Concepts, Data Sources, and Techniques

Handbook of Energy Modeling Methods

National Energy Modeling System (NEMS) Residential Demand Module

Independent Statistics & Analysis

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1. Introduction

The NEMS Residential Demand Module (RDM) generates projections of energy demand (also called energy consumption) for the residential sector by end-use service, fuel type, and U.S. census division. The RDM uses inputs from other NEMS modules, such as projected energy prices and macroeconomic indicators, along with input data from EIA's Residential Energy Consumption Survey (RECS). The NEMS integrating module uses the RDM projections, along with input from other modules, to compute equilibrium energy prices and quantities.

The RDM projects residential sector energy demand in six sequential steps. These steps produce information on housing stocks, technology choices, appliance stocks, building shell integrity, distributed generation, and energy consumption. The module uses a stock-vintaging approach that projects household equipment stock and equipment efficiency over time.

2. Module Output

The RDM projects housing stock and energy consumption per housing unit and can produce a disaggregated projection of appliance stock and efficiency for the following types of equipment:

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

3. Modeling Methods

For each projection year, the RDM performs the following steps:

1. Generate a projection of housing stock based on the retirement of existing housing stock and the addition of new construction as determined in the NEMS Macroeconomic Activity Module (MAM).
2. Project current-year household energy-consuming equipment stock, accounting for housing demolitions and additions.
3. Project market shares for household equipment types and efficiencies by end-use service (e.g., space heating, cooking).

4. Project the current year’s equipment additions and replacements, for both existing homes and new construction vintages, based on estimated housing and equipment survival rates and projected equipment market shares.
5. Project energy efficiencies weighted by market share.
6. Project fuel consumption using Unit Energy Consumption (UEC) and the weighted efficiencies.

The primary module inputs include fuel prices, housing stock characteristics, housing starts, population, and technology characteristics. The technology characteristics used in the module include installed capital costs (in real dollars), equipment efficiency, and expected equipment lifetimes.

The NEMS RDM calculations are based on accounting principles and a representation of residential consumer economic behavior that generates projections of residential sector energy demand, appliance stocks, and market shares of household equipment. For each projection year, the RDM projects the stock of housing units and the corresponding energy-consuming equipment. The housing stock changes over time as houses are removed from the stock (demolished, retired, or converted) and new construction is added or converted to residential use. Similarly, the equipment stock changes each projection year as appliances fail and are replaced, through increases in the saturation of existing appliances, and as new technologies enter the market.

The RDM treats the year of the most recent RECS as a *base year*. Base-year information from the RECS forms the foundation of equipment and housing stock data for the RDM. Market share information from the RECS is used, along with data from the U.S. Census Bureau on characteristics of new housing, 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 for each type of equipment. The RDM projects market shares as functions of the corresponding fuel prices, expected level of equipment usage, and equipment efficiency characteristics.

Log-linear regression coefficients (see Section B.1) are used to estimate the market shares of competing technologies within each of the ten major end-use service categories listed in Table 1. Market shares are projected for both new construction equipment decisions and replacement equipment decisions. The module’s technology choice calculations consider the relative installed capital and operating costs of each equipment type within the logit function to calculate the market shares of the technology within each service, region, and housing type. Several miscellaneous service categories, listed in Table 2, are modeled with a different approach that does not consider investment parameters such as cost or efficiency.

The RDM also considers building shell integrity (e.g., as determined by insulation levels and window sealing) in the projection of end-use consumption. Because homeowners may improve insulation in response to higher energy prices, building shell integrity in existing homes is sensitive to real price increases for space conditioning fuels. The RDM projects residential sector energy consumption as a function of the equipment and housing stock, average unit energy consumption, weighted equipment characteristics, and building shell integrity improvements.

4. RDM Modeling Components

The RDM characterizes energy consumption using a series of algorithms that account for the stocks of housing and appliances, equipment market shares, and energy intensity. The module assesses the shifts of market shares between competing technologies based on fuel prices, equipment costs, and assumptions about the behavior of residential consumers.

