by pollutant, Census Division and forecast year.

Appendix C: Bibliography

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Appendix D: Model Abstract

Model Name:

NEMS Residential Sector Demand Module

Model Acronym:

None

Description:

The NEMS Residential Sector Demand Module is an integrated dynamic modeling system that projects residential energy demand by service, fuel, and Census Division. The modeling methodology is based on accounting principles and considers important issues related to consumer behavior. Housing and equipment stocks are tracked over the forecast period for seven major services. The major services considered are space heating, space cooling, water heating, cooking, clothes drying, refrigeration, and freezers. A logit function is used to estimate market shares of each equipment technology within each major service based on either the installed capital and operating costs or the life-cycle cost. Lighting choices are modeled by assuming market shares for three specific lighting technologies in specific forecast years. Miscellaneous appliance consumption is calculated as a function of Unit Energy Consumption (UEC), a measure of energy intensity developed from the Residential Energy Consumption Survey (RECS) data base.

Purpose of the Model:

As a component of the National Energy Modeling System, the Residential Sector Demand Module generates mid-term forecasts of residential sector energy demand for the period 1990 through 2010. The model facilitates policy analysis of energy markets, technological development, and regulatory development.

Most Recent Model Update:

November 1994.

Component of Another Modeling System:

The Residential Sector Demand Module is designed, executed, and maintained as part of the National Energy Modeling System (NEMS).

Model Interfaces:

The NEMS Residential Sector Demand Module receives population and housing construction input data from the NEMS Macroeconomic Activity Module (MAM). Outputs in the form of quantities of fuel demanded in the residential sector are provided to the NEMS Integrating Module and the NEMS Supply Modules: Electricity Market Module, Petroleum Market Module, and Natural Gas Supply Module.

Office Model Representative:

John H. Cymbalsky
Office of Integrated Analysis and Forecasting
Energy Demand Analysis Branch
(202) 586-4815

Documentation:

Model Documentation Report: Residential Sector Demand Model of the National Energy Modeling System, February 1995.

Archive Media and Installation Manual:

At the time of this writing, the NEMS Residential Sector Demand Module has not been archived. The module will be archived as part of the NEMS production runs that generate the

Annual Energy Outlook 1995 (AEO95) on IBM 3380 magnetic tape compatible with the EIA IBM 3390 mainframe.

Energy System Described:

U.S. residential sector energy consumption.

Scope of Coverage:

- Geographic: Nine Census Divisions: New England, Middle Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, and Pacific
- Time Unit/Frequency: Annual, 1990 through 2010 is the current mid-term horizon
- Products: Fuel consumption including: electricity, natural gas, distillate, liquefied petroleum gas, kerosene, geothermal, wood, solar thermal, and coal. Energy consumption per household. Equipment stock and efficiency.
- Economic Sectors: Domestic residential sector
- Services: Space heating, space cooling, water heating, cooking, clothes drying, refrigeration, freezers, lighting, other electric appliances, other appliances, and secondary space heating.
- Housing Types: Single-Family, Multifamily, and Mobile Homes

Model Features:

- Model Structure: Sequential algorithm composed of housing and equipment stock flow algorithms, technology choice algorithm, housing shell integrity algorithm, end-use consumption, and emissions calculations.
- Modeling Technique: Housing and equipment stock turnover are modeled using linear decay functions. Market shares for each type of equipment choice are based on a logit function employing installed capital costs and operating costs. Unit energy consumption

estimates, fuel prices, and equipment market shares are user inputs that drive the calculation of final end-use consumption.

- Special Features: Technology choice logit function has the ability to use installed capital, and operating costs or life-cycle costs to determine new market shares.

Non-DOE Input Sources:

American Home Appliance Manufacturers Association.

- Shipment-weighted efficiency ratings for refrigerators, freezers, and room air conditioners.

U.S. Bureau of the Census, "Current Construction Reports-Series C25 Characteristics of New Housing: 1993," 1994.

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

Gas Appliance Manufacturers Association, "Consumers' Directory for Certified Efficiency Ratings," 1994.

Lawrence Berkeley Laboratory, "The Potential for Electricity Efficiency Improvements in the U.S. Residential Sector," 1991

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

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

DOE Input Sources:

U.S. Department of Energy, Energy Information Administration, *Residential Energy*

Consumption Survey 1990.