The RDM is a sequential structured system of algorithms, with succeeding computations using the results from previously executed components as inputs. The module is composed of six components: housing stock projection, equipment technology choice, appliance stock projection, building shell integrity, distributed generation, and energy consumption.

In this section, we briefly describe each modeling component. Section 5 provides two examples of how the components are implemented for specific types of household equipment.

4.1. Housing Stock Projection Component

The Housing Stock Projection Component of the RDM received the following inputs:

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

The RDM divides U.S. housing units into two housing vintages: housing that existed in the base year (the year of the most recent RECS) and new construction built in years after the base year. The location and type of housing stock are the primary model drivers of the module's outputs. The RDM uses data from the NEMS Macroeconomic Activity Module (MAM) to project new and existing housing for three dwelling types (single family homes, multifamily homes, and mobile homes) within each census division. Housing units are removed from the housing stock at a constant rate over time, based on an analysis of each building type's historical growth and housing starts. For each projection year, the module assumes the removal of 0.3% of single family homes, 0.5% of multifamily homes, and 3.4% of mobile homes. The RDM also receives projections of new housing construction and square footage from the NEMS MAM.

The RDM assumes that a constant 1.2% share of existing housing is renovated each year, increasing the square footage of the conditioned (heated and cooled) living area by about one-third. Newly constructed homes are assumed to be larger than existing homes, which increases the heating and cooling loads in new construction. This assumption is based on a time-series analysis of RECS data, which shows increased conditioned floorspace per household over time, as well as increased prevalence of slightly higher ceilings.

4.2. Equipment Technology Choice Component

The Equipment Technology Choice Component simulates the behavior of consumers by projecting market shares for each available equipment type. The component receives the following inputs:

- Equipment retail or replacement cost
- Equipment subsidies

- Equipment energy efficiency
- Equipment penetration level (i.e., percent of households with that equipment)
- Water usage factors
- Fuel and equipment switching costs
- Fuel costs

The module models new and replacement equipment decisions for each technology type. For new construction, the home heating fuel is determined by the relative life-cycle costs of all competing heating systems. The RDM assumes that a percentage of space heaters, air conditioners, water heaters, cooking ranges, and clothes dryers may be replaced with competing technologies in single-family homes. Projected switching is based on the retail cost of new equipment and the cost of switching technologies.

The RDM assumes that space heaters, air conditioners (heat pumps and central air conditioners), water heaters, cooking ranges, and clothes dryers may be replaced with competing technologies in single-family homes and that 20% of the replacement market in single-family homes is eligible to switch fuels in any projection year. The projected percentage that switch technologies depends on factors such as retail equipment cost and technology switching cost. Equipment units in multifamily and mobile homes are assumed to be replaced with the same technology.

The efficiency choices projected for residential equipment are based on parameters of a log-linear regression model that relates equipment market shares to equipment life-cycle costs. The life-cycle costs include capital/installed (first cost) and discounted operating (annual fuel) costs. EIA analysts adjust the parameters to agree with the most recently available data. A log-linear regression model is also used to project market share weights of equipment types installed in new construction. The projected market share weights are then used to compute composite average efficiencies for each service listed in Table 1 and Table 2. The technologies are distinguished by the service demand that they satisfy, by the fuel that they consume, and by their energy efficiency.

Energy efficiency can be defined as the ratio of service demand to energy input. For relatively simple devices such as space heaters or light bulbs, service demand is a unit of heat or light, respectively, and thus efficiency is described in terms of heat per unit energy (such as coefficient of performance (COP) or annual fuel utilization efficiency (AFUE)) or light per unit energy (lumens per watt). Because the RDM ultimately converts all energy, heat, and light measures to British thermal units (Btu), energy efficiency is considered unitless.

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

4.3. Appliance Stock Projection Component

The Appliance Stock Projection Component receives the following inputs:

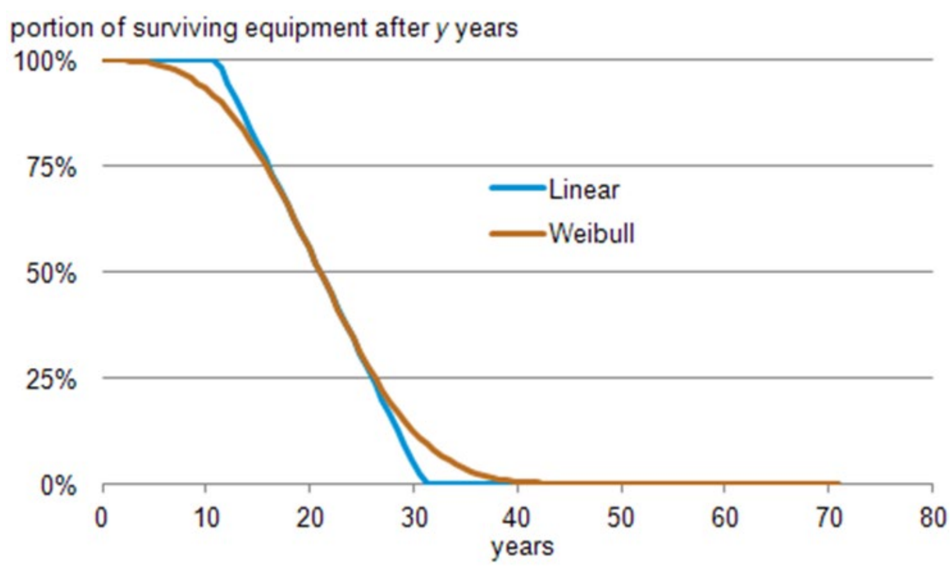
Expected equipment minimum and maximum lifetimes
Base-year equipment stocks
Equipment saturation level (i.e., the number of units per household)

4.3.1. Appliance Stock Assumptions

The component projects the number of end-use appliances within all occupied housing units, tracking equipment additions and replacements using the following assumptions:

- Some energy-consuming equipment is chosen based on its upfront cost compared to its operating costs (like water heaters and refrigerators) while some appliances are chosen based on factors not related to their energy consumption (such as security systems or coffee makers).
- Equipment lifetime is characterized by a *survival function*, which maps the proportion of surviving units against time, as illustrated in Figure 1. The RDM first estimates a linear survival function and then smoothes it using Weibull shape parameters, which are estimated from data on equipment lifetime ranges.
- The equipment contained in a retiring housing structure retires when the structure is removed from the housing stock (zero salvage value for equipment).
- Projected new home heating fuel shares are based on the U.S. Census Bureau's Characteristics of New Housing Survey of Construction microdata and vary over time due to changes in life-cycle cost for each of the heating system types.
- The choice of fuel for water heating and cooking is largely dependent on the choice of heating fuel.
- When old equipment is replaced, the type of fuel used for cooking and water heating is based on the percentage of homes able to switch fuels (e.g., homes with natural gas service may switch from electricity to natural gas) and a technology choice-switching algorithm similar to that described for space heating below.

Figure 1. Weibull and linear equipment survival rate functions



The RDM also incorporates the following assumptions regarding specific appliances:

4.3.2. Room and central air-conditioning units

The RDM disaggregates room and central air-conditioning units based on data for existing housing units. It uses the market penetration of room and central air systems (by census division and housing type), along with new housing construction data, to determine the number of new units of each type. The penetration rate for central air conditioning is estimated by means of time series analysis of RECS data. The RDM also uses RECS data to project the number of room air conditioners per household in new construction.

4.3.3. Solar water heaters

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

4.3.4. Refrigerators and freezers

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

4.3.5. Clothes washers

Because many efficiency features for clothes washers act to reduce the demand for hot water, the RDM links clothes washer choice to the water heating service. Also, like refrigerators and freezers, multiple equipment orientations (top- and front-loading) are compared, with market shares developed from RECS microdata.

4.3.6. Clothes dryers

Based on an analysis of RECS data, the RDM assumes that clothes dryer market penetration increases over the projection period, with a terminal saturation level that is consistent with the market penetration of clothes washers.