- Base year market shares for services and equipment types.
- Base year housing stock.
- Unit energy consumption values (UECs)

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

Computing Environment:

- Hardware Used: IBM 3090
- Operating System: MVS
- Language/Software Used: VS FORTRAN, Version 2.05
- Memory Requirement: 3,000K
- Storage Requirement: Since the Residential Sector Demand Module has not yet been archived at the time of this writing, the number of tracks of an IBM 3380 disk pack that are required are currently unknown. This information will be provided upon completion of the archival process.
- Estimated Run Time: 0.8 seconds CPU time per iteration
- Special Features: None

Independent Expert Reviews Conducted:

Independent expert reviews of the *Residential Sector Component Design Report, May 28,1992* were conducted by Inderjit Kundra, Office of Statistical Standards; Fred Joutz, Office of Statistical Standards; Ronald D. Sands, Batelle Pacific Northwest Laboratory, James E. McMahon, Lawrence Berkeley Laboratory; and Francis X. Johnson, Lawrence Berkeley Laboratory.

Status of Evaluation Efforts by Sponsor:

None.

Appendix E: Data Quality

This Appendix discusses the quality of the survey data source from which the majority of the historical housing stock, appliance stock, and technology information that drives the NEMS Residential Sector Demand Module is drawn. This survey is the 1990 Residential Energy Consumption Survey (RECS). Data quality information pertinent to additional sources used in the module development is not available for this report. The parameter estimates included in the Residential Sector Demand Module are user-specified. A sensitivity analysis of the major parameters is included in Appendix F, **Model Sensitivities**.

Quality of Input Data

RECS Implementation

The RECS procedure is composed of two instruments: the household survey and the energy supplier survey. Data is collected from a representative sample of households through personal interviews. Billing data is next collected through mail questionnaires from the energy supplier to the participating household, provided that authorization is obtained from the household. The results of the household and energy supplier surveys are presented in the Department of Energy documentation of the RECS 1990 survey[1,2].

Stage I of RECS consists of a personal interview. The sample for the interviews is developed based on all units occupied as a primary residence in the 50 states and the District of Columbia. The sample design process is composed of five steps that disaggregate the geographic scope into

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1 U.S. Department of Energy, Energy Information Administration, Residential Energy Consumption Survey: Housing Characteristics 1990, DOE/EIA-0314(90), Washington, D.C., May 1990.

2 U.S. Department of Energy, Energy Information Administration, Residential Energy Consumption Survey: Household Energy Consumption and Expenditures, DOE/EIA-0321(90), Washington, D.C., February 1993.

housing clusters of approximately 5 housing units to be surveyed.

The original RECS 1990 sample consisted of 6,757 units. Out of these units, 848 were determined ineligible due to current vacancy, seasonal occupancy, or inhabitability. Of remaining 6,607 units, 5,095 participated in personal interviews and 267 responded to a mail questionnaire, resulting in a 77.1% response rate.

The interview responses provide information on housing structure including insulation, doors, windows, space conditioning systems, use of wood fuel, energy conservation improvements, household appliances, household vehicles, receipt of government assistance for the cost of space heating, and demographics. Householders were also asked to sign authorization forms to allow access to their billing records with energy suppliers.

Stage II of the survey design consists of a mail questionnaire for energy suppliers of the households interviewed in Stage I. Suppliers of residential electricity, natural gas, fuel oil, kerosene, and liquified propane gas (LPG) are contacted in Stage II. For the 1990 RECS, each supplier was asked to supply billed quantities and expenditures for the households interviewed in Stage I.

Data verification begins with a manual verification of the interview data from Stage I. The questionnaires are checked for completeness and consistency. Interview responses are compared to energy supplier data, and respondents are contacted in the event that an inconsistency persists. These data collection and verification procedures ensure the quality of the survey data.

Appendix F: Model Sensitivities

Solution Methodology

As the description in Section 4, Model Structure, and Appendix B, Detailed Mathematical Description, shows, the solution methodology of the NEMS Residential Module is a direct, one-pass, computation of linear and non-linear systems of equations to develop the residential module outputs such as quantity demanded by fuel type. Consequently, convergence within the NEMS Residential Module is never an issue nor is it relevant since the algorithm within the residential module is not iterative.