4.4. Building Shell Integrity Component

The RDM models building shell integrity for existing and new housing. The Building Shell Integrity Component receives the following inputs:

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

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

New housing stock also incorporates shell integrity improvements. The shell integrity of new housing is a function of capital and operating costs for several levels of total system efficiency. New housing stock includes homes that meet the 2009 International Energy Conservation Code (IECC), those that meet ENERGY STAR® criteria, those that qualify for federal tax credits for efficient shells, and those that include the most efficient commercially available building shell components, as well as some non-code-compliant homes. Building shell efficiency and heating, ventilation, and air-conditioning (HVAC) systems for new housing stock are modeled as functions of the life-cycle cost of competing building shell and HVAC packages.

4.5. Distributed Generation Component

The Distributed Generation Component projects adoption of residential solar photovoltaic (PV) systems, natural gas fuel cells, and small wind turbine systems for on-site generation to compete with purchased electricity in satisfying household electricity needs. The component receives the following inputs:

Equipment cost
Equipment subsidies
Equipment conversion efficiency
Solar insolation values
Macroeconomic indicators (e.g., household income)
Cross-sector capacity levels
System penetration parameters
Wind speeds
Grid interconnection limitations

The RDM uses a hurdle model (see Lent 2017) to project the number of new residential solar PV adoptions. It uses a cash-flow formulation (assuming that the decision to invest in a system is a function of the *payback time*) to project the adoption of natural gas fuel cells and small wind turbines. Electricity generated from these systems is deducted from total housing unit use, or sold back to the grid, if feasible.

4.6. Energy Consumption Component

4.6.1. Input Data

The RDM's Energy Consumption Component calculates end-use consumption for each service and fuel type shown in Table 1 and Table 2. The consumption projections are products of the number of units in the equipment stock and the average technology unit energy consumption (UEC). The average UEC changes as the composition of the equipment stock changes over time. The Energy Consumption Component receives the following inputs:

Base-year unit energy consumption (UEC)
Population-weighted heating and cooling degree days
Population
Household size
Personal disposable income

Energy consumption can vary based on projected heating and cooling shell integrities, fuel prices, personal disposable income, housing unit sizes, and weather, as applicable to specific equipment and end-use services.The RDM incorporates the following assumptions regarding specific types of end-use consumption, as described in the following subsections.

4.6.2. Lighting

The RDM partitions lighting into four main categories of bulb type: general service, reflector, linear fluorescent, and exterior. Within the general service category, several *hours of use* bins further partition this category, allowing bulb choice to vary with the amount of time each fixture is used on an annual basis. For the reflector, exterior, and linear fluorescent categories, the RDM assumes an average hours of use value per DOE's 2015 U.S. Lighting Market Characterization report. Within an application such as general service lighting, a fixed light output level (measured in lumens) is used, so that choices are among bulbs with similar light output. The RDM uses adjustment factors to benchmark shares of general service lighting technologies to agree with National Electrical Manufacturers Association (NEMA) lamp shipment indices.

4.6.3. Furnace fans and secondary heating

The RDM projects furnace fan energy consumption based on the number of housing units that have fossil fuel-fired central forced-air heating and the number of heating and cooling degree days.

The RDM projects the consumption of secondary heating fuels based on the share of housing units that use a secondary heating fuel and the unit energy consumption, adjusted to account for the housing unit shell integrity.

4.6.4. Miscellaneous electric loads and other/unspecified consumption

The RDM uses expected numbers of equipment units or devices and per-unit energy consumption to form projections of miscellaneous electric loads (MELs). These are not modeled at the same level of detail as other end uses. Consumption projections for some of these MELs are also affected by projected changes in square footage and disposable income.

Even with the consumption information collected in RECS, there is consumption attributed to unspecified uses, which are aggregated as *other* uses.

5. Examples of Modeling Component Implementation

Here we discuss the RDM's implementation of the modeling components for three specific types of household equipment: space heating, lighting, and clothes washing equipment. The modeling methods for most household appliances are similar to those used for clothes washers, while some specialized methods are applied for space heating and lighting.

5.1. Example 1: Space Heating Equipment

The RDM models the energy consumption of space heating equipment in two stages. For new construction, the first stage models the consumer's choice of an HVAC/building shell combination package. Each package comprises heating/cooling equipment and a building shell integrity level (including an insulation level). The model accounts for five fuel-specific HVAC/shell packages, defined by the energy efficiency code they are designed to meet: no code; the International Energy Conservation Code (IECC); or 30%, 40%, or 50% better than the IECC. For existing homes, the RDM models fuel choice in the first stage, while the second stage considers efficiency improvements in HVAC equipment for all homes.

5.1.1. *Projecting HVAC unit operating costs*

For each HVAC/shell package considered, the RDM projects a market share weight that accounts for both initial purchasing (or capital) costs and annual operating costs. For existing homes, new equipment operating cost, by housing type, is computed as a product of five factors accounting for the following effects:

- regional fuel price
- unit energy consumption
- a weather effect, based on heating degree days
- an efficiency adjustment, to account for equipment efficiency improvements
- a shell efficiency adjustment, to account for building shell improvements

For new construction, the operating cost for heating is computed similarly, but a second term is added to account for air conditioning costs, because the choice of heating and cooling technologies is linked.

5.1.2. *Simulating price-induced technology change*

The RDM Technology Choice Component can simulate fuel price-induced technology change, i.e., the tendency of manufacturers to make improved-efficiency HVAC technologies available earlier in response to sustained high fuel prices. The RDM first computes the ratio (PriceRatio) of a three-year average fuel price (during the high-price period) to the base-year fuel price. Then it computes the number of years (ShiftYears) that the availability of improved HVAC technologies should be shifted earlier as

$$\text{ShiftYears} = 10 \times (\text{PriceRatio} - 1).$$

5.1.3. *Estimating market share weights for HVAC units*

The RDM technology choice component projects the life-cycle cost for an equipment category as the sum of (1) the initial capital cost of the appliance, net of rebates and other incentives, and (2) the annual operating cost multiplied by a factor that adjusts for inflation, as well as for a delayed payment effect, over the expected number of years of the equipment's operation.

The projected life-cycle cost is used as the independent variable in a log-linear regression model (see Section B.1) that projects a market share weight for each equipment category. The final weight for each projection year is a weighted average of (1) the weight for the previous projection year and (2) the predicted value of the weight, based on the regression coefficients. The RDM projects a final market share weight for each equipment category, housing type, census division, and projection year. It normalizes the final weights to force them to sum to unity within each census division and year. Based on historical data, the module then divides each category into more detailed equipment types and performs a similar weight calculation within each category, resulting in more detailed market share weights.

5.1.4. *Appliance stock projection for HVAC units*

The RDM Appliance Stock Projection Component projects the number of HVAC units in houses constructed since the base year as the product of the number of new houses constructed and the market share for the unit's equipment category. To project the number of replacement units needed in houses built since the base year, the model multiplies the projected number of units by the fixed annual housing unit survival rate (0.997, 0.995, or 0.966 for single-family homes, multifamily homes, and mobile homes, respectively) and by the equipment survival rate characterized by a Weibull survival curve for each equipment and housing type in each census division.

To project the number of replacement units needed in housing units that existed in the base year, the RDM multiplies the total projected number of existing HVAC units by the housing survival rate and a projected equipment retirement rate. Through a similar calculation, the RDM then accounts for the number of units that will be replaced *twice* during the projection period. The module then uses a Weibull function to smooth the survival curve for each equipment type within each census division.

For the HVAC units that are replaced, the RDM next projects the proportion that will be replaced by units of a different technology type (e.g., the proportion of distillate fuel oil furnaces replaced by natural gas furnaces). To project the number of HVAC units eligible to switch technologies, the module applies a fixed estimated proportion for each equipment category. Then, because we assume that the decision to switch technologies is based on a comparison of equipment life-cycle costs, the module uses a log-linear regression with a technology switching weight as the dependent variable and equipment life-cycle cost as the sole independent variable. The RDM normalizes the switching weights to force them to sum to unity within each equipment category, housing type, and projection year. The module then reconciles the *switching from* and *switching to* categories, allocating the projected units to the correct equipment classes.