The model requires no estimate of the current-year solution to compute the solution to the NEMS Residential Module since the current year solution depends on only the values of the solution in the previous year plus the current economic conditions and other inputs from the rest of NEMS. Listed in descending order of model sensitivity (as will be shown below), variation in weather patterns, equipment efficiencies, housing starts and fuel prices do influence the residential module equipment purchase decisions and total quantity of fuel consumed. This appendix contains a series of sensitivity analyses for the purpose of illustrating the behavior of the residential module. These sensitivities illustrate how the model responds to changes in key model inputs.

Although rigorous tests have not been performed to determine the maximal meaningful values for the key model inputs, an indication of values for which the model has proven to be valid is given by those used in the sensitivity analyses. It must be stressed that care must be exercised in selecting input values so that the model produces meaningful results.

Theoretical Considerations

Because of the direct (rather then iterative) solution algorithm and because all of the functions in the NEMS Residential Module are continuous and differentiable in the domain of applicability of the model (that is, when "reasonable and consistent inputs" are provided into the model) the model always produces a unique solution. Existence and convergence are not an issue. As previously mentioned, some of the inputs to the model may be correlated (as in certain demographic and macro-economic inputs) and if inconsistent pairs of such inputs or negative prices are chosen, then the model will produce meaningless results. This behavior, however, is consistent with the well know reality in computer models of "garbage in -- garbage out". When the model is run in a stand-alone fashion, the user must be certain that the inputs are consistent and credible.

Examples of input assumptions that will cause the model to produce meaningless results include:

- severely altering base year data, e.g., doubling the existing 1990 housing stock,
- characterizing unrealistically "super-efficient" technologies with low acquisition costs, and
- modifying prices considerably in excess of variations historically experienced, such as quadrupling prices in one year.

Sensitivity Analyses

To demonstrate the NEMS Residential Module's behavior under a variety of situations, several model runs were made to test its sensitivity to altered values for key input variables. These runs were then compared with the Reference Case forecast used for the AEO 95. The sections below describe the six major inputs and outputs chosen for this exercise, as well as the results of the analysis in tabular and graphical form.

Input Variables

The six input variables chosen for the sensitivity analyses were selected based upon their perceived importance in producing the AEO 95 forecast. The six variables and the magnitude of variation are given below.

Electricity, natural gas, and distillate prices. Prices for the three major residential fuels were each increased by 25 percent over their values in the AEO 95 Reference Case in every year of the forecast (1995 through 2010). Fuel prices affect the projected consumption levels in two ways. First, there is an immediate "short-run" response best thought of as immediate behavioral changes. For example, higher heating fuel prices will result in lower thermostat settings. These near term behavioral responses are captured through the model's short-term price elasticities. Over a longer interval, the efficiency level of both the building shell and the energy-using equipment inside the house will also vary in response to prices. For example, when the replacement of space heating equipment is necessary, higher fuel prices lead to greater efficiency for purchased equipment and lower energy consumption. The longer-term equipment-related responses will alter fuel consumption over an extended number of years in contrast to the immediate short-run effects. Based on these two price-related responses (which operate in the same direction but over different intervals), it is expected that continued higher fuel prices will lower fuel consumption and energy intensity and that the effects will tend to increase over time.

Housing starts. Housing starts by Census Division and housing type (single-family, multifamily, and mobile homes) are the macroeconomic variables which drive the NEMS Residential Model. For each Census Division and housing type, starts were increased by 10 percent every year, relative to the AEO 95 Reference Case beginning in 1995. Logically, these variables represent household formation and are consistent with a scenario with implicitly higher population growth. New residential construction embodies new techniques and technologies and tends to be more efficient than the average existing stock. Thus, it is expected that increasing housing starts will increase overall energy consumption, but at a rate which is less than proportional. Thus, energy consumption per household (energy intensity) will decline for this model run.

Equipment efficiencies. The efficiency of new equipment entering the stock plays a central role in determining the average level of energy intensity for the residential sector. For this sensitivity analysis, every equipment efficiency represented in the model was increased 10 percent relative to the AEO 95 Reference Case beginning in 1995. It is expected that higher equipment efficiencies will cause both energy consumption and energy intensity to decline. It is further expected that the decline in consumption and intensity will deviate further from the Reference Case over time as equipment purchases make up larger and larger shares of total equipment.