Finally, for each equipment category, the RDM adds the projected numbers of surviving HVAC units across years from the base year through the projection year. The sums are computed first for units surviving from the base year and then for units added as replacements since the base year.

5.1.5. Shell integrity component for HVAC units

The Shell Integrity Component uses index values to track increases in the energy efficiency of building shells over time, relative to the base year. Each index is computed as

$$\text{Index} = 1 - \text{Proportional Increase in Efficiency Since the Base Year.}$$

For example, an index value of 0.3 represents a 0.7 (or 70%) increase in efficiency since the base year—the maximum increase that the RDM projects.

Because the RDM assumes only increases (never decreases) in building shell efficiency over time, the index values for a housing category may decrease but cannot increase over the projection period. For each housing category, census division, HVAC fuel, and projection year, the RDM calculates the shell integrity index for housing units that existed in the base year as the product of three factors:

- the shell integrity for the base year
- a parameter representing the annual increase in existing shell efficiency due to technology improvements
- a price elasticity function based on prices from the current projection year and the previous two years

The use of the three-year price elasticity function reflects the assumption that consumers adopt shell improvements based on multi-year price trends.

For housing units built after the base year, the RDM calculates an annual shell integrity index as the weighted average of the shell integrity indices associated with the available HVAC packages that use a particular fuel. The weights in the weighted average are the market share weights computed in the Technology Choice Component. The module then uses annual market share weights to average these index values over the years between the base year and the projection year, providing an annual average shell integrity index for each fuel, projection year, and census division.

5.1.6. Energy consumption component for HVAC units

The RDM's Energy Consumption Component begins by projecting a unit energy consumption (UEC) value for each HVAC equipment category, census division, and projection year. For new HVAC equipment, the projected UEC is a product of the following factors:

- equipment category efficiency (heat output /fuel input)
- equipment market share weight, projected by the Technology Choice Component
- average efficiency of the base-year stock for the equipment category (heat output /fuel input)
- UEC for the base-year stock of the equipment category for the census division and housing type (MMBtu/year)
- an adjustment for the projected number of heating degree days in the year
- an adjustment to account for the increasing conditioned floor space in housing units during the projection period

The RDM uses the same method to calculate a UEC for each category of replacement HVAC equipment, except that the adjustment factor for increasing conditioned floor space is not applied. For equipment surviving from the base year, the module adjusts the base year UEC values to account for changes in heating degree days and the increase in conditioned floor space. For each census division, equipment category, and projection year, the RDM then computes an average UEC, weighting the equipment vintages (new, replacement, and surviving) by their market shares.

Finally, for each HVAC fuel considered, the RDM combines data from all equipment categories that use the specific fuel. The module computes an average UEC by fuel, census division, and projection year. It first performs the calculation for the base year. For each equipment category and each vintage (new, replacement, and surviving), the module computes a product of the following factors:

- number of units in the stock
- UEC
- building shell integrity for the specific fuel

The RDM adds the products across the three equipment vintages and multiplies the sum by the same three-year price elasticity factor used by the Shell Integrity Component. The RDM performs a similar calculation for each year of the projection period, except that, for each equipment category and vintage, the product of the three factors above is further multiplied by a *rebound effect* factor. The rebound effect adjusts the three-year price elasticity for the effect of increased energy efficiency in the equipment category. For each equipment category, census division, and projection year, the RDM computes the rebound effect based on the product of the following factors:

- equipment efficiency for the projection year
- equipment market share weight, projected by the Technology Choice Component
- average equipment efficiency for the base year

The rebound effect increases the projected energy service demand as the equipment efficiency increases, reflecting consumers' tendency to use more services when their equipment uses energy more efficiently. The UEC by fuel, census division, and projection year is the RDM's final output for HVAC equipment.

5.2. Example 2: Clothes Washing Equipment

Clothes washing (and dishwashing) energy consumption is composed of electricity consumption and water heating demand. The RDM accounts for changes in clothes washer efficiency on water heating consumption.

5.2.1. Projecting clothes washer operating costs

For each clothes washer considered, the RDM projects a market share weight that accounts for both initial purchasing (or capital) costs and annual operating costs. For both existing and new homes, equipment operating cost, by housing type, is computed as a product of four factors accounting for the following effects:

- regional fuel price
- unit energy consumption
- projection year equipment efficiency
- base-year stock-average equipment efficiency

5.2.2. Estimating market share weights for clothes washers

The RDM technology choice component functions similarly to that for space heating and cooling; however, shares of top- versus front-loading clothes washers remain fixed at the RECS base-year levels (76% and 24%, respectively). The model can also account for increasing penetration of clothes washers and dishwashers into new construction (as seen in the newest RECS homes between surveys). Because penetration of clothes washers appears to be flat in recent years, no increase is currently assumed.

5.2.3. Energy consumption component for clothes washers

Because clothes washers consume only one fuel directly (i.e., electricity), the energy consumption calculation is simpler than the calculation for most of the other end uses: total consumption is a sum product of number of clothes washers of each vintage and their respective UECs.

Given the relationship between hot water-consuming end uses such as clothes washers and dishwashers, changes in equipment efficiency affect not only the electricity used for clothes washing, but also water heating fuel consumption. The RDM's approach accounts for the following:

- weighted average load adjustment of new clothes washers with respect to water heating load in the current year by housing type and census division
- the equipment weight for each type of new equipment
- the fraction of hot water needed to provide the same level of service relative to the base-year average
- the number of and water heating consumption for clothes washers for each type of water heating fuel type by census division and building type for each vintage of equipment
- the share of and UEC for each type of water heating fuel type by census division and building type for all vintages of equipment
- the number of clothes washers by census division and building type for *all* vintages of equipment
- the adjustment to the water heating UEC to account for the efficiency of clothes washers with respect to hot water load by census division and building type for all vintages of equipment

Table 1. Major services and equipment in NEMS Residential Demand Module

End-Use Equipment	Efficiency Metric
1. Space Heating	
Air-Source Heat Pump	Heating Seasonal Performance Factor (HSPF)
Electric Furnace	COP
Distillate Fuel Oil Boiler	Annual Fuel Utilization Efficiency (AFUE)
Distillate Fuel Oil Furnace	AFUE
Ground-Source Heat Pump	COP
Kerosene Furnace	AFUE
Propane Furnace	AFUE
Natural Gas Boiler	AFUE
Natural Gas Furnace	AFUE
Natural Gas Heat Pump	COP
Wood Stove	COP
2. Air Conditioning	
Air-Source Heat Pump	Seasonal Energy Efficiency Ratio (SEER)
Central Air Conditioner	SEER
Ground-Source Heat Pump	Energy Efficiency Ratio (EER)
Natural Gas Heat Pump	COP
Room Air Conditioner	EER
3. Water Heating	
Electricity Water Heater	Energy Factor (EF)
Distillate Fuel Oil Water Heater	EF
Propane Water Heater	EF
Natural Gas Water Heater	EF

Solar Water Heater	EF
4. Cooking	
Electric Cooking range	kilowatthours per year (kWh / yr)
Propane Cooking range	Thermal Efficiency (Btu Out / Btu In)
Natural Gas Cooking range	Thermal Efficiency (Btu Out / Btu In)

Table 1. Major services and equipment in NEMS Residential Demand Module (continued)