Weather. Weather also has a significant effect on residential energy consumption, since the majority of the energy use in the sector is for space heating and cooling. The Unit Energy Consumption (UEC) estimates are defined as energy consumption per household for specific equipment and end-use categories (examples include gas forced air space heating, electric air conditioning, electric resistance space heating and gas water heating). The UECs are estimated from the Energy Information Administration's Residential Energy Consumption Survey: 1990. These UEC estimates reflect the weather conditions of the 1990 survey year which happened to be abnormally warm. To account for weather-related effects on energy consumption, the forecast UEC values are adjusted from their base year values based on actual weather in 1991 through 1994 and for "normal" weather reflective of long-term climatic conditions for all other forecast years. Depending on the fuel, the heating UEC values are adjusted upward by varying amounts to account for the extremely warm winter during the survey year. For this sensitivity analysis, no weather adjustments were made. It is expected that energy consumption and intensity will fall relative to the AEO 95 Reference Case, since this scenario embodies a forecast of warmer-than-normal winters.

Output Variables

For each input selected, six outputs were chosen to test their sensitivities to these inputs. The six outputs chosen are:

- the quantity demanded of electricity,
- the quantity demanded of natural gas,
- the quantity demanded of distillate oil,
- the quantity demand for all fuels in total,
- the number of occupied households (relevant only to increased housing starts case), and
- the space heating intensity in million Btu per household per year.

Tables F-1 through F-3 show the relationship between the inputs and outputs for the years 2000 and 2010. Table F-1 summarizes the absolute change of each output relative to the AEO 95 Reference Case with separate panels for 2000 and 2010. Similarly, Table F-2 shows the percent change of each output relative to the AEO 95 Reference Case. Table F-3 provides the elasticities (the percent change of the output divided by the percent change of the input) of the selected output variables with respect to the selected input variables. Following the tables, a series of six figures display the elasticities of selected output variables as a time series for each of the six input variable scenarios, respectively. Finally, the summary and conclusions section discusses the results presented in the tables and figures.

Figure F-1.

Figure F-2.

Figure F-3.

Figure F-4.

Figure F-5.

Figure F-6.

Summary and Conclusions

Price Responsiveness

As shown on Table F-3, the NEMS Residential Module exhibits major fuel own-price elasticities for 2010 in the range of -0.08 (electricity) to -0.50 (natural gas). Figures F-1 through F-3 further demonstrate that major fuel price elasticities generally increase over time, reflecting increasing shares of relatively more efficient end-use equipment. Intuitively speaking, electricity demand is expected to exhibit a smaller price elasticity than the other major fuels. This is because the use of electricity is spread across many end uses which are less directly controllable than is space heating, which is readily adjusted via the thermostat setting. Since distillate and natural gas use are dominated by space heating, their price elasticities are expected to be somewhat greater than those for electricity.

Responsiveness to Altered Housing Starts

As shown in Figure F-4, increased housing starts result in the expected decline in heating intensity. This is because new homes on average use less energy per unit for space heating than older homes because of increased shell efficiency. Thus, as the forecast for housing starts is adjusted upward (downward), sectoral energy intensity will decline (increase). In this scenario, a 10 percent increase in housing starts between 1995 and 2010 results in a 1.0 percent decline in average energy intensity relative to the AEO 95 Reference Case -- total energy consumption in 2010 is 5.2 percent higher while total households are 2.7 percent higher.

Responsiveness to Altered Equipment Efficiency

In terms of total energy consumption, the model is most sensitive to equipment efficiency. This is because over the 20-year forecast horizon, a substantial amount of residential equipment will be replaced. For example, roughly two-thirds of all furnace equipment and all of the existing heat pumps and air conditioning equipment will be replaced, along with all existing water heaters and refrigerators. Nearly all replacements occur at higher efficiency levels so that over time the assumed 10 percent increase in new equipment efficiencies will have greater and greater effects on energy consumption levels. This continuously increasing reduction in total energy consumption is clearly demonstrated in Figure F-5. By the year 2010, total energy consumption is 5.2 percent lower that the AEO 95 Reference Case as shown in Table F-2.

Weather Sensitivity

Because of the dominance of space heating for natural gas and distillate, these fuels are more responsive to weather conditions than is electricity. Space heating intensity is most sensitive to weather changes and least sensitive to electricity prices, since electricity represents only a small percentage of total space heating consumption. For the year 2010, the effects of warmer weather would result in a 2.8 percent reduction in total energy consumption and an 11.4 percent reduction in space heating intensity.