End-Use Equipment	Efficiency Metric
5. Clothes Drying	
Electric Clothes Dryer	EF
Natural Gas Clothes Dryer	EF
6. Clothes Washing	
Clothes Washer	kWh / cycle (motor), Modified Energy Factor (MEF), Water Factor (WF)
7. Dishwashing	
Dishwasher	EF, WF
8. Refrigeration	
Refrigerator w/ top freezer (21 cubic foot capacity)	kWh / yr
Refrigerator w/ side freezer (26 cubic foot capacity)	kWh / yr
Refrigerator w/ bottom freezer (25 cubic foot capacity)	kWh / yr
9. Freezing	
Chest Freezer (15 cubic foot capacity)	kWh / yr
Upright Freezer (automatic defrost, 20 cubic foot capacity)	kWh / yr
10. Lighting	
General Service – Compact Fluorescent Lamp (CFL)	lumens per watt
General Service – Incandescent and Halogen	lumens per watt
General Service – Light-Emitting Diode (LED)	lumens per watt
Linear Fluorescent (T12)	lumens per watt
Linear Fluorescent (T8)	lumens per watt
Linear Fluorescent (LED)	lumens per watt
Reflector (Incandescent)	lumens per watt
Reflector (Halogen)	lumens per watt

Reflector (CFL)	lumens per watt
Reflector (LED)	lumens per watt
Exterior (Incandescent)	lumens per watt
Exterior (Halogen)	lumens per watt
Exterior (LED)	lumens per watt
Exterior (High Pressure Sodium)	lumens per watt

Table 2. Miscellaneous services and equipment in NEMS Residential Demand Module

End-Use Equipment	Efficiency Metric
Televisions and Related Equipment	
Televisions	kWh / yr
Set-top Boxes	kWh / yr
Video Game Consoles	kWh / yr
Home Theater Systems	kWh / yr
DVD / VCR players	kWh / yr
Personal Computers and Related Equipment	
Desktops	kWh / yr
Laptops	kWh / yr
Monitors	kWh / yr
Networking Equipment (modems and routers)	kWh / yr
Secondary Heat	
Coal	MMBtu / yr
Distillate Fuel Oil	MMBtu / yr
Electric	MMBtu / yr
Natural Gas	MMBtu / yr
Kerosene	MMBtu / yr
Propane	MMBtu / yr
Wood	MMBtu / yr
Furnace Fans and Boiler Circulation Pumps	
Furnace fans	kWh / yr
Other Uses	
Ceiling Fans	kWh / yr
Coffee Makers	kWh / yr
Dehumidifiers	kWh / yr
Microwaves	kWh / yr
Pool Heaters & Pumps	kWh / yr
Portable Electric Spas	kWh / yr
Rechargeable Electronics	kWh / yr
Security System	kWh / yr
Wine Coolers	kWh/ yr
Unspecified: Distillate Fuel Oil	MMBtu / yr
Unspecified: Electric	MMBtu / yr
Unspecified: Natural Gas	MMBtu / yr
Unspecified: Propane	MMBtu / yr
Distributed Generation	
Solar Photovoltaic	Electrical Efficiency
Natural Gas Fuel Cell	Electrical Efficiency
Small Wind Turbine	Electrical Efficiency

6. Data Quality

Here we discuss the quality of the data collected through EIA's Residential Energy Consumption Survey (RECS). These data form the basis of the historical housing stock, appliance stock, and technology information that drives the NEMS RDM.

The RECS data collection procedure relies on two instruments: the housing unit survey and the energy supplier survey. Data are collected from a representative sample of housing units through personal interviews. Billing data are then collected through mail questionnaires from the companies supplying energy to the participating housing units, provided that authorization is obtained from the housing units. The results of the housing unit and energy supplier surveys are presented in the U.S. Department of Energy documentation of the RECS.

Stage I of RECS consists of personal interviews. The sample for the interviews is drawn from the population of housing units occupied as primary residences in the 50 states and the District of Columbia. The sample design process comprises of five steps that disaggregate the geographic scope into housing clusters of approximately five housing units to be surveyed.

The interview responses provide information on housing characteristics, fuels used, housing unit measurements, fuel bills, kitchen appliances, home appliance and electronics, space heating, air conditioning, water heating, miscellaneous uses, residential transportation, household characteristics, and energy expenditure assistance. Housing unit respondents are 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 housing units interviewed in Stage I. In Stage II, EIA contacts suppliers of residential electricity, natural gas, distillate fuel oil, kerosene, and propane. EIA asks each supplier to provide billed quantities and expenditures for the housing units interviewed in Stage I.

Quality assurance 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.

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

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